Politická ekonomie
2024, Volume 72 (2), Special Issue:
Achieving Energy Transition and Sustainable Development:
The Roles of Political Risk and Energy Technology Investments

PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Comparative Analysis of Technological Innovation in Chinese Cities: Pre and Post-Government Green Performance Assessment

Ye Li, Hooi Hooi Lean, Yiyan Chen

Ye Li (e-mail: 9820210064@nankai.edu.cn): College of Economic and Social Development, Nankai University, China

Hooi Hooi Lean (*corresponding author:* e-mail: hooilean@usm.my): Economics Program, School of Social Sciences, Universiti Sains Malaysia, Malaysia

Yiyan Chen (e-mail: chenyiyan@student.usm.my): Economics Program, School of Social Sciences,Universiti Sains Malaysia, Malaysia

Abstract

To better promote the transformation of the economic development mode and improve technological innovation, the Chinese central government adjusted the performance assessment criteria for local officials. This study explores whether the government green performance assessment can serve to promote technological innovation. Data from 288 Chinese cities from between 2009 and 2018 is taken as the sample and the fixed effects model is utilized as the methodology. The findings show that the government green performance assessment has significant direct and long-term effects on technological innovation. The promotion of technological innovation is more evident in industry-oriented, low-pollution, and center groups, in addition to among veteran, high-education, and senior groups. Proposed policy recommendations include establishing a performance system that emphasizes short and long-term effects, and developing performance standards that are tailored to local conditions.

Keywords: Promotion incentives; government green performance assessment; technological innovation

JEL Classification: O30, C30, P30

Citation: Li, Y., Lean, H. H., Chen, Y.: Comparative Analysis of Technological Innovation in Chinese Cities: Pre and Post-Government Green Performance Assessment. *Politická ekonomie*, 2024, 72 (2), Special Issue, 403–430, https://doi.org/10.18267/j.polek.1440

1. Introduction

Over the past two decades, global climate change has continued to intensify. In addition to environmental hazards such as hurricanes, floods, droughts, forest fires, landslides, and ocean acidification (Ahmed *et al*., 2019; Fernandes, 2022; Ozturk *et al*., 2022), climate change causes several economic glitches. These include short-term unemployment, slower long-term productivity growth, a decline in potential income levels (Rezai *et al*., 2018), and impaired human health (Sohail *et al*., 2022; Sohail *et al*., 2023). Therefore, in the context of global challenges such as climate change, realizing sustainable development is both urgent and essential.

To promote sustainable development worldwide, the United Nations puts forward 17 sustainable development goals (SDGs), which address a variety of economic, social, and environmental aspects. Among these, Science, Technology, and Innovation (STI) is defined as a core tool for implementing SDGs (Walsh *et al*., 2020), while innovation is the driving force behind the majority of SDGs (Cordova and Celone, 2019). Different countries have varied priorities when it comes to advancing technological innovation in order to achieve the SDGs (Omri, 2020). For example, in high-income countries, technological innovation can contribute to the three pillars of economic, environmental, and social development of SDGs by increasing income levels and life expectancy, promoting equity in education, and fostering an environment that is positive and productive (Sahay and Walsham, 2017). However, in the current stage of progressive sustainable development, the significance of technological innovation for middle- and low-income countries lies primarily in environmental improvement (Yu and Du, 2019).

China, the largest developing nation in the world, has made remarkable strides in technological innovation. In 2022, China ranked first in the world in terms of the number of patent applications (Godinho and Simões, 2023), active patents, and international patent applications under the Patent Cooperation Treaty (PCT) (Duan *et al*., 2023). At the same time, on a sector-specific basis, research and development (R&D) investments in China are increasing in frontier areas such as big data (Razzaq and Yang, 2023), artificial intelligence (Beraja *et al*., 2023), renewable energy (Li *et al*., 2023), and aerospace technology (Pollpeter, 2023). Due to the constraints of economic, environmental, and social bottlenecks, China has recently attached great importance to using technological innovation to achieve sustainable development. By doing so, China has fully embarked on a path of sustainable development in several sectors, including transportation (Godil *et al*., 2021), manufacturing (Li and Huang, 2019), forestry (Ma *et al*., 2023), animal husbandry (Shang *et al*., 2014), and mining (Cai *et al*., 2021).

China has long relied heavily on the government to drive innovation and sustainable development. China's prior political system has been changed by a number of economic reforms

the country's central government has enacted since 1978 and its incorporation into globalization (Hasan *et al*., 2009). Political system reforms have contributed to China's achievement of SDGs and enhanced environmental quality (Koçak and Kızılkaya, 2020). Among them, the reform of the government performance system has become one of the key instruments of political system reform in China.

Prior to 2013, China's regional economic growth margin has ranked at the top of the government performance assessment. In this context, local officials often pay more and more attention to short-term local economic growth while ignoring innovative activities with large investments, long cycles, and high risk. For the purpose of better promoting the economic development mode's transformation and improving technological innovation, the Chinese central government adjusted and revised the assessment criteria for local officials (Chen, 2018). A Notice on Improving the Performance Assessment of Local Government Officials (henceforth referred to as the "Notice") was distributed by the central government in December 2013. The "Notice" clearly stated that gross domestic product (GDP) is no longer used as the performance assessment standard for local officials. The promulgation of the "Notice" means establishing a new orientation of government green performance assessment (GGPA), where economic development and environmental protection are placed in a more harmonious and equal position (He *et al*., 2022). Therefore, can the implementation of GGPA promote technological innovation in Chinese cities? This study aims to provide an answer to this question. Answering this question is crucial to realizing global sustainable development.

From a practical perspective, as the largest developing country in the world, the achievements China has made in technological innovation will have a far-reaching impact on the world. This will provide a brand-new development model and experience of building an innovative and powerful country to the rest of the world. From a theoretical perspective, China has a democratic centralized system, a political system that is characterized by a top-down governance model. This means that the higher level of government enacts various orders that must be implemented strictly and unconditionally by the lower level of government. Despite the fact that this political system is considered to have solid social mobilization (Jaros and Tan, 2020; Li *et al*., 2023) and enforcement (Gao and Yu, 2020), it may not be conducive to the creativity of each economic agent. So far, the academic debate on the question of "which political system (authoritarian or democratic) is more conducive to innovation" continues (Kogut and Zander, 2000; Kan Yap *et al*., 2023; Popper, 2020; Salahodjaev, 2015). As a result, examining the impact of government performance system reforms on innovation using Chinese cities as a sample can strengthen the academic understanding of the institutional factors behind innovation.

The following three aspects primarily represent the novelty of this article: (1) Research findings broaden the theory of sustainable innovation from the perspective of promotion

incentives of local officials, offering new empirical evidence at the regional level. (2) This article takes the promulgation of the "Notice" in December 2013 in China, namely the establishment of GGPA, as an explanatory variable for analyzing its direct and long-term impact on technological innovation in Chinese cities. (3) This study provides a more accurate and valuable reference for cities and officials with different characteristics for the development of differentiated performance assessment systems, which is missing in available literature.

This paper uses a fixed effect model to explore the impacts of GGPA on technological innovation in Chinese cities. The findings show that the GGPA has significant direct and long-term promoting effects on technological innovation. Furthermore, this promotion effect is more pronounced in the industry-oriented, low-pollution, and center groups, along with veteran, high-education, and senior groups.

The remaining paper is organized as follows: An overview of the literature and comments are made in Section 2. Section 3 discusses data and methodology. The direct and long-term effects of GGPA on technological innovation are discussed in Section 4. Section 5-7 further conducts the heterogeneity analysis on the basis of the urban and official characteristics. Finally, Section 8 presents a summary and outlook for the article.

2. Literature Review

Multitudinous scholars focus on the effect of local governments' behaviors and policies on technological innovation. The literature mainly focuses on tax incentives, fiscal subsidies, environmental regulation (ER), and corruption.

