



# The impacts of heterogeneous environmental regulations on green economic efficiency from the perspective of urbanization: a dynamic threshold analysis

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## Abstract

Urbanization is a social and complex phenomenon. In recent years, rapid urbanization has not only accelerated economic development in China, but also has raised ecological concerns including biodiversity reduction, habitat degradation and congestion effect, which poses significant challenges to green economic efficiency. Although China proposed its first ecological civilization strategy in 2007, as stressed in the thirteenth Five-Year Plan (2016–2020), resource shortages and environmental degradation caused by urbanization processes have created a bottleneck effect, thus restricting China's green economic efficiency. Therefore, this study aims to determine how heterogeneous environmental regulations affect China's green economic efficiency from the perspective of urbanization over the period 2003–2017. The results of static and dynamic threshold regressions show that command-and-control and voluntary environmental regulations promote green economic efficiency at different urbanization levels. In static threshold model, market-based environmental regulation stimulates green economic efficiency when urbanization is below the first threshold and above the second threshold, while it constrains green economic efficiency when urbanization is between the single and the double thresholds. In dynamic threshold model, market-based environmental regulation improves green economic efficiency when urbanization is below the threshold and impedes it when urbanization exceeds the threshold. Finally, several important policy recommendations are documented.

**Keywords** Environmental regulations · Green economic efficiency · Urbanization · Dynamic threshold regression

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## 1 Introduction

Due to its leapfrogging economic development pattern, China has been facing severe environmental problems and increasing pressure on its natural resources. To harmonize both economic development and environment, China should place primarily importance in sustainable development. During the 19th National Congress of the Communist Party of China (CPC), the government proposed several reforms to the current system in order to promote technological progress and achieve a dream of beautiful China by establishing an environmental governance framework in which the central government is in charge and enterprises are the main stakeholders.

In the past 100 countries, the large-scale migration from rural to urban areas worldwide has resulted in massive consumption of natural and energy resources (Fang et al., 2015) and has become a center of gravity among policy experts and academia (Yang et al., 2018). Due to large-scale industrialization and rapid economic development, the process of urbanization has reached a record level in China (Yin et al., 2014), and has increased from 17.6% in 1978 to 60.60% in 2019 with an average annual growth rate of 1.10%. The on-going process of urbanization in China has brought serious ecological challenges (Xie et al., 2020; Yu et al., 2020; Zhou et al., 2019), such as higher energy consumption and environmental pollution that not only affect urban environment and energy resources, but also impede sustainable development (Shan et al., 2018; Zhao et al., 2016). To provide an opportunity for sustainable development with the efficient use of resources through sustainable use of land and protection of biodiversity loss, China has enforced a number of environmentally friendly regulations including “Measures for the Public Participation in Environmental Protection” (Chinese Ministry of Environmental Protection, 2014), “Guiding opinions on further promoting compensable use and pilot tests of emissions trading” (Chinese Ministry of Environmental Protection, 2014) and “Atmospheric Pollution Prevention and Control Law” (Chinese government, 2018 Revision). Also, the Chinese government formulated its first ecological civilization plan in 2007 as highlighted in the thirteenth Five-Year Plan (2016–2020), resource degradation and environmental burden caused by urbanization processes have resulted in a bottleneck effect which may adversely affect China’s green economic efficiency (Yao et al., 2021). Thus, empirical research on the differential effects of environmental regulations on China’s green economic efficiency during the process of urbanization is put on the agenda in this study.

The green economic efficiency is a typical input–output process that can achieve more economic value with fewer environmental impacts. Previously, several scholars have examined the effects of urbanization on green economic efficiency; there are still some shortcomings in the previous literature. First, most of the existing studies have focused on the linear impact of urbanization on green economic efficiency and did not reach a compromise on whether the process of urbanization improves green economic efficiency or not. Their opinions are rather divided ranging from a positive impact (Qiu et al., 2017), a non-linear relationship (Yuan et al., 2017) to a negative impact (Rubashkina et al., 2015). Second, scholars have mainly considered research on the topic of environmental regulation and green economic efficiency at country-level, while others have focused on the prefecture level, thereby the region-based empirical research is still scarce (Wetwitoo & Kato, 2017; Zhang et al., 2021). Third, regions in China not only show income-based variations but also experience uneven urbanization. The uneven trend in the process of urbanization and income level can significantly undermine the effectiveness of environmental regulation.

Keeping in mind the regional differences in China, it is of great significance to study green economic efficiency at regional scale.

Driven by the above gaps, the primary interest of this study is to provide both empirical and theoretical standpoints concerning the disaggregated effects of environmental regulations on green economic efficiency, while considering the threshold effect of urbanization. The reason why we chose urbanization as a threshold variable is that it is considered the key factor affecting regional green economic efficiency. In general, economists believe that urbanization is the process of changing from a rural economy to an urban economy with the continuous optimization and improvement of industrial structure (Berry, 1961). In addition, various scholars believe that urbanization is a comprehensive concept. Rather than a simple problem of population and economic agglomeration, it is considered as an internal manifestation of human social progress (Qi, 2004). Over the years, China has proposed several varying definitions of urbanization, while consistently emphasizing that the core of urbanization is “urbanization of people.” In recent years, China has been increasingly pursuing social justice and equalization by paying special attention to ecological construction (Yao et al., 2021). Thus, urbanization, as an important economic and social development phenomenon, has several impacts on green economic efficiency. More specifically, this study raises several important policy research questions as follows. (1) Is there a threshold effect in urbanization? If yes, is it single threshold or multiple thresholds? Is it static threshold or dynamic threshold? (2) Under different thresholds, what are the impacts of various environmental regulations on green economic efficiency? (3) What is the impact of heterogeneous environmental regulations on green economic efficiency under different urbanization thresholds among different regions in China?

To answer the above questions, the motivation of this study is to strengthen the evidence base available to policymakers for the design of regulatory policy over the course of urban development. The study aims to contribute to the existing literature in multiple ways. First, we build a comprehensive understanding on the effects of three types of environmental regulations on green economic efficiency over the period 2003–2017. Second, previous studies have explicitly focused on the linear effect of urbanization on green economic efficiency. However, the results obtained from linear model do not provide a detailed policy debate. This study therefore considers the threshold effect of urbanization from both static and dynamic standpoints. Therefore, results derived from threshold regressions will provide robust and reliable results. Third, considering the significance of regional variations, the comprehensive analysis of disaggregated impacts of environmental regulations under the threshold effect of urbanization is presented. Finally, as part of our robustness, we replaced both environmental regulations and control variables in a bid to provide more robust and reliable results.

The subsequent section of this paper proceeds as follows. Section 2 provides a detailed literature review. The theoretical framework of this study is debated in Sect. 3. Methodology is outlined in Sect. 4. Empirical analysis is presented in Sect. 5. Discussion of the results is elaborated in Sect. 6. Conclusions and policy implications are presented in Sect. 7.

## 2 Literature review

### 2.1 Urbanization and environmental regulation

In recent years, there have been many studies that have sought to examine the relationship between urbanization and environmental pollution from different perspectives in terms of methodologies adopted, datasets, and regional or country peculiarities. These studies have provided both negative and positive opinions. For instance, Wang et al. (2016) claimed that region with higher urbanization utilizes energy resources at higher speed. Sheng and Guo (2016) focused on the association between carbon emission and urbanization and found a bi-directional causality between the two variables in the long run. Anwar et al. (2020) showed that urbanization is the main driver of carbon emissions in the Far East Asian countries. Musah et al. (2020) showed that urbanization significantly increases carbon emissions in West Africa.

Other group of studies empirically verified that urbanization may improve the environmental risks after reaching a certain turning point. Khan and Su (2021) found that urbanization has a positive effect on carbon emissions when it does not exceed the threshold value. However, the effect turns negative after exceeding a threshold value in newly industrialized nations. Based on a cross-country analysis, Zhang et al. (2017) found that urbanization accelerates carbon emissions at the initial stage of development, while it significantly lowers the level of carbon emissions after obtaining a certain threshold point. Chen et al. (2019) claimed that urbanization has a U-shaped impact on carbon emissions in the western region of China. This thesis is also validated by Zhao et al. (2020) who argued urbanization and carbon emissions tend to exhibit a U-shaped curve in China.

