# Evaluating green innovation and performance of financial development: mediating concerns of environmental regulation

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# Evaluating green innovation and performance of financial development: mediating concerns of environmental regulation

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**Abstract**
This research measures the relationship between green innovation and the performance of financial development by using an econometric estimation during the year of 2000 to 2018 in 28 Chinese provinces. It is intended to explore the relative role of green technological innovation in driving green financial development in the west and central China, as well as how it influences economic growth in these regions. Ordinary least square (OLS) framework was utilized in mainland China to perform empirical studies by using an econometric estimation. This study claims that China has adopted research-based education system, while those for economic growth and expenditure in the regions while the innovation parts results shows that the tertiary education were 12.42% and 13.53% versus the 10.50% and 10.6% in the eastern area. The research-based education increases the patents in green innovation and boosts the environmental policy. The financial development led to green technological development and innovation. Green innovation and financial development decrease the emissions, and it is apparent that as environmental regulations stimulate technical development, the superiority of human resources increases. The findings indicate that green financing reduces short-term lending, thus limiting clean energy overinvestment, while the long-term loans have little impact on renewable energy overinvestment, and the intermediary effect is unmaintainable. Meanwhile, the green financial growth will reduce renewable energy overinvestment and increase renewable energy investment productivity to certain amount.

**Keywords** Financial development · Environmental regulation · Green economic performance · GMM · Econometric estimation

## Introduction

China's economic growth has accelerated in recent decades, despite the country's high pollution and emissions levels. It has achieved tremendous economic growth, surpassing the USA as the world's second largest economy, but this growth is contingent on resource inputs, which generate significant pollution (Rapsikevicius et al. 2021). The extent of haze in China has sparked international and domestic concern about China's resource and environmental problems. Nowadays, financial support for economic restructuring, upgrading, and green economy development has risen to the level of China's national strategy, such as the "Green Credit Guidelines." However, the current literature barely discusses the relationship between financial development and economic growth in terms of environmental concerns (Li et al. 2017a).

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The widespread economic modes of development in China are increasingly faced with the problem of energy shortages and pollution, so the mode of development needs to be reformed, and the industrial system needs to be changed and updated. In addition, urgent consideration must be given to the conservation of the environment (Trevlopoulos et al. 2021). Thus, the thirteenth 5-Year Plan establishes a new definition of "innovative, organized, renewable, accessible and shared." As economic development in China is gradually becoming green, the way to promote green and healthy industrial development in China is now the biggest obstacle to the adjustment of industrial structure in China (Iqbal et al. 2021; Zhang et al. 2021a), especially as regional economic structure is quickly transformed, becoming one of the main emerging economies. China, the secondary industry dominant, consumed in 2018, 4.55 billion metric tons, making it the world's largest greenhouse gas emitter (Kumar et al. 2017). Thus, the need to address all stakeholders around the world desperately needs to transform the resource-driven economy excessively relying on the conventional fossil fuels into the technology-driven economy of low carbon and green economic growth (Chi et al. 2020; Mohsin et al. 2021a).

Since 1978, China has experienced rapid economic growth. However, this development comes at the expense of capital and has an adverse effect on the ecosystem (Mohsin et al. (2018b), Mohsin et al. (2021b), and (Mohsin et al. (2018a)). China's gross energy consumption and net energy consumption accounted for 23% and 34% of the world's total in 2015, respectively, resulting in a total of 27% of the world's carbon dioxide emissions (Agyekum et al. 2021; Li et al. 2021b). China consumes the most electricity and emits the maximum carbon dioxide among developing countries. Industry, as the backbone of China's economy, is critical to economic development. However, as a result of the extensive development style adopted by industry in China for a long period of time, the massive resource use and pollution generated by industry have reached the environmental load limit (Khairunnessa et al. 2021). Environmental regulation and green innovation are two critical pillars in achieving green and intensive industrial growth (Tiep et al. 2021). On the one side, since resources and the environment are public goods, using market processes to solve environmental issues have some drawbacks (Sun et al. 2020c; Baloch et al. 2020). As a result, environmental protection must be implemented by government agencies (Ping et al. 2019). On the other side, at the intersection of "innovation" and "green," green innovation has emerged as an effective means of overcoming resource and environmental constraints and advancing China's green economic development, which is more critical than ever (Ying et al. 2021). By increasing production quality, conserving electricity, and reducing emissions, green innovation will help save resources and reduce environmental pollution. As a result, it benefits the economy's green growth (Sun et al. (2020d), Sun et al. (2020b), and Sun et al. (2020c)). Under the unified analysis framework, this article examines the function and mechanism of environmental regulation in promoting green industrial development, investigates the concrete effects of green innovation on promoting green industrial development, and provides preliminary empirical evidence for the role of environmental regulation and green innovation in promoting green industrial development (Shan and Wang 2019). It concludes that China's overall success on green industrial growth is inconsistent. Green product and green craft innovation, in the absence of environmental regulation restrictions, have pro- and anti-competitive consequences, respectively. However, where environmental regulations are constrained, market-based environmental regulation achieves a positive effect on industrial green growth by encouraging green craft innovation rather than green product innovation (Zhang et al. (2021b) and Li et al. (2017b)) The findings are discussed in terms of their policy consequences. To encourage banks' rapid growth, the Chinese government has raised funding for bank credit. Simultaneously, the financial industry scans businesses and programs that are more in accordance with the idea of green growth in order to continue resource distribution, potentially increasing the severity of environmental control (Colombelli et al. 2020). As a consequence, financial structure and environmental regulation reinforce one another, resulting in constructive regulation that reduces the negative relationship between financial structure and innovation production (Costa et al. 2018). Companies must allocate a portion of their funds to the procurement of production facilities, changes to the manufacturing method, and waste collection as environmental regulations become more stringent. The lack of funds has a detrimental effect on financial scale growth and productivity enhancement, and there is a negative correlation between financial scale and environmental regulation. The optimistic partnership between financial size and innovation success is weakened by this negative change. The same is true in terms of financial performance (Ding et al. 2018).