In terms of tax incentives, they can be implemented in the form of statutory tax incentives and fiscal subsidies. Studies on statutory tax incentives have found that firms with higher short-term tax incentives have an advantage in technological innovation. However, the high value of incentives invested in the short term may lead to crowding out effects, which can crowd out space for R&D funding and undermine technological innovation (Dai and Chapman, 2022). Multi-year tax incentives can avoid this dilemma, provided that tax incentive programs are not deregulated (Appelt *et al*., 2020). In addition, tax incentives have been found to promote technological innovation in noxious manufacturing (Brown *et al*., 2022), heavy pollution industries (Zhao *et al*., 2022), renewable energy (Su *et al*., 2022), and electric vehicles (Yang *et al*., 2022). Nevertheless, there is regional and industrial heterogeneity in promoting technological innovation by tax incentives. For example, in the integrated circuit industry, promoting technological innovation through tax incentives is less significant in the Pearl River Delta region than the other areas (Song and Wen, 2023). For mining firms, tax rebates for energy conservation and environmental protection can promote technological innovation and enhance environmental performance (Zhang and Song, 2022).

Fiscal subsidies are often regarded as an incentive to promote innovation. It can fill the funding gap for the investment shortage in technological innovation of enterprises and reduce innovation costs and risks (Huang *et al*., 2019; Lin and Luan, 2020). However, the extrusion effect of fiscal subsidies on corporate R&D funds would cause enterprises to innovate less (Clausen, 2009), which would have a negative impact on innovation performance (Wu *et al*., 2018). Some researchers believe that the influence fiscal subsidies have on technological innovation presents an inverted U-shaped relationship. This means that fiscal subsidies can elevate technological innovation and industrial expansion in the early stage of exploration. In the mid-term and mature stages, fiscal subsidies should be withdrawn from the market as a means of preventing overcapacity due to excessive fiscal subsidies, which will inhibit technological innovation (Xiong and Yang, 2016).

In terms of ER, the Porter hypothesis holds that ER could hoist the quality of corporate products and enhance corporate competitiveness. The increased income can completely offset the compliance costs derived from ER (Porter, 1991; Porter and Linde, 1995). Studies that supported Porter hypothesis include Hu *et al*. (2020) and Mbanyele and Wang (2022). However, some studies have questioned Porter's hypothesis, arguing that ERs can impose high compliance costs on firms, leading firms to reduce their investment in R&D funding (Gollop and Roberts, 1983; Gray and Shadbegian, 2003; Wagner, 2007; Liu *et al*., 2020; Aldieri *et al*., 2021; Trevlopoulos *et al*., 2021). Recent studies have revealed that ER's impact on technological innovation presents a U-shaped relationship. In the short term, ER will bring an "offsetting effect" on technological innovation. Still, with the increased ER, enterprises will be compelled to reduce pollution control costs by encouraging technological innovation, forming a "compensation effect" (Ouyang *et al*., 2020). In addition, some researchers believe that the nexus between ER and technological innovation may be an inverted U-shaped relationship (Wang and Shen, 2016) or an N-shaped relationship (Wang and Liu, 2014). These studies show uncertainties in the effect of ER on technical innovation. The latest researches have found regional heterogeneity (Lu *et al*., 2023) and industry heterogeneity (Zhong *et al*., 2023) in the Porter hypothesis.

Regarding corruption, the mainstream view is that this distorts institutional design and rational resource allocation, reducing government administrative efficiency and ultimately affecting both economic growth and technological innovation. (Hao *et al*., 2020; Fang *et al*., 2023). In addition, government corruption would lead to frequent rent-seeking activities and increase transaction costs, thereby squeezing the R&D funds of enterprises and inhibiting technological innovation activities of enterprises (Murphy *et al*., 1993; Anokhin and Schulze, 2009; Mungiu-Pippidi, 2015). It also hinders import liberalization (Lu *et al*., 2021), decreases the initial public offerings (IPO) pricing of companies (Wang and Song, 2021), interferes with innovation decisions (Hanousek *et al*., 2018), and undermines corporate social responsibility (Hossain and Kryzanowski,

2021). All of these behaviors hinder knowledge absorption and learning by companies and they are detrimental to technological innovation. Corruption has also been shown to interfere negatively with technological innovation in specific industries. For example, corruption can exacerbate market segmentation and reduce firms' incentives to innovate in renewable energy technologies (Ren *et al*., 2021). Corruption can weaken environmental regulation and hinder the transitioning from traditional to green electricity markets (Xu *et al*., 2024). However, some scholars believe that although corruption increases transaction costs, it also helps companies refrain from several cumbersome regulations in the bureaucratic system while promoting technological innovation (Xia *et al*., 2018). Besides, due to the high risk of technological innovation, enterprises often face finance difficulties in their innovative behavior. Establishing "political connections" with government officers beyond laws and regulations can help enterprises gain more government fiscal subsidies and stimulate their enthusiasm for technological innovation (Chen *et al*., 2013).

The existing literature attempts to investigate the influence of political factors on technological innovation from the perspectives of local government behaviors. It enriches the theory of technological innovation. However, the performance assessment system, which often largely determines local governments' behavior under centralized political system, is an essential political factor in affecting technological innovation. Theoretically, the impacts of GGPA on technological innovation are mainly reflected in two aspects: On one hand, a scientific and multi-dimensional performance appraisal system can correct the behavior preferences of local officials and improve the "short-sighted behavior" of local officials in promoting economic development (Deng *et al*., 2010; Heberer and Trapple, 2013; Tian and Feng, 2021; Zhou, 2007). Specifically, it can encourage local officials to revise their preferences for physical investment and improve the structure and mismatch of resource allocation.

On the other hand, in the government governance system, there are agency conflicts between local officials as agents and principals. The novel performance evaluation system has obviously increased the weight of important content such as environmental protection, culture and education, and social security. The official governance system that emphasizes "hidden performance" serves to alleviate the agency problem of local officials to a certain extent and also offers sound legal protection and functional policies for enterprises. However, relatively few studies have explored the ways in which reforming the performance assessment system affects technological innovation degree and focused on exploring it at the enterprise level. There is still a lack of studies at the regional level.

3. Data and Methodology

3.1 Data sources

This paper selects all 288 Chinese cities as the samples. As the implementation date of the "Notice" is December 2013, the sample period 2009–2018 is set so that there are five years of observations before and after the implementation of the policy. In this way, on one hand, it can ensure the adequacy of samples and avoid the confounding effect caused by the excessively wide time window mixed with other policy shocks (He *et al*., 2022). We obtained 2880 samples after excluding cities with missing or abnormal data.

Both macro and micro data are used in the empirical analysis. The macro data is related to economic and social development, and the micro data is linked to local officials. The macro data comes from the "China Urban Statistical Yearbook (2010–2019)", "Provincial (City) Statistical Yearbook" (2010–2019), and DRCnet (Information Network of Development Research Center of the State Council) Database. At the micro level, the official characteristics data come from the party and government leading cadres of the People's Daily Online database and the database of Chinese political leaders of "Fenghuang.com". They are supplemented and proofread by Baidu Encyclopedia and XINHUANET (www.news.cn).

3.2 Model settings

In order to examine whether the implementation of GGPA will promote technological innovation, the following regression model is established:

$$Y_{it} = \alpha_0 + \alpha_1 Post_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

The subscripts i and t represent the city and year, respectively. Y is the dependent variable, namely the level of technological innovation of a city. *Post* is the policy variable, which is the proxy for GGPA. X is a matrix of characteristic variables at the city level, including the urban human capital, government intervention, foreign investment, industrial structure, population density, population size, per capita road area, urbanization, and technical expenditure. μ_i and γ_t represent the individual-fixed and time-fixed effects, respectively, which control the inherent characteristics of cities that do not change with time and the time-varying macroeconomic environment that does not vary with cities. ε_{it} is the error term.