### 2.2 Urbanization and green economic efficiency

The energy sector plays an important role in achieving sustainable growth over the course of urbanization. The literature on urbanization and green growth is mainly categorized in three aspects. The first aspect claims that the process of urbanization is conducive to green economic efficiency of a country. Analyzing the impact of urbanization on energy efficiency during the transition period to market economy in 12 Eastern European countries, Markandya et al. (2006) found that urbanization is conducive to the energy efficiency and green economic efficiency of these countries. Yu (2021) investigated the ecological dimensions of urbanization at provincial level in China. The results of dynamic spatial panel model indicate that China's new-type urbanization has effectively improved energy efficiency, but has been significant in terms of its ecological effect. On the other hand, Rafiq et al. (2016) presented the reverse argument that urbanization significantly downgrades energy efficiency in 22 emerging economies. In the similar fashion, Sheng et al. (2017) documented that urbanization significantly declines energy efficiency in 78 countries. Li, He, et al. (2018), Li, Fang, et al. (2018)) argued that the overall impact of urbanization on energy efficiency is negative in China over the period from 2003 to 2014. Lv et al. (2020) found that urbanization is not beneficial to energy efficiency in both short-run and long-run in China. The third aspect provides the varied impact of urbanization on green economic efficiency such as, Bilgili et al. (2017) showed that urbanization has a favorable impact on energy efficiency in China and India, while it has a deteriorating effect on energy efficiency in Vietnam, Nepal, Thailand, South Korea, Philippines and Malaysia. Tang et al. (2020) confirmed a U-shaped curve between eco-efficiency and urbanization in China.

## 2.3 Environmental regulation and green economic efficiency

In this section, we review previous studies that actively scrutinized the association between green economic efficiency and environmental regulations. The empirical results from these studies can be divided into three sections. The first section supports Porter's "Porter hypothesis" which holds that stringent environmental regulations can lead to firm innovation and improve total factor productivity. Albrizio (2017) investigated the impact of environmental policy stringency on firm-and-industry level productivity growth in OECD economies. They found that effective environmental policy improves the industry-level productivity growth across most technologically driven economies in a short-term increase. Danish and Ulucak (2020) found that environmental-related technologies contribute positively to green growth in Brazil, Russia, India, China and South Africa (BRICS) countries.

The second section supports the "cost compliance theory" which infers that environmental regulations can adversely affect innovation capacity of firms by putting additional environmental governance costs to enterprises and crowding out production investment. Hancevic (2016) found that environmental regulation declines productivity between 1 and 2.5%. Jin et al. (2019) found that environmental regulation does not seem to play unprecedented role in improving green TFP of industrial water sources in China during 2000–2016.

The third section highlights an unclear view about the effect of environmental regulations on green economic efficiency. Li and Wu (2016) stated that local environmental regulation positively affects green TFP of higher political attribute cities and negatively affects in lower political attribute cities in China. Wang et al. (2019) validated an inverted U-shaped effect of environmental policy on green productivity across industrial sectors of OECD countries. Applying the Tobit model to estimate the influence of environmental regulation on China's green economic efficiency, Shuai and Fan (2020) concluded that environmental regulation promotes the green economy at initial stage. However, the effect turns deteriorating after exceeding a certain threshold level, thereby validating a U-shape curve. In addition to the uncertainty of time and space, various environmental regulations will also have different regulatory costs and effects. Zhao et al. (2015) argued that both market-based regulations and government subsidies significantly improved the production efficiency, whereas command and control regulations yield insignificant impact. Ren et al. (2018) found that voluntary environmental regulation and market-based have favorable effects on eco-efficiency in the eastern and central regions, while command-and-control regulation has a promotion effect across western and central provinces in China. Table 1 presents an updated literature on the urbanization-environmental regulations-green economic efficiency interplay from different perspectives.

After an extensive review of relevant literature, it is obvious that prior greater part of literature has indeed focused on the relationship between environmental regulation, urbanization, and green economic efficiency. Urbanization, as a mechanism, affects the interaction between heterogeneous environmental regulations and green economic efficiency. Thus, the importance of urbanization should be considered when considering the role of heterogeneous environmental regulations on green economic efficiency. We believe that less attention has been placed on the link between heterogeneous environmental regulations and green economic efficiency by adopting urbanization as a threshold variable. Another shortcoming is that the methodological approach adopted in previous studies focused on the linear relationship between the underline variables which fails to provide an in-depth analysis. To fill this methodological gap, this paper employs the static and dynamic threshold regression

**Table 1** Literature on urbanization-environmental regulation-green economic efficiency interplay

Study	Period	Sample	Methods	Results
Yasmeen et al. (2020)	2008–2018	China	DEA model	Urbanization and environmental regulation have positive and negative effects on green economic efficiency, respectively
Salman et al., (2022a, 2022b)	1980–2017	ASEAN-4	ARDL	No inverted U-shape curve between urbanization and green growth
Khan et al. (2021)	1970–2016	10 countries	Panel model	Urbanization is not conducive to green growth
Liu et al. (2021)	1995–2014	Northeast Asia	Panel model	Urbanization does not promote sustainable growth
Wu, Hao, et al. (2020)	2006–2015	China	GMM	Environmental regulation improves green growth by reducing energy consumption
Wang et al. (2021)	1960–2014	OECD	ARDL	Urbanization has stimulated green growth by decoupling from CO2 emissions
Wang and Wang (2021)	2002–2012	137 countries	Threshold model	Urbanization hinders green economic efficiency through CO2 emissions
Nathaniel et al. (2021)	1992–2016	African countries	Panel model	Urbanization has asymmetric effects on the environment and sustainable development
Wang et al. (2020)	1990–2014	APEC countries	DSUR	Urbanization adversely affects green growth via CO2 emissions
Mahmood et al. (2020)	1968–2014	Saudi Arabia	ARDL	Urbanization increases CO2 emissions, and ultimately downgrades green growth
Dong et al. (2020)	1990–2016	126 countries	Panel model	Urbanization increases PM2.5 emissions, and ultimately degrades green growth
Ahmed et al. (2020)	1971–2014	G7	Panel model	Urbanization increases the ecological footprint, and impedes sustainable growth
Asongu et al. (2020)	1980–2014	Africa	ARDL	Urbanization increases emissions and reduces green economic efficiency
Wu, Xu, et al. (2020)	2005–2016	China	Threshold model	U-shaped relationship found between environmental regulation and green economic efficiency
Song et al. (2021)	2004–2017	China	OLS	An inverted U-shaped relationship found between environmental regulation and green economic efficiency
Wang et al. (2019)	2004–2010	OECD	SBM-DDF	Environmental regulation has a positive impact on green productivity growth
Wang and Shao (2019)	2001–2015	G20	Panel model	Environmental regulation shows significant positive effect on green growth

DEA Data Envelopment Analysis, OECD Organization for Economic Co-operation and Development, ARDL Auto-regressive distributed lag, OLS ordinary least square, GMM generalized method of moments, DSUR Dynamic seemingly unrelated regression

using the panel dataset of 30 provinces in China to investigate the influence of heterogeneous environmental regulations on green economic efficiency at different levels of urbanization with the aim to deliver a theoretical description for these two variables.

### 3 Theoretical framework

The theoretical aspect of urbanization and green economic efficiency is explained in the context of three famous theories: the compact city, urban transition, and ecological modernization theories. The compact city theory emphasizes on the importance of urban design in accordance with the sustainable development principles. The sustainable development design reduces energy consumption in housing, industrial, transportation, and other sectors which mitigates pollution and ultimately accelerates green economic efficiency (Adams & Klobodu, 2017). The urban transition theory assumes that the ecological degradation is based on the level of income. More specifically, as income level increases and cities become rich through industrial development, it will consequently increase electricity demand, heating, infrastructure, and construction activities. This will lead to higher pollution and lower green economic efficiency. However, green economic efficiency may be improved through government intervention (national policies and regulations), technological improvement, and change of economic structure (Bekhet & Othman, 2017). The ecological modernization theory develops a relationship between urbanization and green economic efficiency at the national-level and states that the societal transformation from low to the middle-income may increase ecological degradation and reduce green economic efficiency. This theory further elaborates that societies typically prioritize improving their income level over environmental protection. However, as the income level reaches a certain promising level, societies will change their prominence in order to achieve green economic efficiency (Poumanyong & Kaneko, 2010).

According to the institutional ecological economics, the purpose of environmental regulation is to promote ecology and green economic efficiency, simultaneously. However, it is quite challenging to set optimum governance measures in advance, and interdependence and conflicts of interests between various levels of governance institutions may coexist (Williamson, 2007). The resulting transaction costs may prevent environmental regulations from achieving the purpose of stimulating green economic efficiency. Porter's hypothesis, which is based on a closed economy, argues that well-crafted environmental regulations can trigger corporate innovation, build a competitive advantage and ultimately enhance green economic efficiency (Porter & Claas, 1995). On contrary, the "Green Paradox" hypothesis states that an environmental regulation that becomes greener with the passage of time acts like a proclaimed expropriation for the owners of fossil fuel resources by provoking them to hasten resource exploitation and hence decelerates green economic efficiency (Sinn, 2012).