Currently, the central and western China's human capital has emerged, and GDP per capita has grown more rapidly. Average growth in per capita (over a period of 16 years) was 10.16% and faster in the central and western areas in comparison to the 9.99% in the eastern region. Workforce participation in the central and western regions was slightly lower in 1995. However, in the western zone, labor has turned from a relative advantage to a disadvantage because of slower growth (Sun et al. (2020b) and Chandio et al. (2020)).

The contribution of the paper lies in the following aspects. The current study measures the relationship between green innovation and the performance of financial development by using an econometric estimation. The

policy makers can use the analysis for decision makers. We also added a comprehensive policy framework and added the existing literature at the proposed topic. The central and western areas have a comparative advantage in human resources. The comparatively faster growth of green technology brought on by the competitive advantage of human resources could be the secret to achieving backwardness advantage and sustainable economic catch-up, surpassing the central and western regions under environmental protection. If the above perspective is confirmed, it will be extremely useful in resolving the conflict between economic growth and environmental conservation in China's central and western regions, as well as a complement to the theory of sustainable development in other developing countries.

The literature review is presented in Section 2. The third section delves into the theoretical mechanisms of human capital, green technological development, and the backwardness advantage hypothesis. Sections 4 and 5 clarify the data and methods, while Section 6 summarizes the paper and offers policy proposals and discussion.

## Literature review

At present, there is abundant research on the theory of backwardness advantage but few are related to green technological progress. The essence of the advantage of backwardness is that developing countries or districts have a vast space and strong driving force to learn the technology, systems, and successful experience from the developed countries or districts when they carry out their own industrialization and modernization (He et al. 2021). Environmental protection and green development are hot issues of common concern to all countries in the world. Many researchers have studied the relationship between environmental management and business economic efficiency. Environmental management as a dynamic management task requires not only concrete steps to avoid and monitor emissions but also the collaboration and cooperation between environmental department and other departments as well as the balance between environmental targets and other firm goals (Alemzero et al. (2020b), Sun et al. (2020b), and Alemzero et al. (2020a)). The goals and resources needed for various types of environmental management activities will vary considerably and have a different effect on economic performance and indicate, for example, that more rigorous management of the environment can have a more beneficial effect on organizational efficiency compared with the implementation of basic practices of environmental management (Sun et al. 2020a). Therefore, one explanation for the controversial findings of current research is to consider the different environmental management activities and examine their relationship to economic performance as a whole.

Zhang et al. (2021a) conclude that to more precisely explore the relationship between environmental management and company results, a more fair and systematic classification of the possible contents of environmental management should be carried out therefore in this regard (Wasif Rasheed and Anser (2017), (Xu et al. (2020), and Ahmad et al. (2020)) and examines their impacts on economic efficiency. EMB refers to the diversified environmental management practices implemented by the firm. As far as we know, former scholars seldom study green finance and the issues involved, although their research on sustainable finance and environmental finance is highly similar to China's green credit, both of which seek to change the current environmental system through full financial resources. For example, Ringler et al. (2017) indicated that environmental consideration must be taken into account in the adaptation of the industrial system. Exiting literature shows various methodologies has been used in energy environment and other applications (Liu et al. 2020; Xiong et al. 2021).