To estimate the model, joint significance tests for individual and random effects are first needed to discern whether a panel data model is required. The results of the F-test and Breusch–Pagan test both show that the model is significant at the 5% level. Therefore, it is necessary to consider

individual and random effects, *i.e.*, it should be estimated using a panel data model. Next, the selection of fixed effect or random effect model is carried out by the Hausman test. The test results show that the model is significant at 5%. Thus, the null hypothesis is rejected, and the fixed effects model is used for estimation. Meanwhile, we use cluster standard error identified by individuals (provinces) because these estimates are robust to disturbances that are heteroscedastic and autocorrelated.

Previous studies have shown that over time, the long-term effect of a policy shows different characteristics (Wu *et al*., 2015). Technological innovation is a long-term systematic project. The sustainability of innovation depends on the long-term input of human, material, and financial resources. Therefore, the effect of GGPA has a change trendover time. On the one hand, the strong incentive effect of GGPA on local officials will gradually decline over time.

On the other hand, the local governments will look for long-term solutions to achieve the assessment objectives. So, the effect of GGPA may increase gradually over time. Hence, to further analyze the long-term impact of GGPA, referring to the existing literature, a dummy variable is set for the *i*-year implementation of GGPA (Jiang and Chai, 2017). The specific model is as follows:

$$Y_{it} = \alpha_0 + \alpha_1 Post1_{it} + \alpha_2 Post2_{it} + \alpha_3 Post3_{it} + \alpha_4 Post4_{it} + \alpha_5 Post5_{it} + \alpha_6 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

In equation (2), *Post*1–*Post*5[1] represent dummy variables for the first to fifth years of implementing GGPA, respectively. The selection of other variables is the same as equation (1). The results of the joint significance test for all year dummy variables strongly reject the null hypothesis of "no long-run effect". The results suggest that the long-run effect of time should be considered in the model. In addition, the Hausman test show that equation (2) should be estimated using a fixed effects model.

3.3 The variables

This paper uses the total number of patent applications per 10,000 people (TNPAP) in a city to measure the technological innovation level (Yu *et al*., 2020).

In 2013, the promulgation of the "Notice" changed the performance appraisal standards for local officials in China fundamentally by determining the importance of environmental performance indicators (Zhang *et al*., 2020). In this paper, the promulgation of the "Notice," namely the implementation of GGPA, is set as a dummy variable. The years (2014–2018) after the implementation of the GGPA are taken as 1, and the other years (2009–2013) are taken as 0.

1 There are 5 years in the sample period after the implementation of GGPA. To study the impact of GGPA on technological innovation over time, five dummy variables are set here. We set all the years before GGPA to 0, so there will be no multicollinearity.

The long-term effect of GGPA. The *i*-th dummy variable takes the value *i* when the assessment is in the *i*-th year; otherwise, it is 0. As GGPA started to be implemented in December 2013, the first year of implementing GGPA was 2014. Therefore, *Post*1 = 1 if the year is 2014; otherwise, 0. And so on for the rest of the dummy variables.

China has a vast territory, and different regions' economic and social characteristics vary significantly. A series of control variables are measured as follows: urban human capital (*Edu*) is measured by the ratio of the number of students in secondary and higher education schools to the number of urban permanent residents. Government intervention (*Gov*) is proxied by the ratio of the general budget expenditure of the local government to GDP. Foreign direct investment (*Fdi*) is assessed by the amount of foreign capital used per capita (unit: yuan). Industrial structure (*Ind*) is measured by the ratio of the output value of the tertiary industry to the output value of the secondary industry. Population density (*Pden*) is measured by the ratio of the number of employees in the secondary and tertiary industries to the construction land area in the urban districts. Population size (*Psize*) is measured by the number of employees in the secondary and tertiary industries in the municipal districts. The per capita road area (*Road*) is measured by the ratio of the actual urban road area at the end of the year in the municipal district to the population size of the municipal district. Urbanization rate (*Urban*) is measured by the ratio of the non-agricultural population to the city's total population. Technical expenditure (*Texp*) is measured by the ratio of expenditures for scientific undertakings to the general budget expenditure of the local government.

4. Empirical Results

4.1 Direct effect of GGPA on technological innovation

Table 1 shows the direct effect of GGPA on technological innovation in cities. Specifically, the results show that the "Notice" significantly and positively affects TNPAP. In China's centralized political operating system, local officials' fulfillment of performance appraisals set by higher levels of government is the primary basis for their promotions. As a consequence, the implementation of GGPA changed the behavior of local governments. These behavioral changes, including strengthening government fiscal subsidies and ER, ultimately affected local technological innovation (Domazlicky and Weber, 2004; Huang *et al*., 2019). In terms of control variables, population density significantly and negatively influences TNPAP. Population size, urbanization rate, and technical expenditure significantly and positively affect TNPAP.

Table 1: The direct effect of GGPA on the level of technological innovation

Variables	*TNPAP*
Post	9.2726***(0.7995)
Edu	0.0738 (0.1932)
Gov	−0.0061 (0.0300)
Fdi	0.0004 (0.0005)
Ind	0.1751 (0.1738)
Pden	−0.0008**(0.0003)
Psize	0.1315***(0.0428)
Road	−0.0001 (0.0064)
Urban	0.6588**(0.3008)
Texp	5.1759***(0.8435)
Time Fixed Effects	Control
Individual Fixed Effects	Control
Adjust R^2	0.5555
Sample Size	2826
Hausman test	260.64

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively, and the numbers in brackets are robust standard errors.

Source: Authors' own elaboration

4.2 Long-term effect of GGPA on technological innovation

Table 2 shows the results of the intertemporal analysis of the implementation effect of GGPA. The results in Table 2 reveal that the positive effect of the implementation of GGPA on TNPAP has continued to be significant since the first year (2014) of the assessment. The coefficient reaches the maximum in the assessment's fourth year (2017). Therefore, it can be shown that the implementation of GGPA has a significant long-term effect on improving the level of technological innovation. The positive impact of GGPA on TNPAP has continued to rise in the first to fourth year

(2014–2017) of the assessment and then decreased. These results suggest that GGPA has provided Chinese cities with lasting motivation for technological innovation. It is no longer simply about meeting government performance assessments and now involves maintaining the green image and environmental sustainability of the city in the long term. This has led to steady long-term progress toward sustainable development.

Table 2: The long-term effect of GGPA on the level of technological innovation

	TNPAP
***Post*1**	0.7634** (0.3549)
***Post*2**	1.7154***(0.1877)
***Post*3**	1.7965***(0.1520)
***Post*4**	1.9324***(0.1510)
***Post*5**	1.6476***(0.1269)
Other variables	Control
Adjust R^2	0.5529
Sample size	2826
Hausman test	244.73

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively, and the numbers in brackets are robust standard errors.

Source: Authors' own elaboration

4.3 Robustness check

To check the reliability of baseline regression results, this paper conducts robustness tests from multiple dimensions.

There may be other policy shocks affecting technological innovation from 2009 to 2018. In November 2013, the State Council of China issued the "National Sustainable Development Plan for Resource-Oriented Cities (2013–2020)" (hereafter "Political Document"). According to this political document, specific arrangements have been made in four aspects: economic development, improvement of people's livelihood, resource security, and ecological protection. The promulgation of this political document is likely to affect technological innovation in re-

source-oriented cities. To exclude this possible policy influence, we remove the observed values of all resource-oriented cities in China from the sample and then perform the regression. As shown in column (1) of Table 3, the regression results are consistent with the baseline regression.

To test the influence of the dependent variable selection on the regression results, this paper uses the total number of patents (TNP) (unit:100 pieces) in the city to replace the TNPAP. The results in column (2) of Table 3 reveal that the estimated results are still consistent with the baseline regression results.

In order to test the sensitivity of the regression results, this study considers that the research sample in 2013 was only affected by the "Notice" that was issued in December, and there may be noise in the sample in the policy implementation year. So, the sample observations in that year are deleted. In Table 3, the results in column (3) demonstrate that the estimated results following the deletion of the observation samples in 2013 are still consistent with the baseline regression results. Hence, we conclude that the GGPA has a significant positive impact on technological innovation, which is robust and credible.