Considering the heterogeneity of environmental regulation tools, different types of environmental regulations may have different effects on green economic efficiency. Therefore, this paper mainly analyzes the impact of command-and-control, market-based, and voluntary environmental regulations on green economic efficiency. The Command-and-control environmental regulation (CER) refers to the environmental protection laws and regulations on economic entities imposed by the government aimed at protecting the environment. Economic players, such as enterprises are forced to obey these regulations or face severe penalties, thus the effective implementation of these regulations prompts economic

subjects to intensify technological innovation and improve existing processes to enhance the green economic efficiency. However, the application cost of command-and-control environmental regulation is too high to provide a long-term dynamic supervision. Moreover, due to information asymmetry, the phenomenon of "government failure" may occur, which affects the effect of command-and-control environmental regulation on the improvement of green economic efficiency. Therefore, we formulate hypothesis 1:

**Hypothesis 1** As the urbanization increases, the magnitude of the effect of CER on green economic efficiency decreases.

Market-based environmental regulation (MER) is designed by the government based on the principle of "source control" aiming at guiding enterprises to reduce environmental pollution through market mechanism, such as investment in the source of environmental pollution. In the implementation process of market incentive environmental regulations, the government does not directly interfere in the production decisions of enterprises, but indirectly regulates the market environment faced by them, and entrusts enterprises to make independent management decisions. Market incentive environmental regulation gives enterprises and other economic subjects a certain amount of free choice, and allows them to make independent decisions on production and management and constrains environmental pollution in the process of economic activities. It is a regulatory approach that gives consideration to green economic efficiency and environment. Moreover, this type of environmental regulation follows the market mechanism and has low implementation cost. With the growing market economic system in China and the continuous improvement of environmental monitoring and law enforcement system, the role of market incentive environmental regulation will be more and more significant. In contrast, the increase in pollution control investment will have a "crowding-out effect" on the production and innovation of enterprises, and inhibit the production performance of enterprises as well as the green development of the region. Thus this study develops hypothesis 2.

**Hypothesis 2** As the urbanization increases, the effect of MER on green economic efficiency gradually turns from positive to negative.

Voluntary environmental regulation (VER) is not imposed by the government, but depends on the public awareness of environmental protection and comes from the pursuit of the essence of survival. When environmental pollution caused by economic activities threatens public health, the public will consciously exercise the environmental supervision rights and citizens' litigation rights granted by the environmental protection laws, and put pressure on the government and environmental violators to supervise their efforts to eliminate environmental hazards. Such environmental regulations act on the reputation of economic entities, such as enterprises through petitioning, news media, and other means which may further affect their market valuation and market benefits. However, economic entities that cause environmental pollution are forced to negotiate and deal with environmental pollution in a timely manner due to the potential loss of reputation and market operation.

At present, more mature environmental protection organizations formed by the public have been established in various countries which are specialized in the collection of environmental information, the supervision of polluting enterprises, the publicity of environment-friendly behaviors, and other voluntary environmental regulation work. In contrast, China's public environmental awareness is still relatively weak; the public voluntary



environmental organizations are quite rare. With the development of urbanization, the continuous enhancement of public environmental awareness, the public voluntary environmental regulation will play more obvious role. Thus, we formulate hypothesis 3.

**Hypothesis 3** As the urbanization increases, the effect of VER on green economic efficiency becomes more obvious and positive.

## 4 Methodology

### 4.1 Measuring green economic efficiency

We assume that a production system comprised  $N$  decision making units (DMUs) and each DMU is composed of three elements, namely inputs, desirable output and undesirable output. The inputs of certain production factors  $x \in R_+^M$ , have desirable output  $y^g \in R_+^G$  and undesirable output  $y^b \in R_+^B$ . The production probability set is as follow:

$$P = \{(x, y^g, y^b) | x \geq X\theta, y^g \geq Y^g\theta, y^b \leq Y^b\theta, \theta \geq 0\} \quad (1)$$

The actual expected output is lower than the frontier ideal expected output, whereas the actual unexpected output is higher than the frontier ideal unexpected output.

Data envelopment analysis (DEA) proposed by Charnes et al. (1978), is a nonparametric approach aims at estimating the relative efficiency of multiple DMUs having several inputs and outputs (Salman et al., 2022b). DEA is further classified into radial and non-radial models. However, both models suffer from a pivotal drawback which is the lack of information about the neglected slackness and effectiveness (Zhou et al., 2012). Moreover, radial models yield in overestimation of efficiency in a case where nonzero inputs are better than bad outputs. Also, the oriented DEA provides inaccurate results because it considers only one perspective of inputs and outputs. To confront these issues, this study measures the green economic efficiency through non-oriented and non-radial Super-SBM model developed by Tone (2002). Super-SBM model can efficiently address the slackness by directly considering desirable output shortfall, undesirable output excess, and input redundancy which is suitable for estimating efficiency considering undesirable output (Wang et al., 2019). Following production probability set, the Super-SBM model in its general form can be outlined as:

$$\rho = \min \left( \frac{\frac{1}{M} \sum_{i=1}^M \bar{x}_i}{\frac{1}{G+B} \left( \sum_{r=1}^G \frac{\bar{y}_r^g}{y_{r0}^g} + \sum_{r=1}^B \frac{\bar{y}_r^b}{y_{r0}^b} \right)} \right)$$

$$s.t. \begin{cases} \bar{x} \geq \sum_{j=1, \neq k}^N \theta_j x_j \\ \bar{y}^g \leq \sum_{j=1, \neq k}^N \theta_j y_j^g \\ \bar{y}^b \geq \sum_{j=1, \neq k}^N \theta_j y_j^b \\ \bar{x} \geq x_0, \bar{y}^g \leq y_0^g, \bar{y}^b \geq y_0^b, \bar{y}^g \geq 0, \theta \geq 0 \end{cases} \tag{2}$$

where  $\rho$  indicates the efficiency score,  $M$ ,  $G$ , and  $B$  are the inputs, good outputs, and bad outputs, respectively.

### 4.2 Threshold model

To investigate the nonlinear impact of environmental regulations on green economic efficiency, while considering the heterogeneous characteristics in urban development in China, this study adopts the Hansen (1999) panel threshold regression model. Based on the fixed effects, we divided the observations into various regimes which may or may not exceed the threshold value. A single static threshold regression model is computed as:

$$GEE_{it} = c + \beta_1 ER_{it} I(urban_{it} \leq \gamma) + \beta_2 ER_{it} I(urban_{it} > \gamma) + \theta_1 TP_{it} + \theta_2 OPEN_{it} + \theta_3 HC_{it} + \theta_4 GII_{it} + \alpha_i + u_{it} \tag{3}$$

where  $i$  and  $t$  are, respectively, the provinces and year dimensions;  $urban_{it}$  is the threshold parameter;  $GEE_{it}$  is the green economic efficiency;  $ER_{it}$  represents various environmental regulations;  $TP_{it}$  indicates technical progress;  $OPEN_{it}$  is openness;  $HC_{it}$  is human capital;  $GII_{it}$  is government intervention;  $\gamma$  represents threshold value;  $u_{it}$  indicates random error;  $\beta_1, \beta_2$  are the coefficients of the core variables;  $\theta_i, i = 1, 2, 3, 4$  indicates the coefficients of the control variables;  $\alpha_i$  is the single effect;  $I()$  is an indicator function which is equal to 1 when the conditions in the brackets are satisfied, otherwise it is equal to 0. However, the regression model (3) assumes only a single threshold. In some applications, multiple thresholds may be encountered. Moreover, in the single threshold, if the primary hypothesis is rejected, we then focus on the double-threshold model as Eq. (4).

$$GEE_{it} = c + \beta_1 ER_{it} I(urban_{it} \leq \gamma_1) + \beta_2 ER_{it} I(\gamma_1 < urban_{it} \leq \gamma_2) + \beta_3 ER_{it} I(urban_{it} > \gamma_2) + \theta_1 TP_{it} + \theta_2 OPEN_{it} + \theta_3 HC_{it} + \theta_4 GII_{it} + \alpha_i + u_{it} \tag{4}$$

The Panel Threshold Regression Model (PTRM) effectively measures the correlation between variables and various regimes, and requires no precondition of the nonlinear model, and estimates based on the endogenously sample data (Pan et al., 2016). However, being static in nature, this approach assumes that all variables should be homogeneous which is against the come sense because panel data models are often prone to endogenous

problems. To encounter this difficulty, Kremer et al. (2013) integrated Hansen (1999) threshold regression with Caner and Hansen (2004) instrumental variable estimation technique and developed a dynamic panel threshold regression. Therefore, we further analyze the dynamic threshold effect of urbanization on ER and GEE using differential generalized method of moments (GMM) to overcome the endogenous problems. The extended dynamic threshold regression in this paper is outlined as:

$$GEE_{it} = c + \beta_0 GEE_{it-1} + \beta_1 ER_{it} I(\text{urban}_{it} \leq \gamma_1) + \beta_2 ER_{it} I(\text{urban}_{it} > \gamma_1) + \theta_1 TP_{it} + \theta_2 OPEN_{it} + \theta_3 HC_{it} + \theta_4 GII_{it} + \alpha_i + u_{it} \quad (5)$$

where  $GEE_{it-1}$  is lagged period of  $GEE_{it}$ . The panel threshold model has been extensively employed to analyze the nonlinear relationship between independent and dependent variables. The other advantage is that it takes heterogeneous effects into consideration ().