Environmental management activities include the development of environmental management strategies, the use of environmental evaluation methods, setting out environmental performance objectives, and preparation for staff in the area of environmental protection. EMD includes the integration of environmental management practices into other corporation core management processes and tasks (e.g., strategic planning, quality management, health, and safety), such as integrating environmental management with quality management in order to achieve full environmental quality management that enhances the company's capacity for pollution prevention (Von Wagner et al. 2007). This research would more explicitly show the process of environmental management for firm economic success by subdividing environmental management on the basis of the above criteria.

Gast et al. (2017) coined the word "backwardness" advantage, arguing that developing countries have an advantage over developed countries because they can implement advanced country technology, manufacturing processes, and management strategies more easily and with less risk. In addition, the farther a nation is from the world's technological frontiers, the greater the possible benefits it can derive from this advantage. Despite the fact that the backwardness advantage is a powerful economic phenomenon that has been theoretically explained by influential studies, empirical evidence to support it is limited. The lack of sufficient evidence for performing detailed investigations to test this theory may be one explanation for the lack of support.

As the green economy grows, more banks are introducing innovative green finance patterns to meet consumer demand.

For example, Industrial Bank Co. Ltd. proposed order lending for green finance. Order financing is capital finance focused on high-quality orders, with lenders relying on the orders' potential sales as a means of repayment. Green order funding, on the other hand, is order financing reserved for businesses that manufacture energy-saving and environmental protection devices. Industrial Bank Co. Ltd. is committed to the green transformation with order financing as a leader in green finance. As of June 2016, Industrial Bank Co. Ltd. has made over RMB 900 billion in green financial investments, funding over 6400 energy saving ventures and businesses. The expenditure culminated in a decrease in carbon dioxide emissions of 73.83 million tons, which is equivalent to 26.29 million tons of conventional gas.

## Environmental regulation and green technological progress

Environmental regulations are a collection of policies or initiatives enacted by the government to protect the environment. Environmental regulations have largely limited environmental degradation by businesses and have played a significant role in environmental protection (Jinjarak et al. 2021). Scholars have primarily researched the effect of environmental legislation on businesses from the standpoint of the enterprise. Appropriate environmental regulations, they claim, will help businesses develop relative competitive advantages while also acting as a motivator for them to improve their efficiency (Hartley et al. 2019). Environmental regulations, on the other hand, have raised the operational costs of businesses, which could have an effect on their operating conditions and are not conducive to performance growth.

Environmental regulations should actively encourage green finance in manufacturing enterprises, according to the findings of the study. Environmental regulations were divided into three groups by (Shahbaz et al. 2020) command-control environmental regulations and environment attributes (Li et al. 2021c), market-driven environmental regulations, and voluntary environmental regulations. To demonstrate, all three forms of environmental regulations can have a positive impact on green technological finance in Chinese businesses. Although the findings of this paper's research are close to Li's, environmental regulations would increase not only the benefits of green technological finance, but also the production costs of businesses (Raikar and Adamson 2020). On environmental legislation and green finance, the findings of various testing methods and samples are not entirely consistent.

Green innovation will actively encourage the intelligent upgrade of manufacturing enterprises, according to the findings of the study. Green innovation, on the other hand, will serve as a bridge between environmental legislation and the intelligent upgrading of manufacturing businesses. Green innovation, in other words, will facilitate the intelligent upgrade of manufacturing enterprises, while other factors remain constant. The greater the capacity for green innovation, the more advantageous it is for manufacturing companies to upgrade intelligently. Environmental regulations, on the other hand, have an indirect impact on the intelligent upgrade of manufacturing enterprises by green innovation (Goodell and Goutte 2020).

## Technological progress and environmental regulation

The pace at which the earth's system is undergoing drastic environmental changes is frightening. Human activities such as the use of fossil fuels, coal combustion, high energy consumption, and pollution of all kinds, combined with rapid economic growth and complete disregard for environmental health, have resulted in the steady degradation of the ozone layer, posing a potential threat to human existence, resulting in an increased knowledge of global environmental health. To ensure long-term growth, developed and developing countries have recognized the importance of combining economic development and environmental protection Wang et al. (2020).

Environmental sustainability development necessitates that technical progress be effectively used for the good of humanity in order to meet current and future generational needs. Many researchers have recently stressed the significance of technological advancement and its function in achieving environmental sustainability. Energy use, according to (Deleidi et al. 2020), is critical to economic growth, and their findings in their study of the relationship between energy use and economic growth revealed a positive relationship (Kim et al. 2021).

In addition, the interaction effect between technological innovation and renewable energy consumption improves environmental efficiency in all the study countries. In order to examine ties between environmental dynamics, green product innovation, and corporate success in China, for example, He et al. (2018) used structural equation modeling. The findings indicate that the impact of environmental dynamics on the relationship between green product innovation and cost efficiency is moderate and the relationship between green product innovation and firm profitability is slightly modulated. By using 2011–2012 Chinese panel statistics for pollution-intensive companies, Hashemizadeh et al. (2021) have developed panel regression models to investigate impacts on corporate innovation and competitiveness from environmental regulations. Guo et al. created an integrated model to examine the connections between environmental regulation, technical innovation, and the success of regional green development. It was found that environmental regulation cannot directly support the performance of regional green growth, but that regional green growth performance would be affected positively by environmental regulation powered by technology (Khan et al. 2021).