Table 3: Robustness results

	Exclude "Political Document" Influence	**Replace dependent variable**	**Delete the 2013 Observation Sample**
Variables	***TNPAP***	***TNP***	***TNPAP***
	(1)	**(2)**	**(3)**
Post	11.1496*** (1.2082)	36.0420*** (5.2488)	8.9723*** (0.8374)
Control Variable	Control	Control	Control
Time Fixed Effects	Control	Control	Control
Individual Fixed Effects	Control	Control	Control
Adjust R^2	0.5962	0.5026	0.5836
Sample Size	1696	2761	2542

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively, and the numbers in brackets are robust standard errors.

Source: Authors' own elaboration

5. Further Discussion Based on Heterogeneity Analyses

The previous analysis focuses on the overall level. Although understanding the impact GGPA has on technological innovation from a national perspective is important, the effect may vary according to the different characteristics of cities and local officials. First, cities with different characteristics often have different development paths (Yang *et al*., 2020). Different development paths have different demands on technological innovation and reach different stages of technological innovation in different ways (Nickels, 2008). Therefore, after implementing GGPA, technological innovation with different characteristics will be affected differently.

Second, China's political system is unique. The "one-party" and "people's democratic dictatorship" systems differ widely from the Western democratic election system. But, it shows high efficiency in implementing laws and administrative orders. This institutional advantage is often used as the "hand of macro-control" to intervene and supplement the market. In recent years, the Chinese government poured huge attention to environmental protection, and this "emphasis" is often reflected in many command-and-control ERs. The Chinese government copied the "whole-nation system" and "concentrated efforts doing big things" that are used in economic development to environmental protection. The central government issues some administrative orders to guide and restrict the local governments. The leaders of the local governments often actively implement these orders to obtain more opportunities for their promotion. This behavior enables the central government's order to be implemented step by step from the province to the city, from the city to the county, and from the county to the township. In this bureaucratic system, officials at all levels play a very critical role.

China's "one-party system" determines that China is a "party-government integration" country. The "party committee responsibility" system is the governance standard for governments in all hierarchies in China. Under this system, most of the administrative agencies' leadership teams are members of the CPC. Take a city as an example, and the mayor is not the most powerful official. His position in the CPC is often deputy secretary of the CPC Municipal Party Committee (CPCMPC). The person with the biggest influence in collective decision-making is the secretary of the CPCMPC. He is the top leader and usually also holds the administrative position of the deputy mayor. Therefore, in China's officialdom, there is no strictly equal "dual-head" system, *i.e*., the secretary of the CPCMPC and the mayor are the two leaders running side by side. However, in reality, the most influential person is the secretary of the CPCMPC. The position ranking in the party instead of the government determines the power size. The ranking within the party also determines the leader's influence on the government's governance. Therefore, when studying the impact of GGPA on innovation, we should consider the secretary of the CPCMPC rather than the mayor.

On the other hand, due to thousands of years of traditional cultural inheritance, the influence of "personal rule" is still huge in modern political occasions. A well-recognized excellent leader often has the characteristics of "dignity and decisiveness," *i.e*., the ability to "Have the final say" in daily leadership and governance. The unspoken rules of Chinese officialdom culture also advocate that "subordinates obey their superiors". The subordinates cannot resist the decisions of their superiors, and obedience to their superiors is a virtue recognized by officials. This phenomenon is inseparable from the edification of Confucian culture, and there is a common expectation of the phenomenon of "top leader has the final say" in Chinese officialdom.

Under the collective leadership of the "party committee responsibility" system, a CPCMPC often holds meetings, which are generally limited to members of the CPCMPC, to decide on major administrative matters. However, due to the factors mentioned above, the secretary of the CPCMPC can achieve

"I have the final say" on most occasions. The speeches and instructions of the CPCMPC secretary are the core content. At the same time, other leaders who rank lower in the CPC often make supplements based on the opinions of the CPCMPC secretary. These supplementary contents will not violate the instructions of the CPCMPC secretary. As a result, the so-called "collective leadership" generally becomes the "single speech" of the CPCMPC secretary, and the personal opinion of the highest-ranking leader in the party almost replaces the collective opinion of the leadership team under this system.

Although the CPC has issued numerous orders opposing "single speech" and curbed this trend to a certain degree through anti-corruption campaigns and party discipline inspections, the phenomenon is still widespread. The instructions of the CPCMPC secretary and his personal policy tendencies will considerably affect the daily operation of the administrative agencies under his jurisdiction. According to Maslow's hierarchy of needs theory, these "top leaders" have already satisfied the physiological, safety, belonging, and respect needs. Under the profound influence of the bureaucracy-oriented consciousness of the strong Confucian culture, officials often pursue self-realization. This involves supporting and implementing the instructions of the central government to gain the favor of superior leaders and obtain a higher chance of promotion. They generally believe promotion can enable them to gain more power and achieve greater ideals and ambitions in Chinese officialdom. The strong desire for promotion results in the CPCMPC secretary actively catering to the requirements of the GGPA, which prompts it to exert more influence on the congregate policy decision under the "party committee responsibility" system. Therefore, through the CPCMPC secretary, GGPA is bound to impact the innovation of the city (the jurisdiction of the CPCMPC secretary). Moreover, this influence will vary according to the different personal characteristics of the secretary of the CPCMPC (Besley *et al*., 2011).

For this reason, we further conduct the heterogeneity analysis from the city and official characteristics perspectives to enrich the findings.

6 Heterogeneity Analysis of City Characteristics

6.1 Administrative level

The entire sample is segregated into two groups: central cities and non-central cities. Among them, the central city group includes municipalities directly under the central government, provincial capital cities, and sub-provincial cities. The non-central city groups include the rest of the ordinary prefecture-level cities.

The regression results in columns (1)–(2) of Table 4 reveal that the estimated coefficients of policy variables are significantly positive in both central and non-central cities. Still, the estimated coefficients in central cities are 2.38 times that of non-central cities. This result demonstrates that following GGPA implementation, the TNPAP in central and non-central cities is significantly improved, but more so in the central cities. Central cities have a higher administrative level, and these cities tend to have a higher technical level than non-central cities. Due to their dependence on the development paths, it has often been easier for these cities to take advantage of their original advantages and continue exerting them in technological innovation after GGPA implementation (Glaeser, 1999).

6.2 Industrial structure

Based on the ratio of the tertiary industry's output value to the secondary industry's output value, this paper divides the entire sample into two groups: service-oriented cities and industry-oriented cities[2]. The regression results in columns (3)–(4) of Table 4 reveal that the estimated coefficients of policy variables are significantly positive in both service- and industry-oriented cities. Still, the estimated coefficients in industry-oriented cities are 2.3 times that of service-oriented cities. This result shows that after the implementation of GGPA, the TNPAP in both service-oriented and industry-oriented cities will be significantly improved. Still, it will be improved more in industry-oriented cities. GGPA implementation has led to an increased demand for technological

2 As the proportion of the service industry tends to increase with economic growth, the original industry-oriented cities may become service-oriented cities. To exclude this influence, our research only considers the urban industrial structure before the "Notice" was promulgated. The specific calculation method is as follows: First, calculate the ratio of the tertiary industry to the secondary industry in the city every year (from 2009 to 2012). Next, calculate the average value of the ratio within four -years. If the average value is greater than 1, the city is service-oriented. Otherwise, it is an industry-oriented city.

transformation and upgrading in industry-oriented cities, thereby strengthening their technological innovation (Yu *et al*., 2015).