### 4.3 Variables and data

#### 4.3.1 Explained variable

This paper adopts green economic efficiency (GEE) as explained variable. For input, we employ the classical input variables, namely labor, capital stock, and energy consumption. For the labor, this paper selects the number of employees in each province at the end of the year. Regarding energy input, this study converted the energy consumption of each province into standard coal. We followed Wang and Yi (2021) to calculate capital inputs through the perpetual inventory method in the following manner:  $k_t = k_{t-1}(1 - \delta) + I_t/p_t$ ,  $k_t$  and  $k_{t-1}$  indicate capital stocks over the periods  $t$  and  $t + 1$ . Consistent with Zhang (2004), the depreciation rate ( $\delta$ ) is fixed to 9.6%.  $I_t$  and  $p_t$  are, respectively, the total fixed capital formation and the investment price index in fixed assets based on the year 2000. Capital stock in the year 2000 is the total fixed capital formation divided by 10%. This paper uses GDP to represent the expected output deflated to the constant price as of the year 2000 in accordance with the consumer price index. The undesired outputs include sulfur dioxide emissions, smoke (dust) emissions, and wastewater emissions.

#### 4.3.2 Core variable

The core variable that this study considers is the environmental regulation which further disaggregated into three types, namely command-and-control, market incentive and public voluntary. Command-and-control environmental regulation (CER) adopts comprehensive utilization rate of industrial solid waste (Li et al., 2021). Following Zhao et al. (2018), proportion of investment in environmental pollution control to GDP is used to proxy market-based environmental regulation (MER). Voluntary environmental regulation (VER) is proxied by logarithm of the number of letters and personnel for the Environmental Letters and Visits Office (Ren et al., 2018).

#### 4.3.3 Threshold variable

Urbanization is the process of population concentration in cities which will inevitably affect the economy and environment. This paper uses urbanization to represent the threshold variable, and represented by the share of the urban population in the total population.

#### 4.3.4 Control variables

- (1) Technical progress (TP). Green technical progress is a key driving force to promote environmentally sustainable economic growth (Yuan et al., 2020). This study uses logarithm of the number of domestic patent applications to represent technical progress (Salman et al., 2019a).
- (2) Degree of opening (OPEN). Opening may either cause the environmental cost of the transfer of high-polluting industries, thus hindering the growth of green economy or obtain foreign advanced technology spillover to improve the green growth efficiency (Salman et al., 2019b; Xie et al., 2017). This study employs the percentage of foreign direct investment in GDP to measure the degree of outward economy.
- (3) Human capital (HC). Human capital is one of the important factors use for an innovation system of a country including green innovation (Zhang et al., 2020). Assuming the average years of education of illiteracy, primary, middle, high, university are 2, 6, 9, 12, and 16, respectively, the total education years = illiteracy \* 2 + primary \* 6 + middle \* 9 + high \* 12 + university \* 16. Years of education per capita represents the human capital in this study.
- (4) Government intervention (GII). In the early stage of economic development, the local governments are more inclined to pursue economic development, while allocating low funds for environmental protection (Copeland & Taylor, 2004). However, as the level of economic development increases, the public becomes more eager for a high-quality environment. Therefore, the local governments will pay more attention to the environmental protection (Wang et al., 2021). This study uses proportion of general budget expenditure of local finance to GDP to proxy the government intervention.

#### 4.3.5 Data sources

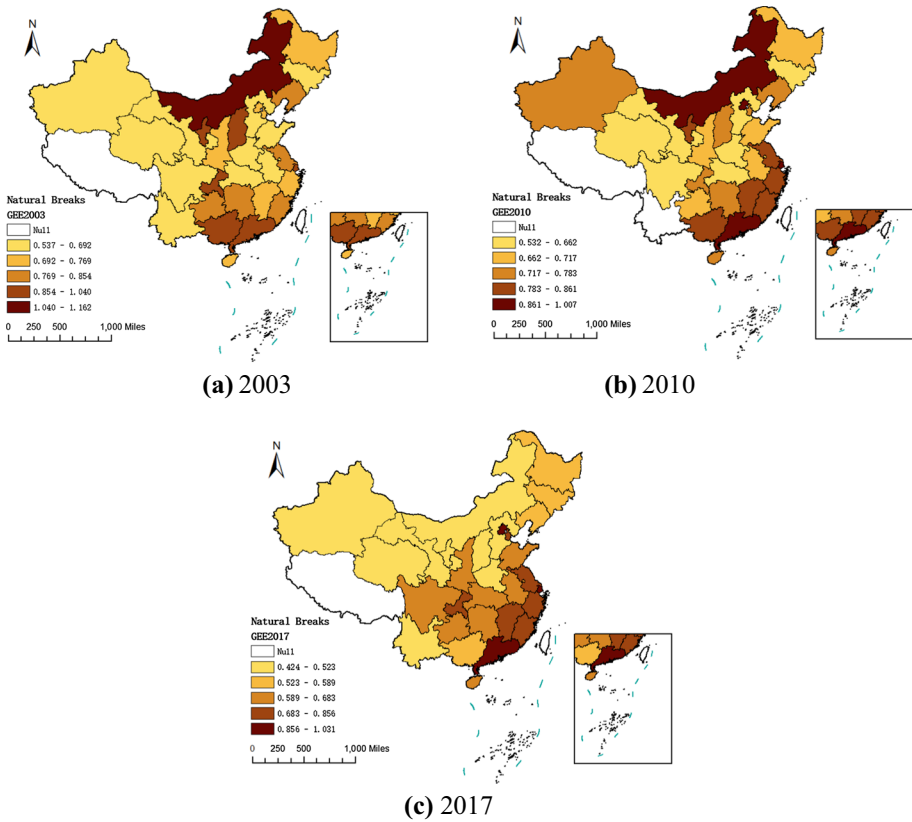
This study uses the dataset of thirty provincial administrative regions in China over the period 2003–2017.<sup>1</sup> Considering data availability and consistency, we extract the data on command-and-control environmental regulation, degree of opening, government intervention, urbanization, human capital from the China Statistical Yearbook for each year. The data on technical progress is gathered from the China National Intellectual Property Administration (CNIPA). The data source on market-based environmental regulation is obtained from the China Environment Database of EPS (Easy Professional Superior). The data source on voluntary environmental regulation is collected from the China Environmental Yearbook. The results of descriptive statistics are shown in Table 2.

Notes: Std.Dev. indicates standard deviation. The descriptive estimates are presented in natural logarithm.

<sup>1</sup> The Tibet region is excluded from the quantitative analysis based on the unavailability of data.

**Table 2** The descriptive statistics of the variables

Variable	Mean	Std. Dev	Min	Max
GEE	0.744	0.138	0.424	1.162
CER	0.661	0.203	0.203	1.040
MER	1.338	0.669	0.300	4.240
VER	9.850	1.264	3.951	12.576
urban	0.512	0.145	0.139	0.896
TP	9.631	1.648	4.820	13.350
OPEN	0.025	0.021	0.000	0.184
HC	8.826	0.943	6.413	12.533
GII	0.208	0.094	0.079	0.627



**Fig. 1** GEE in 2007, 2010, and 2017

## 5 Empirical results and analysis

### 5.1 Characteristic of GEE

Figure 1 shows the trends in green economic efficiency at different time horizons, i.e.,

**Table 3** Threshold effect results

Environmental regulation	Number of thresholds	Threshold values	F-Statistic	<i>p</i> Value	Bootstrap replications
CER	Single threshold	0.849	55.58	0.047	300
	Double threshold	0.849 0.621	13.32	0.620	300
MER	Single threshold	0.849	55.76	0.030	300
	Double threshold	0.849 0.518	43.68	0.030	300
	Triple threshold	0.450	14.26	0.653	300
VER	Single threshold	0.849	54.76	0.070	300
	Double threshold	0.849 0.358	12.14	0.667	300