These environmental factors are factored into the overall performance measurement (using the DDF), which includes the output, input, and flow. The Green Technical Progressivity Index was calculated by Malmqvist et al. using a flow accumulation method (cumulative multiplication) (Malmqvist et al. 2019). While distorted and anti-technological, it examines the factors that influence green change and the consequences of having a negative impact on human capital. In this regard, the consequences of green technological transition, on the other hand, place modernization in perspective. The project then derives the findings using provincial panel data from the panel study-GCMS data from 1995 and later data from 2017 to conduct empirical research on the small sample population theory (or systematic-GCMS) implications. By significantly extending the study of the results, this current research will contribute to the advancement of the sustainable development theory (Atsu and Adams 2021).

## Data and methodology

The study used an econometric estimation to measure the relationship between green innovation and financial development. The similar methodologies has been used for measurement purpose such as relibaility and safety (Li et al. 2021d) electric vehicle (Li et al. 2020) and green products (Li et al. 2021a). This paper assumes that technological progress develops in two directions: one being the direction of green production and the other being the direction of pollution production (Sun et al. 2019). The production function of a country is then composed of the green production sector and pollution production sector:

$$Y_t = \alpha + \beta_1 x_1 + \beta_2 x_2 \ldots\ldots\ldots + \varepsilon_t, \quad t = 1, 2 \ldots, T \tag{1}$$

where $Y$ shows the dependent variable, $\alpha$ represents the constant, $\beta_n$shows the coefficients of explanatory variables, and $x$ represents the independent variables, while $\varepsilon_t$ shows the error term. The detail of the variables about model construction is given in the Table 1. The production functions of both the production sectors are defined as:

**Table 1** Descriptive variables

| Variable | Mean | Med | Std | Min | Max | Obs |
|---|---|---|---|---|---|---|
| $CO_2$ | 3.224 | 3.578 | 3.897 | 0.754 | 68.77 | 442 |
| Energy | 3.124 | 3.145 | 0.241 | 1.745 | 1.443 | 442 |
| $Energy^2$ | 7.324 | 7.658 | 0.642 | 6.300 | 8.553 | 442 |
| Trade | 7.124 | 7.458 | 2.254 | 3.248 | 8.79 | 442 |
| Renewable | 4.123 | 4.456 | 0.457 | − 2.412 | 8.077 | 442 |
| R&D | − 0.412 | − 0.213 | 1.234 | − 2.564 | 3.102 | 442 |
| Capital | 8.745 | 8.457 | 0.864 | 7.587 | 10.84 | 442 |
| GDP | 4.451 | 4.560 | 0.726 | 2.451 | 4.654 | 442 |
| Green Finance | 6.123 | 6.457 | 2.010 | 0.664 | 6.451 | 442 |

$$= \int_{i=1}^{n} (K)_n (P_n) r_\alpha (K_{n-1}) \tag{1}$$

$$Z_n = \int_{i=1}^{n} (P)_n (K_n) \gamma_\alpha (P_{n-1}) \tag{2}$$

By and large, the higher the degree of quality (that is, the more complicated the R&D is but the greater the benefit from effective R&D), the lower the likelihood of successful green technology R&D. These two variables are usually relatively constant. Thus, the primary variable influencing the trajectory of technological advancement toward green production technology is human capital; the more people working in the green sector, specifically more skilled labor or high-level skills, the more likely it is that technological R&D would focus on green production technology. As a result, proposition 1 is advanced, in which it is argued that increasing human resources would foster green technological development. Environmental pollution is a global issue that stifles industrial production and economic expansion (Wang and Shen 2016). National governments have established a set of policy instruments known as ERs in order to facilitate long-term economic growth (Anser et al. (2018), Anser (2019), and Anser et al. (2020)).