6.3 Pollution levels

This paper constructs the environmental pollution index using four indicators: solid comprehensive waste utilization rate, centralized sewage treatment rate, domestic garbage harmless treatment rate, and sulfur dioxide emission reduction. Based on the environmental pollution index, we divide the entire sample into two groups: high-pollution and low-pollution cities[3]. The regression results in columns (5)–(6) of Table 4 show that the estimated coefficients of policy variables are significantly positive in both high-pollution and low-pollution cities. Furthermore, the estimated coefficient in low-pollution cities is 1.96 times that of high-pollution cities. This result shows that after the implementation of GGPA, the TNPAP in both high-pollution and low-pollution cities will be significantly improved. Still, they will be improved more in the low-pollution cities. Low-pollution cities are mainly those that pay more attention to ecological protection or have relatively clean industries. The implementation of GGPA has served to strengthen the existing advantages of these cities due to path dependence (Hein and Schubert, 2021), enabling them to invest more resources in innovative activities with longer cycles and higher risks. These results suggest that the central government of China cannot improve the technological innovation level in high-pollution cities simply by changing the promotion incentives for local officials.

3 The specific division is as follows: First, the value of the *j*-th indicator of the *i*-th city in year *t* is denoted as w_{ijt} ($I = 1, \ldots, 280; j = 1, \ldots, 4; t = 2009, \ldots, 2012$), and calculate $W_{ij} = \frac{1}{4}\sum_{t=2009}^{2012} w_{ijt}$, and $\bar{W}_j = \frac{1}{288}\sum_{i=1}^{288} W_{ij}$. Next, the score of the *j*-th indicator of the *i*-th city is denoted as S_{ij}, *if* $W_{ij} < \bar{W}_j$ ($j = 1, 2, 3$), $S_{ij} = 1$; if $W_{ij} < \bar{W}_j$ ($j = 4$), $S_{ij} = 0$. Finally, the environmental pollution index of the *i*-th city is denoted as S_i, $S_i = \sum_{j=1}^{4} S_{ij}$. If $S_i > 2$, *i*-th city belongs to the high pollution group; otherwise, it belongs to the low pollution group.

Table 4: Group test based on city characteristics

Variables	Dependent Variable: *TNPAP*					
	Urban Administrative Level		Industrial Structure		Pollution Levels	
	Center Cities	Non-Central City	Service-Oriented Cities	Industry-Oriented Cities	High-pollution Cities	Low-pollution Cities
	(1)	(2)	(3)	(4)	(5)	(6)
Post	18.5472*** (4.0123)	7.7831*** (0.8565)	6.6873*** (0.7103)	15.4010*** (1.9970)	5.3413*** (0.9405)	10.4594*** (0.9343)
Control Variable	Control	Control	Control	Control	Control	Control
Time Fixed Effects	Control	Control	Control	Control	Control	Control
Individual Fixed Effects	Control	Control	Control	Control	Control	Control
Adjust R^2	0.7735	0.4964	0.5772	0.6092	0.5264	0.5751
Sample Size	350	2476	1838	988	563	2263

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively, and the numbers in brackets are robust standard errors.

Source: Authors' own elaboration

7. Heterogeneity Analysis of Official's Characteristics

7.1 The appointment time of officials

In this section, the entire sample is compartmentalized two groups: newcomer and veteran. The specific division method is based on the incumbent secretary of the Municipal CPC Committee in January 2014[4]. If the secretary took office in January 2013 onwards, the city is a newcomer group member; otherwise, it is a veteran group member.

The regression results in columns (1)–(2) of Table 5 show that the estimated coefficient of the policy variable is significantly positive in both groups. Moreover, the estimated coefficient

4 Since the "Notice" was promulgated in December 2013, the local officials' behavior was most affected by the change of assessment method in 2014, the year after the "Notice" was issued. Therefore, this paper groups the samples according to the characteristics of the incumbent officials in January 2014.

in the veteran group is 24.33% higher than that of the newcomer group. This shows that the TNPAP in both the newcomer and veteran groups is significantly improved after the implementation of GGPA, but they are more enhanced in the latter group. This result could be due to the newly appointed officials always having to do several noteworthy things in a short time to show their capabilities. As an old Chinese phrase says, "A new broom sweeps clean". The new officials are more inclined to do some high-return work to deal with GGPA, rather than the risky and long-term work of technology innovation. Therefore, the improvement of TNPAP in the newcomer group was lower than in the veteran group.

The entire sample is compartmentalized two groups according to the education qualifications of the secretary of the Municipal CPC Committee as of January 2014. The city is classified as a high-education group if the secretary has a postgraduate degree or above. Otherwise, it is assigned to a low-education group.

The regression results in columns (3)–(4) in Table 5 show that the estimated coefficients of policy variables are significantly positive in both the high-education and low-education groups. Still, the estimated coefficient in the high-education group is 26.18% higher than in the low-education group. This result shows that after the implementation of GGPA, the TNPAP in both groups is significantly improved, but it is improved more in the high-education group. This is mainly because officials with higher education are more capable of adapting to the new system (Cheng *et al*., 2020).

7.3 The age of officials

The entire sample is compartmentalized into two groups according to the actual age of the incumbent officials as of January 2014. The city where the secretary of the Municipal CPC Committee is above the average age is under the senior group. Otherwise, the city is put into the younger group.

In table 5, the regression results of columns (5)–(6) show that the estimated coefficients of the policy variables are significantly positive in both groups. However, the estimated coefficient in the senior group is 12.27% higher than in the younger group. This result shows that after the implementation of GGPA, the TNPAP in both groups were significantly improved, but it were improved more in the senior group. Younger officials have stronger promotion incentives (Yu *et al*, 2020), so they prefer to accumulate promotion capital in the short term. Therefore, compared with senior officials, the younger officials pay more attention to work with low investment and high returns.

Table 5: Group test based on official characteristics

Variables	Dependent Variable: *TNPAP*					
	Time in Office (Seniority)		Education Level		Age	
	Newcomer	Veteran	High	Low	Senior	Younger
	(1)	(2)	(3)	(4)	(5)	(6)
Post	7.9282*** (1.1532)	9.8574*** (1.1509)	9.5471*** (0.9327)	7.5658*** (1.4605)	9.3323*** (1.1213)	8.3122*** (1.2150)
Control Variable	Control	Control	Control	Control	Control	Control
Time Fixed Effects	Control	Control	Control	Control	Control	Control
Individual Fixed Effects	Control	Control	Control	Control	Control	Control
Adjust R^2	0.5192	0.6084	0.5570	0.6752	0.5406	0.5893
Sample Size	1176	1618	2337	457	1347	1447

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively, and the numbers in brackets are robust standard errors.

Source: Authors' own elaboration

8. Conclusions and Outlook

8.1 Research findings and policy implications

This study explores the effects of GGPA on technological innovation in Chinese cities. The panel regression model is used to examine the direct and long-term effects of GGPA on technological innovation. Finally, the regional variation of the impacts of GGPA on technological innovation is analyzed based on the characteristics of cities and officials, respectively.

This study has provided a novel perspective to understanding technological innovation development under the centralized political system of China and provided a reference for the optimization of the performance assessment system. Our research finds that implementing GGPA has a significant positive impact on technological innovation. The effect has proven to be valid under different robustness tests, including the exclusion of other policy influences, the replacement of dependent variables, and the deletion of partial observation samples. In addition to the direct short-term impact, implementing GGPA has a significant long-term effect on technological inno-

vation. The positive impact of GGPA on technological innovation has continued to be significant since the first year of the assessment. Specifically, the positive effect of GGPA on technological innovation continues to rise from the first year to the fourth year of the assessment, and then it decreases.

Furthermore, this research also conducts group examinations in addition to the national level. First, we group all samples according to the city characteristics, including administrative level, industrial structure, and pollution levels. Following GGPA implementation, technological innovation in central and non-central cities has improved significantly, but more so in the central cities. Technological innovation in both service-oriented and industry-oriented cities has been significantly improved, but it is greater in industry-oriented cities. Technological innovation in high-pollution and low-pollution cities has also improved significantly, the low-pollution cities showing the greatest amount of improvement. Second, all samples are grouped according to the official characteristics, including appointment time, education level, and age. After GGPA was implemented, technological innovation in both newcomer and veteran groups has improved significantly, the greatest improvement being evident in the veteran group. Technological innovation in high-education and low-education groups has also improved significantly, but it has improved more in the former group. Technological innovation in the senior and younger groups has improved significantly, but there is more improvement in the senior group.