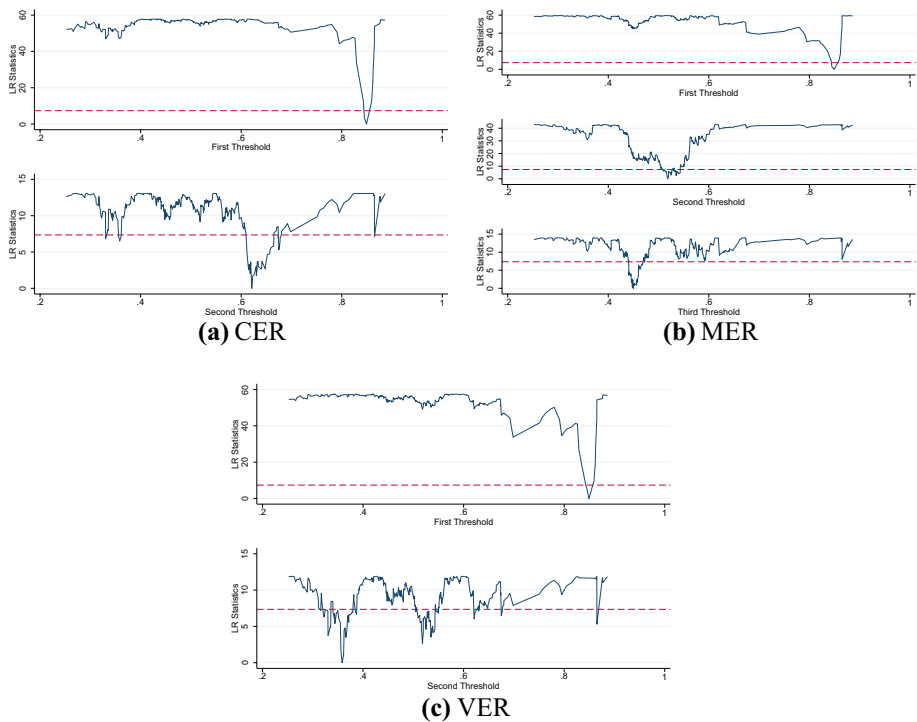
2003, 2010, and 2017. Clearly, there is a considerable heterogeneity in GEE at different time periods. In 2003, the region-based gap in GEE among eastern, central, and western regions were relatively small. In 2010, the results demonstrated the eastern-western-central phenomenon meaning that GEE decreased from eastern and western to central region. In 2017, we noticed that the trend in GEE was decreasing from eastern and central to western region. In summary, the results demonstrated that eastern region experienced an upward trend in GEE, while central and western regions had a downward trend over the study period<sup>2</sup>.

## 5.2 Threshold test analysis

Before applying the threshold regression, several steps need to be carried out. First, it is essential to examine whether the model yields a single or multiple thresholds and their significance levels. After having confirmed that the model has a threshold effect, we then determine the numbers of thresholds such as, single threshold, double thresholds, or three thresholds. To make it work, we followed the bootstrapping method proposed by Hansen (1999) to obtain the estimates of the F statistics and then calculate the *p* value. The results are reported in Table 3.

For command-control regulation, we noticed that the *p* value of single threshold is 0.047, which is significant at 5% level suggesting that the null assumption of linear association between the variables is rejected. Regarding double threshold, the *p* value is 0.620, which exceeds the 10% significance level, thereby providing no evidence of double threshold effect between the variables. In the brief, it is evident that the model yields a single threshold effect. Additionally, both CER and GEE do not have a single linear correlation under the impact of urbanization. Moreover, at 0.05 confidence level, the single threshold values are 0.8492. For market-based regulation, the *p* value is statistically significant at 5% confidence interval which infers that the null hypothesis of linear effect between variables cannot be accepted. In relation to double threshold effect, the *p* value is recorded as 0.030.

<sup>2</sup> China map no. GS (2019) 1822.



**Fig. 2** Threshold parameter of urbanization in different static threshold models, solid blue line indicates LR. The red dotted line indicates the 95% significance level

Therefore, the null hypothesis of single threshold effect between the variables is rejected. Also, the p value for triple threshold is higher than 0.6533 which leads to the rejection of the null hypothesis of double threshold effect. The double threshold values at 95% confidence level are 0.5182 and 0.8492. Regarding voluntary regulation, the p value of single threshold rejects the null assumption of linear association between variables as the p value is statistically significant at 5% confidence level. Regarding the double threshold effect, the p value is 0.667 which is statistically insignificant, thereby rejecting the null hypothesis of single threshold effect. These results are also graphically plotted in Fig. 2.

### 5.3 Threshold model estimation for a whole sample

#### 5.3.1 Static threshold model estimation

For a whole sample, the results showed that the model has a single threshold effect. Based on this, this study further explores the effects of ER and other control variables on GEE at various threshold points of urbanization (see Table 4). From CER, the results verify the presence of one threshold in the model, which is further classified into two intervals of urbanization level. The impact of CER on GEE varies at each interval. Overall, CER seems to play a positive role in accelerating GEE. Regarding the two stages of urbanization level, the effect of CER is strongly positive at 1% confidence interval. Precisely, when the level of urbanization does not exceed the first threshold value of 0.849, the impact of CER on GEE

**Table 4** Static threshold and fixed effect model estimation: whole sample

Variables	(1) GEE	(2) GEE	(3) GEE	(4) GEE	(5) GEE	(6) GEE
CER	0.143*** (3.14)					
MER			0.002 (0.19)			
VER					0.007 (1.45)	
CER ( <i>urban</i> ≤ 0.849)		0.150*** (3.49)				
CER ( <i>urban</i> > 0.849)		0.450*** (7.32)				
MER ( <i>urban</i> ≤ 0.518)				0.014* (1.73)		
MER (0.518 < <i>urban</i> ≤ 0.849)				-0.027*** (-3.13)		
MER ( <i>urban</i> < 0.849)				0.097*** (5.35)		
VER ( <i>urban</i> ≤ 0.849)						0.006 (1.32)
VER ( <i>urban</i> > 0.849)						0.029*** (5.11)
Urban	-0.002 (-0.03)	-0.276*** (-3.44)	-0.003 (-0.03)	0.002 (0.03)	0.007 (0.09)	-0.214*** (-2.73)
TP	-0.031*** (-2.95)	-0.015 (-1.45)	-0.031*** (-2.87)	-0.021** (-2.17)	-0.032*** (-3.03)	-0.018* (-1.77)
OPEN	-0.593** (-1.99)	-0.557** (-1.97)	-0.568* (-1.86)	-0.503* (-1.83)	-0.559* (-1.86)	-0.536* (-1.87)
HC	0.013 (0.73)	0.003 (0.16)	0.011 (0.61)	0.004 (0.26)	0.008 (0.43)	-0.004 (-0.20)
GII	-0.479*** (-3.78)	-0.456*** (-3.80)	-0.395*** (-3.12)	-0.429*** (-3.73)	-0.400*** (-3.20)	-0.375*** (-3.16)
Cons	0.947*** (9.45)	0.999*** (10.50)	1.037*** (10.68)	1.005*** (10.92)	1.008*** (10.21)	1.079*** (11.43)
R <sup>2</sup> (Within)	0.252	0.331	0.235	0.380	0.238	0.314
N	450	450	450	450	450	450

t-statistics are in parentheses; \*, \*\*, \*\*\* are, respectively, significance levels at 10%, 5% and 1%

is 0.149. When the level of urbanization is greater than the threshold, CER improves green economic efficiency by 0.377 point. This result is similar to the study of Xie et al. (2017). They divide CER into three segments and found that the three segments of CER promote Green "Productivity" at different intensities. Overall, the interpretation of the results is that CER promotes GEE for a whole sample. Regardless of urbanization level, CER will reduce pollutant emissions and partially improve green economic efficiency. In particular, when



the urbanization level is high, the pollutant emission and energy use increase, and the magnitude of the effects of CER are stronger.

Regarding MER, the results confirm two thresholds in the model, which are classified into three turning points of urbanization level. At each point, the effect of MER on GEE is different. Specifically, when the urbanization level is not beyond the first threshold coefficient of 0.518, the MER stimulates green economic efficiency by 0.014 point. When the level of urbanization is beyond the first threshold, but is not greater than 0.849, MER reduces GEE by 2.7%. However, the impact turns positive and improves green economic efficiency by 9.7% point after exceeding the threshold point of 0.849. At initial stage of urban development, appropriate investment in source governance is beneficial to GEE. However, as the rate of urbanization increases, MER is not conducive to green economic efficiency in a short term because most of China's manufacturing industries are emissions-intensive and energy-intensive ones. In addition, excessive investment in source governance cuts enterprise funds and increases enterprise costs, thereby exerting negative effect on GEE. When the urbanization level is high, the source governance has a certain basis, and stringent MER significantly contributes to the green economic efficiency.