Because of the increased concern in China about the depletion of natural resources and pollution, concerns about how to achieve green growth and what factors drive it have become hot topics. Two major fulcrums in the realization of green growth are environmental policy and technical advancement. However, there is a conceptual gap in our understanding of the effect of environmental regulation and technical progress on green development. The results show that (1) environmental regulation has stifled green growth in the short term, but has a long-term positive effect on green growth; (2) technological innovation helps to boost green growth; and (3) the causality chain between regulation, technological innovation, and green growth is a traditional mediation model. In the causal chain, technological progress plays an important role as a mediator. This research not only adds to and expands on green growth ideas, but also effectively incorporates and improves green growth practices. According to econometric estimation, this may not be conducive for green technological progress. From a theoretical basis to empirical research, the role of human capital and technology in deciding growth has been debated for a long time. For example, according to Lucas (1990), human capital is a significant determinant of economic growth, while Romer (1990) claims that economic growth is dependent on research and development (R&D) and spillovers from the R&D process. The above analysis is consistent with Asif et al. (2020), Sarker et al. (2020), Iram et al. (2020), and Tehreem et al. (2020); that is, when environmental regulations are weak, it will hurt the green technological progress (Yousaf et al. (2020), Tehreem et al. (2020), Wasif Rasheed and Anser (2017), and Xu et al. (2020)). The variables range from 2000 to 2018 due to data availability. Data is taken from the China

Statistical Yearbook, Statistical Yearbooks of Provinces, Educational Statistical Yearbook of China, China Population and Employment Statistics Yearbook, China Statistical Yearbook on Science and Technology, China Statistical Yearbook on Environment, and China Energy Statistics Yearbook, unless otherwise stated. The statistical description of the main variables is shown in Table 1.

## Results and discussion

### Estimation analysis

Table 2 shows that the short-term loans serve as a complete broker (column 3). The findings indicate that green financing reduces short-term lending, thus limiting clean energy overinvestment. This is consistent with the bank loan's intermediary impact. Inhibiting renewable energy overinvestment is more successful via the intermediary process of a short-term loan. Long-term loans have little impact on renewable energy overinvestment, and the intermediary effect is unsustainable.

**Table 2** OLS-based econometric estimation

| Indicators | (1) | (2) | (2) |
|---|---|---|---|
| $CO_2$ | 6.4422*** | | 1.5231** |
| | (5.31) | | (1.54) |
| Energy | | − 234.6455* | |
| | | (− 14.25) | |
| $Energy^2$ | | 7.4859*** | |
| | | (12.45) | |
| Trade | | − 20.4578** | |
| | | (− 3.58) | |
| Renewable | | 2.4126*** | |
| | | (3.58) | |
| R&D | | − 0.6457* | |
| | | (− 1.54) | |
| Capital | 1.6658*** | | |
| | (8.54) | | |
| Green finance | 2.04123*** | | |
| | (3.21) | | |
| Constant | 740.2351*** | 547.241*** | 354.5687*** |
| | (7.52) | (24.15) | (4.12) |
| Wald test | 451.12 (0.000) | 2142.25 (0.000) | 456.28 (0.000) |
| AR(2) test | 1.23 (0.158) | 1.83 (0.169) | 1.14 (0.107) |
| Hansen test | 36.4 (0.301) | 36.24 (0.711) | 19.42 (0.126) |
| GMM instruments | 0.49 (0.972) | 1.54 (0.893) | 1.36 (0.898) |
| Number of provinces | 29 | 29 | 29 |
| Obs | 704 | 580 | 580 |

***, **, * represent the significance level of 1%, 5%, and 10%

Meanwhile, the direct impact of green financial growth on renewable energy overinvestment is important, as seen in columns with a coefficient of 0.0099. The findings show that green financial growth will reduce renewable energy overinvestment and increase renewable energy investment productivity to some degree. Furthermore, green financial growth will help renewable energy companies with overinvestment issues reduce their long-term loans. This is in accordance with what theorists predicted.

### Result analysis about environmental regulation

Green industrial structures will help to turn technical progress into green technology innovation, increase environmental sustainability, and foster sustainable economic development. Green technology advancement creates economic gains through conventional technological progress on the one side, thus internalizing global environmental emissions on the other. Enterprises' information accumulation grows as a result of innovation production. The stronger an organization's creativity output, the better it will leverage its own capital. As its central productivity improves, it will be able to benefit from selling its own innovation production to external businesses. Improvements in financial performance will aid in the conversion of investments into cash and the more efficient usage of financial resources. The distribution of domestic credit services is skewed in China due to the present low level of financial performance. Many private businesses are dissatisfied with their credit and are experiencing financial problems, forcing them to look for financial services from abroad and to search FDI. As a result, FDI contributes to the formation of China's domestic capital, but the majority of FDI adopted is of a poor quality. The results in Table 3 of the Wald test, AR (2) test, and Hansen test meet all the requirements.

Furthermore, in order to draw high-quality FDI, businesses must develop their own innovation understanding, internal development technology, and financial capital utilization capability. The transition of corporate savings to resources is more fluid at this period, funding pressures are less serious, and international capital demand is less urgent. Imported FDI is subjected to more rigorous inspection, reducing the issue of resource overuse and environmental degradation incurred by low-level FDI inflows. As a result, environmental policy has the potential to mitigate the detrimental relationship between financial performance and green technology advancement. Environmental policy has a strongly negative association with green technology innovation in Table 3 columns (1)–(3), meaning that the spending in emissions management would not encourage the growth of green technology innovation. On the one side, this finding may be explained by the fact that as businesses fail to comply with environmental regulations, they may incur the burden of emissions protection, which has a capital offsetting impact on their economic activity.