Based on the empirical results, the following policy recommendations are proposed to further optimize the performance appraisal management system and ensure that it aligns with the broader SDGs.

Firstly, this study finds the GGPA can effectively promote urban technological innovation. In the future, the central government should fully utilize the GGPA as a means of ensuring that cities achieve sustainable development in a more holistic way. For example, to provide motivation for the promotion of more comprehensive sustainable development, the central government could further adjust the indicators in the GGPA by integrating them more closely with the SDGs. More specifically, clean energy and carbon emission reduction could be included as the key indicators in the assessment of the performance of local officials. The central government could also consider the efforts of local governments to address climate change and disaster risk reduction. In addition, the government could include related indicators in the GGPA system, including urban planning and land use, as a means of encouraging the adoption of sustainable urban planning measures.

Secondly, this study finds that in addition to the short-term effect, GGPA still has a long-term promoting effect on technological innovation. The central government should fully utilize this for technological innovation. GGPA could be used to incentivize investment in technological innovation projects with long-term sustainable development potential by local governments and enterprises. This includes investing in basic research, talent training, and infrastructure development.

Thirdly, the results show that issuing the "Notice" has had a heterogeneous impact on the technological innovation of different types of Chinese cities. Therefore, the central government could formulate differentiated assessment standards for local officials in different types of cities. For example, the development and application of emission reduction technologies could be an essential indicator in high-pollution cities. At the same time, innovation in digital technologies and information services could be included as part of the assessment in service-oriented cities. By using different assessment indicators, these cities would be incentivized to promote technological innovation and sustainable development through adaptation to local development directions.

8.2 Research limitation and future research direction

Although the findings of this paper expand the existing research to some extent, there are some limitations.

First, this paper excludes the effects of other policy (The "Political Document" issued by the State Council of China in November 2013 mentioned in Section 4.3). While this ensures some degree of confidence in the results, it is difficult for any study to rule out all potential externalities. The future research can consider the interactive effect of different policies. For example, analyze whether the effects of different policy implementations on technological innovation cancel each other out or strengthen each other. Alternatively, one could also analyze whether policy mixes have nonlinear effect on technological innovation.

Second, the heterogeneity tests of this paper are only based on the characteristics of city and official. However, it may be reflected from other aspects such as regional culture, social network, local political environment etc. Future research should consider expanding the heterogeneity analysis from these perspectives as a means of capturing the comprehensive impact GGPA has had on innovation under different conditions.

Finally, while this study has explored the immediate and long-term impacts of GGPA on technological innovation, it has not fully covered all SDGs, including poverty reduction, health, education, and environmental issues. Future research could consider the impact of GGPA on these areas to better understand the panorama of sustainable urban development.

Acknowledgement

Funding: There was no funding, either externally or internally, towards this study.
Conflicts of interest: The authors hereby declare that this article was not submitted nor published elsewhere.

References

Ahmed, N., Thompson, S., Glaser, M. (2019). Global aquaculture productivity, environmental sustainability, and climate change adaptability. *Environmental Management*, 63, 159–172. https://doi.org/10.1007/s00267-018-1117-3

Aldieri, L., Kotsemir, M., Vinci, C. P. (2021). Environmental innovations and productivity: Empirical evidence from Russian regions. *Resources Policy*, 74, 101444, https://doi.org/10.1016/j.resourpol.2019.101444

Anokhin, S., Schulze, W. S. (2009). Entrepreneurship, innovation, and corruption. *Journal of Business Venturing*, 24(5), 465–476. https://doi.org/10.1016/j.jbusvent.2008.06.001

Appelt, S., Bajgar, M., Criscuolo, C., et al. (2020). The Effects of R&D Tax Incentives and Their Role in the Innovation Policy Mix Findings from the OECD MicroBeRD Project, 2016–19. [Retrieved 2020-07-24] Available at: https://www.oecd-ilibrary.org/deliver/65234003-en.pdf?itemId=/content/paper/65234003-en&mimeType=pdf

Beraja, M., Yang, D. Y., Yuchtman, N. (2023). Data-intensive innovation and the State: evidence from AI firms in China. *The Review of Economic Studies*, 90(4), 1701–1723. https://doi.org/10.3386/w27723

Besley, T., Montalvo, J. G., Reynal-Querol, M. (2011). Do educated leaders matter?. *The Economic Journal*, 121(554), F205–227. https://doi.org/10.1111/j.1468-0297.2011.02448.x

Brown, J. R., Martinsson, G., Thomann, C. (2022). Can environmental policy encourage technical change? Emissions taxes and R&D investment in polluting firms. *The Review of Financial Studies*, 35(10), 4518–4560. https://doi.org/10.1093/rfs/hhac003

Cai, M., Li, P., Tan, W., et al. (2021). Key engineering technologies to achieve green, intelligent, and sustainable development of deep metal mines in China. *Engineering*, 7(11), 1513–1517. https://doi.org/10.1016/j.eng.2021.07.010

Chen, X. (2018). The evolution of China's system for the management of officials since the 1970s: A longitudinal study. *Comparative Economic & Social Systems*, (3): 136-144. (In Chinese)

Chen, Y., Liu, M., Su, J. (2013). Greasing the wheels of bank lending: Evidence from private firms in China. *Journal of Banking & Finance*, 37(7), 2533–2545, https://doi.org/10.1016/j.jbankfin.2013.02.002

Cheng, Z., Yu, T., Pan J., et al. (2020). Local officials' promotion incentive, political achievement system and technological innovation of firms. *Nankai Business Review*, 6: 64-75. (In Chinese)

Clausen, T. H. (2009). Do subsidies have positive impacts on R&D and innovation activities at the firm level?. *Structural Change and Economic Dynamics*, 20(4), 239–253. https://doi.org/10.1016/j.strueco.2009.09.004

Cordova, M. F., Celone, A. (2019). SDGs and innovation in the business context literature review. *Sustainability*, 11(24), 7043, https://doi.org/10.3390/su11247043

Dai, X., Chapman, G. (2022). R&D tax incentives and innovation: Examining the role of programme design in China. *Technovation*, 113, 102419. https://doi.org/10.1016/j.technovation.2021.102419

Deng, X., Huang, J., Rozelle, S., et al. (2010). Economic growth and the expansion of urban land in China. *Urban Studies*, 47(4), 813–843. https://doi.org/10.1177/004209800934977

Domazlicky, B. R., Weber, W. L. (2004). Does environmental protection lead to slower productivity growth in the chemical industry?. *Environmental and Resource Economics*, 28, 301–324. https://doi.org/10.1023/B:EARE.0000031056.93333.3a

Duan, F., Li, Y., Zhong, T. (2023). International patent cooperation, patent prosecution highway agreements, and export product quality. *China & World Economy*, 31(6), 111–133. https://doi.org/10.1111/cwe.12499

Fang, L., Lerner, J., Wu, C., et al. (2023). Anticorruption, government subsidies, and innovation: Evidence from China. *Management Science*, 69(8), 4363–4388. https://doi.org/10.1287/mnsc.2022.4611

Fernandes, P. M. (2022). Make Europe's forests climate-smart and fire-smart. *Nature*, 609(7925), 32. https://doi.org/10.1038/d41586-022-02318-2

Gao, X., Yu, J. (2020). Public governance mechanism in the prevention and control of the COVID-19: information, decision-making and execution. *Journal of Chinese Governance*, 5(2), 178–197. https://doi.org/10.1080/23812346.2020.1744922

Glaeser, E. L. (1999). Learning in cities. *Journal of Urban Economics*, 46(2), 254–277. https://doi.org/10.1006/juec.1998.2121