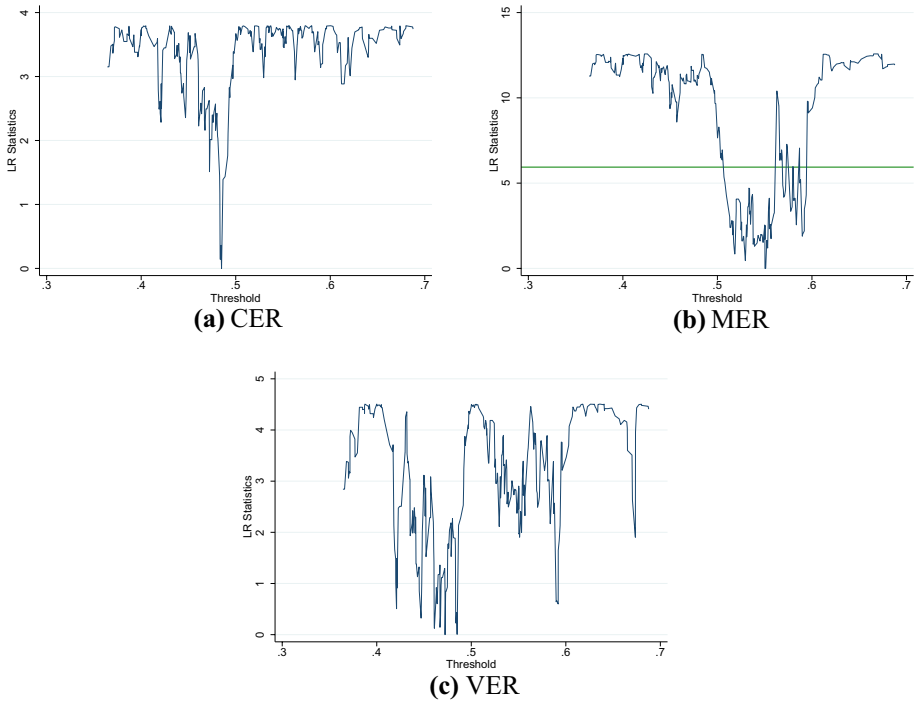
With respect to VER, the results showed a single threshold effect in the model, which further decomposed into two turning points of urbanization level. Specifically, when the urbanization level is less than the single threshold coefficient of 0.849, VER promotes (insignificantly) green economic efficiency. When the level of urbanization is beyond the threshold point, VER significantly accelerates green economic efficiency by 0.029 point. This is consistent with Wang and Shao (2019). The possible interpretation for these results is that when the urbanization level is low, less-educated citizens have low awareness about improving green economic efficiency without jeopardizing environment. On the other side, as the level of urbanization increases, citizens are well-educated and aware about the importance of environmental protection, which has a more profound impact on green economy.

Regarding control variables, the results are in line with our expectations. The impact of technical progress on GEE is negative. The reason is that although the number of patents has considerably increased over the past two decades in China. However, most of them focus on traditional innovation rather than green innovation. The degree of opening negatively affects green economic efficiency. Government intervention does not seem to promote significantly green economic efficiency. This outcome is not surprising to us as government primarily prioritizes economic development by allocating extensive amount of funds to infrastructure development, while ignoring the environmental risks during the initial and middle stages of industrialization (Li, Fang, et al., 2018; Li, He, et al., 2018). Finally, the impact of human capital on GEE is positive but not significant.

### 5.3.2 Dynamic threshold model estimation

Based on the dynamic panel threshold regression, the threshold values of urbanization in the models of different ER are evaluated. The threshold values of CER, MER and VER are 0.485, 0.550, and 0.472, respectively. Moreover, Fig. 3 shows the LR statistics of the threshold value in different models. It is obvious that all the threshold values pass the LR tests.

Dynamic threshold regression includes lag term of dependent variable ( $GEE_{it-1}$ ), which may lead to endogeneity due to the potential correlation between the independent variables and the error terms. Hence, we use differential GMM to overcome the endogeneity



**Fig. 3** Threshold value of urbanization in different dynamic threshold models

issue. Table 5 reports the dynamic threshold regression results of heterogeneous ERs when urbanization is an endogenous threshold. By measuring the lag term of explanatory variable, it is found that the coefficient is significantly positive. This means that GEE is in the process of continuous accumulation. Meanwhile, it also verifies that the adopting of the dynamic model is reasonable.

Clearly, the effects of CER and VER on GEE are positive. However, the magnitudes of their effects become weaker when urbanization is larger than the threshold value. This means that as the process of urban transformation advances, the urban economic development and innovation capacity are also enhanced, which in turn improves the urban resource utilization efficiency and accelerates green economic efficiency. At this point, the promotion effects of CER and VER on GEE are stronger. The impact of MER on GEE is positive when the urbanization level is below the threshold value, and becomes negative after crossing the threshold point. This is similar to the findings of Wang et al. (2019). This shows that further development in urbanization accelerates the resource utilization efficiency, whereas the proportion of investment in environmental pollution control gradually decreases. At this stage, massive investment in environmental pollution control will crowd out enterprise innovation funds and decelerate green development in a long-term.

**Table 5** Dynamic threshold regression: whole sample

Variables	(1) GEE	(2) GEE	(3) GEE
L.GEE	0.701*** (15.27)	0.636*** (28.52)	0.732*** (14.28)
CER ( <i>urban</i> ≤ 0.485)	0.147*** (4.07)		
CER ( <i>urban</i> > 0.485)	0.093*** (3.04)		
MER ( <i>urban</i> ≤ 0.550)		0.027*** (5.36)	
MER ( <i>urban</i> > 0.550)		-0.020*** (-3.59)	
VER ( <i>urban</i> ≤ 0.472)			0.021*** (8.09)
VER ( <i>urban</i> > 0.472)			0.012*** (5.35)
urban	0.741*** (6.95)	1.096*** (7.65)	0.941*** (5.57)
TP	-0.046*** (-6.72)	-0.073*** (-5.96)	-0.055*** (-4.84)
OPEN	-0.064 (-0.23)	0.243 (1.20)	0.015 (0.05)
HC	-0.005 (-0.56)	0.011* (1.88)	-0.013 (-1.52)
GII	-0.248*** (-4.19)	-0.356*** (-4.38)	-0.044 (-0.52)
cons	0.300*** (9.63)	0.361*** (8.65)	0.209 (1.59)
<i>N</i>	420	420	420

t-statistics are in parentheses

\*, \*\*, \*\*\* are, respectively, significance levels at 10%, 5% and 1%

## 5.4 Threshold model estimation of subsample

To obtain a comprehensive view of ER's effect on GEE under different urbanization level, the dataset is further disaggregated into eastern, central, and western regions<sup>3</sup> (see Table 6). We adopt the static threshold regression based on Hausman test. In eastern region, the p values of CER's single and double thresholds are 0.007 and 0.350, respectively. The p values of MER's single and double thresholds are 0.003 and 0.423, respectively. The p values of VER's single and double thresholds are 0.010 and 0.317, respectively. Under the 95%

<sup>3</sup> Eastern includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan; Middle includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Western includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang.

**Table 6** Static threshold effect results of subsample

area	Environmental Regulation	Number of thresholds	Threshold values	F-Statistic	<i>p</i> Value	Bootstrap replications
eastern	CER	Single threshold	0.849	34.58	0.007	300
		Double threshold	0.849 0.515	12.44	0.350	300
	MER	Single threshold	0.849	29.24	0.003	300
		Double threshold	0.849 0.515	8.81	0.423	300
	VER	Single threshold	0.849	36.86	0.010	300
		Double threshold	0.849 0.515	13.58	0.317	300
central	CER	Single threshold	0.325	2.46	0.983	300
	MER	Single threshold	0.557	8.72	0.587	300
	VER	Single threshold	0.325	2.66	0.983	300
western	CER	Single threshold	0.526	3.67	0.893	300
		Double threshold	0.609 0.539	15.04	0.110	300
	MER	Single threshold	0.609	26.52	0.040	300
		Double threshold	0.609 0.539	15.04	0.110	300
VER	Single threshold	0.609	9.05	0.550	300	

confidence level, the single threshold values of CER, MER and VER are 0.849. In central region, the *p* values of single threshold F-statistics of CER, MER and VER are not significant. In western region, only MER has a significant single threshold (0.609) value at 95% significance level.

Based on the results, urbanization has a single threshold on the impact of CER, MER and VER on GEE in eastern region having two intervals of urbanization level. For CER, it has a positive insignificant impact on GEE under the threshold value (0.849). As the process of urbanization exceeds the turning point, green economic efficiency significantly improves by 0.250 point with one point increase in CER (Table 7). For MER, when urbanization level is below the single threshold of 0.849, MER stimulates insignificantly green economic efficiency. However, after exceeding the threshold point, the effect of MER on GEE becomes positive and significant. From VER, it negatively affects green economic efficiency when the urbanization level is not above single threshold. However, VER is conducive to green economic efficiency when the urbanization level is above the threshold point. The eastern region is economically developed, where the local governments emphasize on the sustainable urban development via strict environmental regulation. However, as the urbanization level exceeds a certain threshold point, it leads to several ecological problems, including excessive resource consumption, and higher environmental pollution. In this situation, both CER and MER will suppress environmental pollution and improve resource utilization efficiency, which will obviously promote green economic efficiency.