**Table 3** Regional estimation analysis

| Indicators | (1) | (2) | (3) |
|---|---|---|---|
| $CO_2$ | 12.5461*** | 25.7445*** | 25.2233*** |
| | (4.12) | (3.45) | (3.54) |
| Energy | − 741.3212** | − 187.214*** | − 68.541 |
| | (− 3.54) | (− 1.45) | (− 1.08) |
| $Energy^2$ | 24.658** | 10.587*** | 5.3698 |
| | (1.40) | (3.78) | (2.03) |
| Trade | − 7.2454 | − 21.5786* | − 19.4214* |
| | (− 1.45) | (− 0.46) | (− 1.96) |
| Renewable | 0.4869* | 4.5678** | 1.8745* |
| | (1.69) | (1.24) | (1.58) |
| R&D | − 1.7548** | − 1.8842 | 0.4325 |
| | (1.45) | (− 2.35) | (0.68) |
| Capital | 6.4455 | 2.4785 | 2.522** |
| | (1.52) | (2.41) | (1.42) |
| Green finance | 3.1004 | 4.6621*** | 7.1245*** |
| | (0.46) | (3.54) | (6.78) |
| Constant | 2140.4456*** | 2014.5478*** | 846.2147*** |
| | (8.45) | (12.87) | (4.24) |
| Hansen test | 8.45(0.111) | 3.58(0.732) | 0.68(0.342) |
| GMM instruments | 1.45(0.265) | 0.49(0.722) | 0.58(0.221) |
| Number of provinces | 28 | 28 | 28 |

***, **, * represent the significance level of 1%, 5%, and 10%, respectively

**Table 4** Regional analysis

| Indicators | (1) | (2) | (3) |
|---|---|---|---|
| $CO_2$ | 1.1510*** | 0.2140*** | 2.1144*** |
| | (45.75) | (43.57) | (47.58) |
| Energy | − 0.0048 | − 1.0456*** | − 0.0314*** |
| | (− 0.45) | (− 3.14) | (− 1.74) |
| $Energy^2$ | 0.0009*** | | |
| | (1.84) | | |
| Trade | − 7.342(− 1.62) | | |
| Renewable | 0.472(1.75) | | |
| R&D | − 1.626(1.43) | | |
| Capital | 0.2134*** | | |
| | (4.89) | | |
| Green finance | 0.2147*** | | |
| Export | (8.45) | | |
| | 0.2145*** | | |
| GDP | (10.89) | | |
| | − 0.2145*** | | − 0.4521*** |
| | (− 1451) | | (− 7.84) |
| Constant | − 0.2481** | − 0.4545 | − 0.3258 |
| | (− 3.45) | (− 0.21) | (− 1.11) |
| Hansen test | 6.36(0.100) | 5.68(0.780) | 0457(0.633) |
| GMM instruments | 2.01(0.297) | 0.49(0.778) | 0.47(0.3443) |
| Number of instruments | 5 | 7 | 9 |
| Number of provinces | 28 | 28 | 28 |

***, **, * represent the significance level of 1%, 5%, and 10%, respectively

## Estimation and analysis

Table 4 shows the effects of the test of innovation performance as a mediating factor in the partnership between financial growth and green technology innovation. The effects of the effect of financial growth on innovation success are recorded in columns. At a 1% significance stage, the first-order lag term of invention success has a positive effect, indicating an apparent circular accumulated utility. With a 1% significance stage, the regression coefficients of financial form, financial size, and financial performance are 0.031, 0.253, and 0.217, respectively. This suggests that financial complexity has a negative effect on innovation output, while financial size and productivity have a positive impact. The financing sector dominates China's financial system, and it is from it that most financial services are distributed. Banks' risk tolerance makes them more vigilant when it comes to loan issuance. As a result, the science and technical innovation market attracts a lower share of capital allocation, making it impossible to increase the number of patent authorizations in the invention sector and resulting in inadequate innovation production. These patents are of limited innovative and functional merit, rendering it difficult to satisfy scientific and technological advancement standards. If the value of social capital rises, a negative association between creative success and green technology innovation as calculated by input-output performance can emerge.