Godil, D. I., Yu, Z., Sharif, A., et al. (2021). Investigate the role of technology innovation and renewable energy in reducing transport sector CO2 emission in China: a path toward sustainable development. *Sustainable Development*, 29(4), 694–707. https://doi.org/10.1002/sd.2167

Godinho, M. M., Simões, V. C. (2023). The Tech Cold War: What can we learn from the most dynamic patent classes?. *International Business Review*, 32(6), 102140. https://doi.org/10.1016/j.ibusrev.2023.102140

Gollop, F. M., Roberts, M. J. (1983). Environmental regulations and productivity growth: The case of fossil-fueled electric power generation. *Journal of Political Economy*, 91(4), 654–674. https://doi.org/10.1086/261170

Gray, W. B., Shadbegian, R. J. (2003). Plant vintage, technology, and environmental regulation. *Journal of Environmental Economics and Management*, 46(3), 384–402. https://doi.org/10.1016/S0095-0696(03)00031-7

Hanousek, J., Shamshur, A., Tresl, J. (2018). Innovation decisions in uncertain business environments of CEE countries. *Politická ekonomie,* 66(3), 287–301. https://doi.org/10.18267/j.polek.1189

Hao, Y., Zheng, S., Zhao, M., et al. (2020). Reexamining the relationships among urbanization, industrial structure, and environmental pollution in China – New evidence using the dynamic threshold panel model. *Energy Reports*, 6, 28–39. https://doi.org/10.1016/j.egyr.2019.11.029

Hasan, I., Wachtel, P., Zhou, M. (2009). Institutional development, financial deepening and economic growth: Evidence from China. *Journal of Banking & Finance*, 33(1), 157–170. https://doi.org/10.1016/j.jbankfin.2007.11.016

He, F., Hu, Y., Fan, H. (2022). Study on the impact of green performance evaluation on urban land allocation: A quasi-natural experiment based on improved performance evaluation. *China Land Science*, 36(2), 78–83. https://doi.org/10.11994/zgtdkx.20220207.162043 (In Chinese)

Heberer, T., Trappel, R. (2013). Evaluation processes, local cadres' behaviour and local development processes. *Journal of Contemporary China*, 22(84), 1048–1066. https://doi.org/10.1080/10670564.2013.795315

Hein, C., Schubert, D. (2021). Resilience and path dependence: A comparative study of the port cities of London, Hamburg, and Philadelphia. *Journal of Urban history*, 47(2), 389–419. https://doi.org/10.1177/0096144220925098

Hossain, A. T., Kryzanowski, L. (2021). Political corruption and corporate social responsibility (CSR). *Journal of Behavioral and Experimental Finance*, 31, 100538. https://doi.org/10.1016/j.jbef.2021.100538

Hu, J., Pan, X., Huang, Q. (2020). Quantity or quality? The impacts of environmental regulation on firms' innovation – Quasi-natural experiment based on China's carbon emissions trading pilot. *Technological Forecasting and Social Change*, 158, 120122. https://doi.org/10.1016/j.techfore.2020.120122

Huang, Z., Liao, G., Li, Z. (2019). Loaning scale and government subsidy for promoting green innovation. *Technological Forecasting and Social Change*, 144, 148–156. https://doi.org/10.1016/j.techfore.2019.04.023

Jaros, K. A., Tan, Y. (2020). Provincial power in a centralizing China: the politics of domestic and international "development space". *The China Journal*, 83(1), 79–104, https://doi.org/10.1086/706256

Jiang, Y., Chai, G. (2017). Target-evaluation, promotion incentive and effectiveness of workplace safety evaluation – an empirical analysis of panel data in China. *Journal of Public Management*, 3, 44–59+156. (In Chinese)

Kan Yap, W., Gryzelius, J., Tek Wei Saw, A. (2023). Searching for growth-conducive institutions in emerging economies: A stochastic frontier analysis. *Politická ekonomie*, 7 (5), 591–618. https://doi.org/10.18267/j.polek.1398

Koçak, E., Kızılkaya, O. (2020). Towards sustainable development in China: do political rights and civil liberties matter for environmental quality?. *Environmental Science and Pollution Research*, 27(28), 35488–35500. https://doi.org/10.1007/s11356-020-09813-x

Kogut, B., Zander, U. (2000). Did socialism fail to innovate? A natural experiment of the two Zeiss companies. *American Sociological Review*, 65(2),169–190. https://doi.org/10.2307/2657436

Li, B., Huang, L. (2019). The effect of incremental innovation and disruptive innovation on the sustainable development of manufacturing in China. *Sage Open*, 9(1), 2158244019832700, https://doi.org/10.1177/2158244019832700

Li, J., Burgess, G., Sielker, F. (2023). Political mobilisation and institutional layering in urban regeneration: Transformation of land redevelopment governance in China. *Cities*, 141, 104508. https://doi.org/10.1016/j.cities.2023.104508

Lin, B., Luan, R. (2020). Do government subsidies promote efficiency in technological innovation of China's photovoltaic enterprises?. *Journal of Cleaner Production*, 254, 120108. https://doi.org/10.1016/j.jclepro.2020.120108

Liu, J., Zhao, M., Wang, Y. (2020). Impacts of government subsidies and environmental regulations on green process innovation: A nonlinear approach. *Technology in Society*, 63, 101417. https://doi.org/10.1016/j.techsoc.2020.101417

Lu, J., Zhang, H., Meng, B. (2021). Corruption, firm productivity, and gains from import liberalization in China. *Economic Modelling*, 101, 105555. https://doi.org/10.1016/j.econmod.2021.105555

Lu, M., Daixu, L., Peng, W., et al. (2023). Heterogeneous environmental regulation tools and green economy development: evidence from China. *Environmental Research Communications*, 5(1), 015007. https://doi.org/10.1088/2515-7620/acb1f9

Ma, Z., Liu, T., Li, J., et al. (2023). Spatial Effect Analysis of Forestry Technology Innovation on Forestry Industry Economic Growth. *Forests*, 14(3), 557. https://doi.org/10.3390/f14030557

Mbanyele, W., Wang, F. (2022). Environmental regulation and technological innovation: Evidence from China. *Environmental Science and Pollution Research*, 29(9), 12890–12910. https://doi.org/10.1007/s11356-021-14975-3

Mungiu-Pippidi, A. (2015). Corruption: Good governance powers innovation. *Nature*, 518(7539), 295–297, https://doi.org/10.1038/518295a

Murphy, K. M., Shleifer, A., Vishny, R. W. (1993). Why is rent-seeking so costly to growth?. *The American Economic Review and Proceedings*, 83(2), 409–414.

Nickels, M. J. (2008). *US collaborative-engagement with China using Strategic Technological Collaborative Leadership* (Doctoral dissertation, Monterey, California. Naval Postgraduate School).

Omri, A. (2020). Technological innovation and sustainable development: does the stage of development matter?. *Environmental Impact Assessment Review,* 83, 106398. https://doi.org/10.1016/j.eiar.2020.106398

Ouyang, X., Li, Q., Du, K. (2020). How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data. *Energy Policy*, 139(C), 111310. https://doi.org/10.1016/j.enpol.2020.111310

Ozturk, U., Bozzolan, E., Holcombe, E. A., et al. (2022). How climate change and unplanned urban sprawl bring more landslides. *Nature*, 608(7922), 262–265. https://doi.org/10.1038/d41586-022-02141-9

Pollpeter, K. (2023). Innovation in China's space industry: overcoming decoupling. *Asian Security*, 19(2), 114–128. https://doi.org/10.1080/14799855.2023.2256241

Popper, K. R. (2020). The open society and its enemies (Vol. 119). Princeton University Press. ISBN 9780691210841.