In central region, we adopt fixed effect model to estimate impacts of heterogeneity environmental regulation on GEE. The results indicate that CER and MER both promote (insignificantly) green economic efficiency, while VER has insignificant deteriorating effect. In western region, both CER and VER significantly promote GEE, whereas MER impedes GEE at different thresholds. When the level of urbanization is above the threshold, the impact of MER turns significant. On the one hand, there are considerable differences

**Table 7** Threshold model estimation: subsample

Variables	eastern			central			western		
	GEE	GEE	GEE	GEE	GEE	GEE	GEE	GEE	GEE
CER				0.091 (1.12)			0.385*** (4.36)		
MER					0.009 (0.47)				
VER						-0.00008 (-0.01)			0.015* (1.86)
CER ( <i>urban</i> ≤ 0.849)	0.020 (0.25)								
CER ( <i>urban</i> > 0.849)	0.250*** (2.88)								
MER ( <i>urban</i> ≤ 0.849 or 0.609)		0.016 (1.19)							-0.005 (-0.31)
MER ( <i>urban</i> > 0.849 or 0.609)		0.105*** (5.53)							-0.129*** (-4.30)
VER ( <i>urban</i> ≤ 0.849)									
VER ( <i>urban</i> > 0.849)									
urban	-0.215*** (-2.68)	-0.031 (-0.45)	-0.012 (-1.25)	-0.640* (-1.86)	-0.600* (-1.75)	-0.593* (-1.70)	0.407 (0.78)	0.541 (1.04)	0.518 (0.95)
TP	0.026 (1.29)	0.021 (1.07)	0.006 (0.61)	0.078*** (3.08)	0.077*** (3.01)	0.079*** (3.11)	-0.098*** (-3.36)	-0.106*** (-3.65)	-0.103*** (-3.34)
OPEN	0.045 (0.15)	-0.039 (-0.13)	0.039 (0.13)	-3.868*** (-2.85)	-4.057*** (-3.00)	-4.072*** (-3.01)	1.078 (0.86)	-0.915 (-0.73)	0.422 (0.32)
HC	0.045	0.036	0.049	-0.071*	-0.072*	-0.072*	-0.059	-0.014	-0.066

**Table 7** (continued)

Variables	eastern		central		western		
	GEE	GEE	GEE	GEE	GEE	GEE	
GII	(1.50) -1.582***	(1.19) -1.625***	(1.62) -1.525***	(-1.85) -1.493***	(-1.88) -1.534***	(-1.55) 0.190	(-0.35) 0.253
cons	(-5.82) 0.510***	(-6.02) 0.552***	(-5.49) 0.598***	(-3.28) 1.196***	(-3.37) 1.258***	(0.94) 1.659***	(1.27) 1.522***
R2(Within)	(3.08) 0.337	(3.50) 0.350	(3.65) 0.345	(5.10) 0.406	(5.39) 0.401	(8.03) 0.490	(7.24) 0.505
N	150	150	150	120	120	165	165

t-statistics are in parentheses; \*, \*\*, \*\*\* are, respectively, significance levels at 10%, 5% and 1%

**Table 8** Threshold effect test

Environmental Regulation	Number of thresholds	Threshold values	F-Statistic	<i>p</i> Value	Bootstrap replications
CER	Single threshold	0.849	65.14	0.020	300
	Double threshold	0.849 0.648	14.20	0.663	300
MER	Single threshold	0.845	29.90	0.093	300
	Double threshold	0.849 0.518	37.96	0.017	300
	Triple threshold	0.876	14.51	0.193	300
VER	Single threshold	0.849	45.24	0.060	300
	Double threshold	0.849 0.358	10.29	0.777	300

among different regions in terms of geographic position, economic development level and level of opening up. On the other hand, it may be related to the higher degree of economic development, better market mechanism, and the stringent environmental regulations.

## 5.5 Robustness test

As robustness, this study replaces both environmental regulation and control variables. Specifically, CER is represented by the logarithm of comprehensive index of environmental indicators— sulfur dioxide emissions, dust emission, and total waste water discharge using entropy evaluation method. We use the logarithm of proportion of investment in environmental pollution control to GDP to proxy MER. The logarithm of number of environmental proposals for NPC (the National People's Congress) and CPPCC (the Chinese People's Political Consultative Conference) are employed to proxy VER. We further adopted an alternative proxy of degree of opening that is total imports and exports as a percentage of GDP. The Logarithm of expenditure of local finance general budget represents government intervention. The results of static threshold model are shown in Table 8, Table 9 and Fig. 4 show threshold values of urbanization in different ERs' static models. We noticed that the threshold of ER is consistent with the results presented in the above section. Meanwhile, the insignificant coefficient of VER is below 0.849, the sign and significance of the variables are similar to the above results, thereby indicating the robustness of the above empirical analysis.

Further, we consider the dynamic threshold model. In the dynamic threshold regression model, although the threshold values are different in heterogeneous ER model, threshold values pass the LR tests (see Fig. 5). In Table 10, it is found that the results of model are similar to the results in Table 5. Hence, this confirmed the robustness of previous empirical analysis.

**Table 9** Robustness test: Static threshold

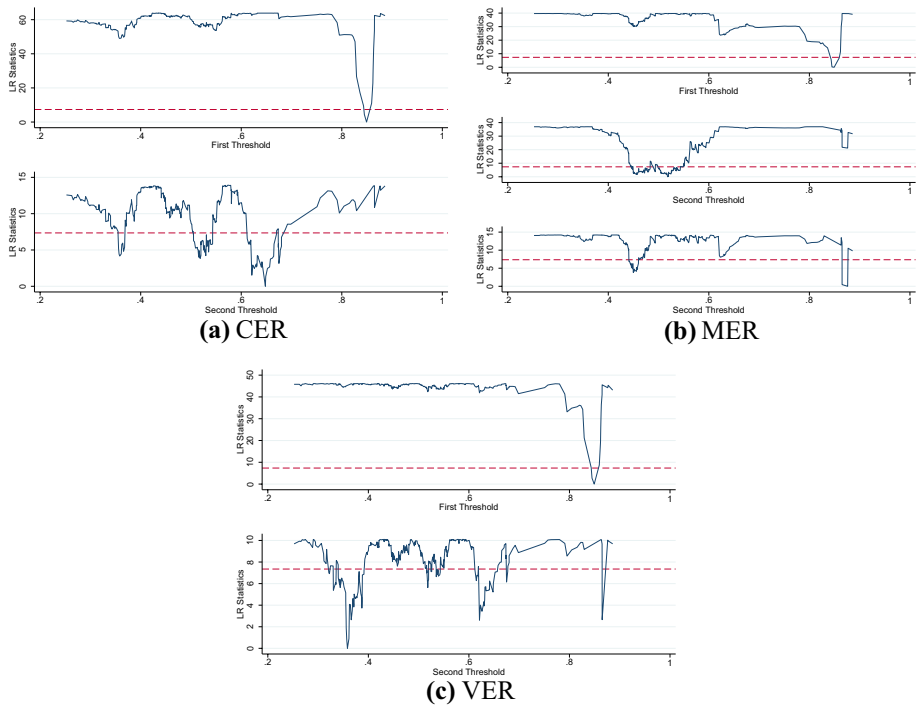
Variables	(1) GEE	(2) GEE	(3) GEE
CER ( <i>urban</i> ≤ 0.849)	0.108*** (5.76)		
CER ( <i>urban</i> > 0.849)	0.005 (0.22)		
MER ( <i>urban</i> ≤ 0.518)		0.048*** (3.45)	
MER (0.518 < <i>urban</i> ≤ 0.849)		−0.047*** (−3.31)	
MER ( <i>urban</i> > 0.849)		0.230*** (5.15)	
VER ( <i>urban</i> ≤ 0.849)			−0.001 (−0.17)
VER ( <i>urban</i> > 0.849)			0.042*** (4.28)
Urban	−0.082 (−1.12)	0.139* (1.92)	−0.187** (−2.30)
TP	−0.010 (−0.81)	−0.034*** (−2.81)	−0.026** (−2.05)
OPEN	−0.009*** (−2.93)	−0.009*** (−2.65)	−0.009*** (−2.78)
HC	−0.011 (−0.56)	−0.005 (−0.26)	−0.014 (−0.71)
GII	−0.029* (−1.80)	−0.022 (−1.40)	−0.005 (−0.29)
cons	1.355*** (13.87)	1.235*** (12.41)	1.270*** (12.41)
R2(Within)	0.359	0.342	0.301
N	450	450	450

t-statistics are in parentheses; \*, \*\*, \*\*\* are, respectively, significance levels at 10%, 5% and 1%

## 6 Discussion

Based on the empirical results, the following discussions could be drawn. First, the results of static and dynamic threshold regressions found that command-and-control (CER) and voluntary environmental regulations (VER) drive China's green economic efficiency under a single threshold. Meanwhile, market-based environmental regulation (MER) has double and single threshold effects in static and dynamic threshold models, respectively. In other words, MER improves green economic efficiency in case urbanization is below the first threshold or above the second threshold in static threshold model, while it exerts promotion effect on green economic efficiency when urbanization is below the threshold point in dynamic threshold model. In summary, this study verifies the differential effects of the three types of environmental regulations on green economic efficiency at different urbanization levels. The result indicates that only if the intensities of CER and VER exceed a