## Robustness of the empirical findings

Financial growth has a impact on enterprise investment shows high degree of financial development which would increase enterprise investment performance in energy sector. The opposite inference is reached by Zhai and An (2020). The key explanation for (Najini et al. 2020) assertion is that soft expenditure restrictions reduce the easing impact of financial growth on state-owned enterprise funding constraints, resulting in overinvestment and productivity losses. Furthermore, Wang et al. (2020) believe that the extent of financial growth is adversely linked to expenditure performance for state-owned enterprises. Non-state-owned companies will benefit from increased financial growth by reducing funding restrictions and increasing expenditure productivity (Govindan et al. 2015).

Table 5 shows the robustness analysis. It's worth noting that some researchers have suggested that financial growth

**Table 5** Robustness analysis

| Case (1) | | Case (2) | | Case (3) | |
|---|---|---|---|---|---|
| Model (1) | Z-value | Model (1) | Z-Value | Model (1) | Z-Value |
| 0.31 | 1.24 | 1.112 | 1.45 | 2.48 | 0.48 |
| 0.21 | − 2.14 | 1.24 | 1.45 | 0.7 | 1.89 |
| 0.25 | 2.40 | 0.54 | 0.77 | 0.45 | 1.39 |
| 0.65 | 0.4 | 01.89 | 1.50 | 0.25 | 2.76 |
| 0.4 | − 1.06 | 1.04 | 2.48 | 1.01 | 1.42 |
| .1.45 | 0.31 | 0.41 | 1.89 | 1.24. | 1.04 |
| 0.59 | 2.10 | 0.60 | 1.48 | 1.05 | 3.54 |
| 2.46 | 0.11 | 2.42 | 0.75 | 0.41 | 2.58 |
| 0.57 | − 2.00 | 0.22 | 0.19 | 0.77 | 3.45 |
| 0.47 | − 1.99 | 0.25 | 2.13 | 0.38 | 1.78 |
| 0.39 | − 2.54 | 0.18 | 1.45 | 0.29 | 2.44 |
| 0.28 | 1.39 | 0.45 | 0.45 | 0.03 | 1.05 |
| 0.44 | − 1.88 | 0.21 | 1.93 | 0.04 | 3.74 |
| 0.66 | 1.94 | 0.72 | 2.46 | 0.04 | 3.04 |
| 0.14 | 1.87 | 0.96 | 1.41 | 0.41 | 2.46 |
| 0.18 | − 1.99 | 0.27 | 1.88 | 0.54 | 2.89 |
| 0.2 | 2.58 | 0.57 | 0.75 | 0.21 | 2.48 |
| 0.34 | − 1.87 | 0.68 | 1.44 | 0.15 | 2.41 |
| 0392 | 0.99 | 0.45 | 2.14 | 0.29 | 3.16 |
| 0.41 | − 0.79 | 0.11 | 2.14 | 0519 | |

influences the partnership between business finance and investment performance. According to some empirical studies, the greater the negative association between bank loans and overinvestment is, the higher the degree of financial growth; that is, financial development has a favorable adjustment impact on the relationship between bank loans and investment performance (Zailani et al. 2015). There are a few different facets of this. Green financial growth will boost the macro-financial climate while also encouraging micro-economic institutions to prioritize environmental benefits. Green financial growth, on the other side, has altered the conventional "financing–investment" channel and had a complex effect on business investment.

## Discussion

Since reform and opening-up began, China has produced several notable advancements in its GDP rating, coming in second in behind only the USA. Furthermore, the current development model, which utilizes a high level of inputs, energy use, and pollution, causes the country to heavily depend on carbon inputs and wind up becoming the world's largest polluter (the IEA reports that China generated 6.2 billion tons of carbon dioxide in 2007, which made it the world's most polluting country by far. As such, China consumes a high percentage of all of global resources), while it causes environmental problems by raising carbon emissions. The "2018 Global Environmental Performance Index (Global EPI)" notes that China has a score of 50.74 and ranks 61st from the bottom out of the participating countries and regions. Thus, it can be seen that most existing studies focus on the relationship between environmental regulation and green technology progress and the relationship between financial development and green technology progress. However, the research conclusions are quite controversial due to the differences in research objects and research periods and the lack of incorporating regional financial development factors to consider the impact of environmental regulations on green technology progress. Simultaneously, more of the literature focuses on pure empirical analysis but less of the literature on theoretical analysis; more empirical analysis is based on provincial samples and samples from cities are rare. Since it was evident in this study that human development and public awareness have a major positive impact on environmental quality, it should be prioritized. Environmental laws are more likely to be followed by educated people than by those who are not. As a result, policy makers in selected countries should invest more in their human resources, such as education and skills, in order to have a long-term positive impact on the climate.

Technological innovation is a double-edged sword that enhances manufacturing processes while also lowering emission levels. It is also suggested that the regions work together to strengthen, collaborate, and implement open innovation so that they can share green technology and boost long-term environmental efficiency. They should aim to invest more in research and development in order to encourage the use of technology that can help them save energy and protect the environment. Four, international companies should be screened in order to reduce the influx of polluting industries into host countries.