Porter, M. E., Linde, C. V. D. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of economic perspectives*, 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Razzaq, A., Yang, X. (2023). Digital finance and green growth in China: Appraising inclusive digital finance using web crawler technology and big data. *Technological Forecasting and Social Change*, 188, 122262. https://doi.org/10.1016/j.techfore.2022.122262

Ren, S., Hao, Y., Wu, H. (2021). Government corruption, market segmentation and renewable energy technology innovation: Evidence from China. *Journal of Environmental Management*, 300, 113686. https://doi.org/10.1016/j.jenvman.2021.113686

Rezai, A., Taylor, L., Foley, D. (2018). Economic growth, income distribution, and climate change. *Ecological Economics*, 146, 164–172. https://doi.org/10.1016/j.ecolecon.2017.10.020

Sahay, S., Walsham, G. (2017). Information technology, innovation and human development: Hospital information systems in an Indian state. *Journal of Human Development and Capabilities*, 18(2), 275–292. https://doi.org/10.1080/19452829.2016.1270913

Salahodjaev, R. (2015). Democracy and economic growth: The role of intelligence in cross-country regressions. *Intelligence*, 50, 228–234. https://doi.org/10.1016/j.intell.2015.04.013

Shang, Z. H., Gibb, M. J., Leiber, F., et al. (2014). The sustainable development of grassland-livestock systems on the Tibetan plateau: problems, strategies and prospects. *The Rangeland Journal*, 36(3), 267–296. https://doi.org/10.1071/RJ14008

Sohail, A., Du, J., Abbasi, B. N., *et al*. (2022). The nonlinearity and nonlinear convergence of CO2 emissions: Evidence from top 20 highest emitting countries. *Environmental Science and Pollution Research*, 29(39), 59466–59482. https://doi.org/10.1007/s11356-022-19470-x

Sohail, A., Du, J., Abbasi, B. N. (2023). Exploring the interrelationship among health status, CO2 emissions, and energy use in the top 20 highest emitting economies: based on the CS-DL and CS-ARDL approaches. *Air Quality, Atmosphere & Health*, 16, 1419–1442. https://doi.org/10.1007/s11869-023-01350-z

Song, L., Wen, Y. (2023). Financial subsidies, tax incentives and technological innovation in China's integrated circuit industry. *Journal of Innovation & Knowledge*, 8(3), 100406. https://doi.org/10.1016/j.jik.2023.100406

Su, C. W., Khan, K., Umar, M., *et al*. (2022). Renewable energy in prism of technological innovation and economic uncertainty. *Renewable Energy*, 189, 467–478, https://doi.org/10.1016/j.renene.2022.02.110

Tian, Y., Feng, C. (2021). The heterogeneous impact of environmental regulation on urban green scale economy: an empirical analysis based on city-level panel data in China. *Environmental Science and Pollution Research*, 28(35), 48392–48407. https://doi.org/10.1007/s11356-021-14031-0

Trevlopoulos, N. S., Tsalis, T. A., Evangelinos, K. I., et al. (2021). The influence of environmental regulations on business innovation, intellectual capital, environmental and economic performance. *Environment Systems and Decisions*, 41, 163–178. https://doi.org/10.1007/s10669-021-09802-6

Wagner, M. (2007). On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Research Policy*, 36(10), 1587–1602. https://doi.org/10.1016/j.respol.2007.08.004

Walsh, P. P., Murphy, E., Horan, D. (2020). The role of science, technology and innovation in the UN 2030 agenda. *Technological Forecasting and Social Change*, 154, 119957. https://doi.org/10.1016/j.techfore.2020.119957

Wang, J., Liu, B. (2014). Environmental regulation and enterprises' total factor productivity: An empirical analysis based on China's industrial enterprises data. *China Industrial Economics*, 3, 44–56. https://doi.org/10.19581/j.cnki.ciejournal.2014.03.004 (In Chinese)

Wang, X., Song, D. (2021). Does local corruption affect IPO underpricing? Evidence from China. *International Review of Economics & Finance*, 73, 127–138. https://doi.org/10.1016/j.iref.2021.01.007

Wang, Y., Shen, N. (2016). Environmental regulation and environmental productivity: The case of China. *Renewable and Sustainable Energy Reviews*, 62, 758–766. https://doi.org/10.1016/j.rser.2016.05.048

Wu, J., Hu, C., Zhang, P., et al. (2015). Can efficient construction improve government Performance? An empirical analysis of panel data from 30 provinces. *Journal of Public Management*, 3, 126–138. https://doi.org/10.16149/j.cnki.23-1523.2015.03.012 (In Chinese)

Wu, Y., Ke, Y., Zhang, T., et al. (2018). Performance efficiency assessment of photovoltaic poverty alleviation projects in China: A three-phase data envelopment analysis model. *Energy*, 159, 599–610. https://doi.org/10.1016/j.energy.2018.06.187

Xia, H., Tan, Q., Bai, J. (2018). Corruption and technological innovation in private small-medium scale companies: Does female top management play a role?. *Sustainability*, 10(7), 2252. https://doi.org/10.3390/su10072252

Xiong, Y., Yang, X. (2016). Government subsidies for the Chinese photovoltaic industry. *Energy Policy*, 99, 111–119. https://doi.org/10.1016/j.enpol.2016.09.013

Xu, R., Pata, U. K., Dai, J. (2024). Sustainable growth through green electricity transition and environmental regulations: Do risks associated with corruption and bureaucracy matter?. *Politická ekonomie*, 72 (2), Special Issue, Forthcoming articles. https://doi.org/10.18267/j.polek.1420

Yang, D. X., Meng, J., Yang, L., et al. (2022). Dual-Credit Policy of new energy automobile at China: Inhibiting scale or intermediary of innovation?. *Energy Strategy Reviews*, 43, 100932. https://doi.org/10.1016/j.esr.2022.100932

Yang, Z., Yang, H., Wang, H. (2020). Evaluating urban sustainability under different development pathways: A case study of the Beijing-Tianjin-Hebei region. *Sustainable Cities and Society*, 61, 102226. https://doi.org/10.1016/j.scs.2020.102226

Yu, W., Shi, W., Xiang, C., et al. (2015). *Studies on Morphological Characteristics and Typical Power Supply Modes of Distribution Networks for New-Type Towns.* Paper presented at the 2015 International Forum on Energy, Environment Science and Materials. https://doi.org/ 10.2991/ifeesm-15.2015.123

Yu, Y., Du, Y. (2019). Impact of technological innovation on CO_2 emissions and emissions trend prediction on "New Normal" economy in China. *Atmospheric Pollution Research*, 10(1), 152–161. https://doi.org/10.1016/j.apr.2018.07.005

Yu, Y., Sun, P., Xuan, Y. (2020). Do constraints on local governments' environmental targets affect industrial transformation and upgrading?. *Economic Research Journal*, 8, 57–72. (In Chinese)

Zhang, J., Fan, H., Xu, Z. (2020). Structural decline in the GDP growth rate: The impact of the official assessment mechanism. *Economic Research Journal*, 55(5), 31–48. (In Chinese)

Zhang, Y., Song, Y. (2022). Tax rebates, technological innovation and sustainable development: Evidence from Chinese micro-level data. *Technological Forecasting and Social Change*, 176, 121481. https://doi.org/10.1016/j.techfore.2022.121481

Zhao, A., Wang, J., Sun, Z., et al. (2022). Environmental taxes, technology innovation quality and firm performance in China – A test of effects based on the Porter hypothesis. *Economic Analysis and Policy*, 74, 309–325. https://doi.org/10.1016/j.eap.2022.02.009

Zhong, C., Hamzah, H. Z., Yin, J., et al. (2023). Impact of environmental regulations on the industrial eco-efficiency in China—based on the strong porter hypothesis and the weak porter hypothesis. *Environmental Science and Pollution Research*, 30(15), 44490–44504. https://doi.org/10.1007/s11356-023-25410-0

Zhou, L. (2007). Governing China's local officials: An analysis of promotion tournament model. *Economic Research Journal*, 7, 36–50. (In Chinese)