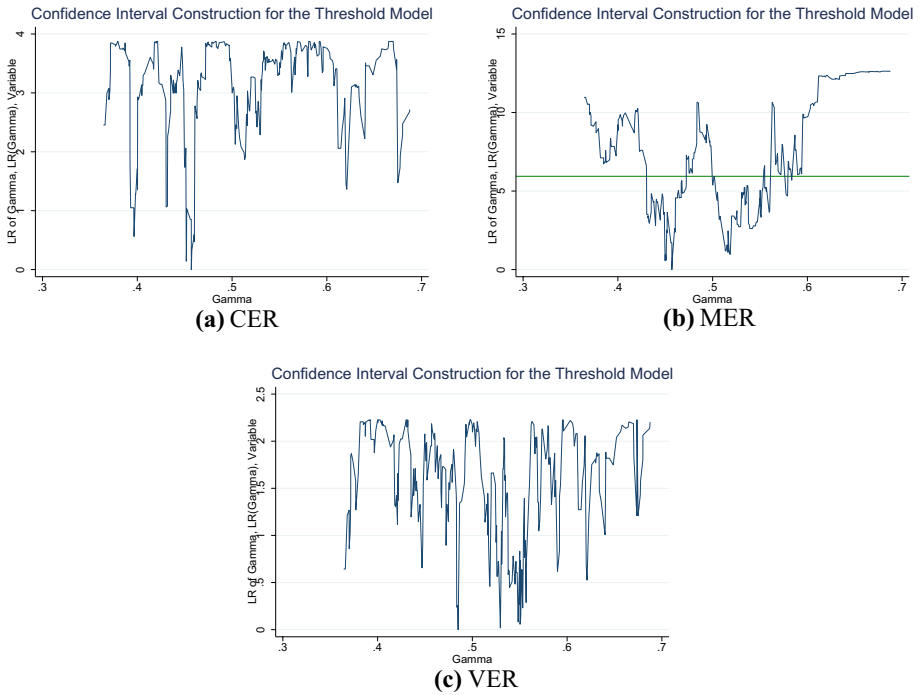




**Fig. 4** Threshold parameter of urbanization in different static threshold models, solid blue line indicates LR. The red dotted line is the threshold level

certain threshold level of urbanization, the win–win situation of the Porter effect can be achieved. Furthermore, their intensities have an optimum range to improve green economic efficiency. If they are relative loose, then the effective incentives on promoting green economic efficiency will not be induced; while the effect of incentives will be limited if they are too strict. It also turns out that there exists a double threshold relationship between MER and green economic efficiency. This is because the social costs of pollution can be converted into firms' private costs more effectively with MER, driving firms to solve the problem fundamentally by improving production technology, optimizing resource allocation, and conducting R&D activities. This makes market-based environmental regulation more flexible than command-and-control environmental regulation. Our results are partially consistent with the study of Guo and Yuan (2020).

The results further identified that the three types of environmental regulations have different effects on green economic efficiency at various threshold levels of urbanization across different regions. In eastern region, both CER and MER promote green economic efficiency when the level of urbanization is greater than the threshold, while VER adversely affects green economic efficiency when the urbanization level is below the threshold and accelerates green economic efficiency after exceeding the threshold point. In central region, the results did not find a threshold effect. We found that CER and MER stimulate green economic efficiency (insignificantly), while VER insignificantly deteriorates it. In western region, CER and VER significantly improve green economic efficiency, while VER negatively affects green economic efficiency after the urbanization level is



**Fig. 5** Threshold parameter of urbanization in different dynamic threshold models

above the certain threshold level. The possible explanation for these results is that there are significant variations among the underlined regions in terms of industrial structure, level of economic development, level of urbanization, market mechanism, and the stringency of environmental regulations. Our results are in line with Yao et al. (2021).

## 7 Conclusions and policy recommendations

The primary interest of this study is to examine the heterogeneous effects of various environmental regulations, namely Command-and-control environmental regulation (CER), Market-based environmental regulation (MER), and Voluntary environmental regulation (VER) on green economic efficiency (GEE) from the perspective of urban development across 30 provinces in China from 2003 to 2017. For that purpose, this study employs urbanization as a threshold variable and analyzed its threshold effect from static and dynamic both perspectives. Additionally, this study considers technical progress, openness, government intervention, and human capital as control variables to avoid variable bias.

The results of threshold regression are summarized as: (1) in both static and dynamic threshold regression analysis, CER and VER have a single threshold effect and stimulate GEE at different urbanization levels. MER has double threshold effect in static threshold model and promotes GEE significantly when urbanization is below first threshold or over second threshold. MER has a negative effect on GEE when urbanization is between the first threshold and second threshold. In dynamic threshold model, MER has a single threshold

**Table 10** Robustness test:  
Dynamic threshold

Variables	(1) GEE	(2) GEE	(3) GEE
L.GEE	0.701*** (31.70)	0.587*** (18.17)	0.693*** (18.77)
CER ( <i>urban</i> ≤ 0.457)	0.005 (0.43)		
CER ( <i>urban</i> > 0.457)	0.026*** (3.22)		
MER ( <i>urban</i> ≤ 0.457)		0.114*** (3.38)	
MER ( <i>urban</i> > 0.457)		-0.008 (-0.54)	
VER ( <i>urban</i> ≤ 0.485)			0.034*** (5.71)
VER ( <i>urban</i> > 0.485)			0.016*** (2.90)
urban	0.752*** (6.37)	0.826*** (3.57)	1.447*** (5.01)
TR	-0.070*** (-7.13)	-0.085*** (-4.27)	-0.098*** (-4.01)
OPEN	-0.013*** (-5.02)	-0.011*** (-2.66)	-0.012*** (-2.98)
HC	-0.023** (-2.10)	-0.047*** (-3.33)	-0.030** (-2.10)
GII	0.019 (1.35)	0.035* (1.70)	0.017 (0.62)
cons	0.633*** (9.22)	0.877*** (9.96)	0.463*** (6.20)
N	420	420	420

t-statistics are in parentheses; \*, \*\*, \*\*\* are, respectively, significance levels at 10%, 5% and 1%

effect and accelerates GEE when urbanization level is below threshold value. Then, MER inhibits GEE when the level of urbanization exceeds the threshold. (2) In eastern region, the impacts of CER and MER on GEE are positive but not significant when urbanization level is less than the threshold value. With the ongoing development in the urbanization process, the impact of CER and MER on GEE are positive and significant. For VER, its impacts on GEE are not significant at different urbanization levels. When urbanization is less than the threshold, the impact coefficient is negative. When urbanization exceeds the threshold, its coefficient is positive. In central region, there is no threshold effect. CER and MER promote (insignificantly) GEE, while VER has insignificant deteriorating effect. In western region, there is only threshold effect on MER. Both CER and VER significantly promote GEE, while MER inhibits GEE at different thresholds. When urbanization level is above the threshold point, the impact becomes significant.

Based on our research conclusions, we propose the following suggestions. First, environmental regulation is an efficient approach of improving China's green economic

efficiency. Thus, it is necessary to formulate well-crafted and reasonable environmental regulation. In doing so, China should shift its dominant policy type of environmental regulation from command-and-control to market-based advocated by Porter's hypothesis. In particular, the Chinese government should learn from the experience of developed economies, promote the reform of resource and emission tax, and better utilize the function of market mechanism to improve the green economic efficiency of resource-based industries. Meanwhile, in the context of significant regional differences in green economic efficiency, it also requires the Chinese government to implement more prudent environmental regulations in order to avoid industries with low energy efficiency but high pollution migrating to the western and central regions. Second, the threshold effect of urbanization is regionally different in China. The government should raise the environmental threshold for industrial transfer and avoid "race-to bottom competition" between regions. Meanwhile, the government should continue to vigorously develop population urbanization, optimize the household registration system, increase the intensity of talent introduction, and implement the plan of "introducing talents from the cloud" to promote the circulation of talents among regions and realize the sharing of high-quality resources.

There are some future research avenues. First, although this article has analyzed the heterogeneous effects of three main types of environmental regulations on the green economic efficiency, it does not consider the possible effects of informal environmental regulations, such as education level. Second, this study only incorporates one aspect of urbanization (i.e., population urbanization), and ignores other dimensions such as, economic urbanization and land urbanization. In future research, it would be more interesting to consider other types of urbanization as well.

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## Declarations

**Conflict of interest** The authors declare that they have no competing interests.

**Ethical Approval** We testify that this study is our original research with all data acquired by our examination and there is no plagiarism in it. We also affirm that this study has not been published elsewhere and is not under consideration by another journal.

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