Green industrial structures will help to creates economic gains through conventional technological progress on the one side, thus internalizing global environmental emissions by stronger an organization's creativity output. The distribution of domestic credit services is skewed in China dissatisfied with their credit and is experiencing financial problems, forcing them to look for financial services from abroad and to search FDI. Furthermore, in order to draw high-quality FDI, businesses must develop their own innovation understanding and are subjected to more rigorous inspection, reducing the issue of resource overuse and environmental degradation incurred by low-level FDI inflows. While the businesses fail to comply with environmental regulations, they may incur the burden of emissions protection, which has a capital offsetting impact on their economic activity.

## Conclusion and policy implications

The current study measures the relationship between green innovation and the performance of financial development by using an econometric estimation during the year of 2000 to 2018 in 28 Chinese provinces. The policy makers can use the analysis for decision makers. We also added a comprehensive policy framework and added the existing literature at the proposed topic. When applying for financial services in areas of strict environmental regulations, businesses must report their own environmental records. The financial development led to green technological development and innovation. Green innovation and financial development decrease the emissions, and it is apparent that as environmental regulations stimulate technical development, the superiority of human resources increases. The findings indicate that green financing reduces short-term lending, thus limiting clean energy overinvestment, while the long-term loans have little impact on renewable energy overinvestment, and the intermediary effect is unmaintainable. Chinese government must monitor the waste and pollution emitted during the manufacturing phase in order to better their own environmental data. They will upgrade their manufacturing equipment in order to reduce potential emissions. The costs incurred as a result of this mechanism place financial strain on Chinese provinces that depend on the financial sector for funding and are unable to withstand such costs and would opt for regional or industrial transition. However, the expenditure expense of environmental emission management is higher owing to the more secure reserves of certain large-scale companies, which gives banks trust in their pollution control capability. As a result, they find it simpler to access financial capital by bank credit and use them to reduce emissions, replace outdated facilities, and perform green technology R&D. This paper provides the following policy recommendations on the basis of the above conclusions. First, constantly innovate and launch green credit products, use securities market resources to assist green and green-based firms to raise funds, and facilitate finance for green ventures that respond to corporate financing needs. Secondly, strengthen the existing policies for environmental protection in China, introduce differentiated policies for the protection of the environment, and prevent "one size fits all" policies. Encourage the versatile conjunction of types of environmental regulations, introduce diversified reward instruments, and remove crude and straightforward one-size shutdown activities, ensuring that the severity of regulations does not fall. Thirdly, improve organized regional growth, and reduce the regional green technology gap. Given the differences in green technology level in various regions, the government should concentrate on steering interregional trade and cooperation, progressively narrowing the regional growth gap and ensuring coordinated regional development. Further investment in green technologies and an active leverage of technology spillover impacts should be made in economically developed regions.

Environmental regulations are enchanting a positive impact on the process of intelligent upgrading of manufacturing enterprises. Environmental policies are having a positive impact on green innovation in manufacturing businesses. Green engineering is having a positive impact on the intelligent upgrade of manufacturing enterprises. Green engineering serves as a bridge between environmental legislation and the intelligent modernization of industrial enterprises. The relationship between green innovation and intelligent upgrading of manufacturing enterprises is positively controlled by environmental regulation. Specifically, when environmental dynamism is high, green innovation has a relatively strong positive impact on the intelligent upgrading of manufacturing enterprises; when environmental dynamism is poor, green innovation has a relatively weak positive impact on the intelligent upgrading of manufacturing enterprises. The article analyzes and discusses the relationship between environmental regulations, green innovation, intelligent upgrading of manufacturing enterprises, and environmental dynamism, starting with environmental regulations. Simultaneously, it has enriched and extended pertinent research on the intelligent upgrading of manufacturing enterprises. Furthermore, from the standpoint of environmental dynamism, it examines the significance of shifts in internal and external conditions, as well as consumer demands, for the intelligent upgrading of manufacturing enterprises. The study's findings can provide the following theoretical insights for the transformation and upgrade of manufacturing enterprises to intelligentization.

**Availability of data and materials** The data that support the findings of this study are openly available on request

**Authors' contributions** Ching-Chi Hsu: Conceptualization, data curation, methodology, writing-original draft
Quang-Thanh, Ngo: Data curation, visualization
FengSheng Chien: Visualization, supervision, editing
Li Li: Methodology, review, and editing
Muhammad Mohsin: Writing review and editing and software

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## Declarations

**Ethical approval** The manuscript has not been submitted to more than one journal for simultaneous consideration. No data, text, or theories by others are presented in our manuscript. We don't have any conflict of interest.

**Consent for publication** We do not have any individual person's data in any form.

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