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The relationship between innovative performance and environmental regulations: Evidences from Jiangsu Province, China

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With the endless constraints brought about by limited resources and increased pollution, practices that aim for sustainable and innovative development is often seen as the thing of the future. Despite this collective shift towards sustainability, the relationship between regional innovation and environmental protection still vastly differs between different geographic units. This paper takes the Jiangsu province, a pioneering economic zone in East China, as a study object, and uses its thirteen cities' panel data from 2006 to 2020 to check human capital input, foreign direct investment, research and development fund input, environmental pollution, and other independent variables that influence its innovation output. The study finds a strong positive relationship between R&D investment of enterprises, human capital input, local loans scaled for technical innovation, environmental regulation and innovative output. while the same is untrue between research and development fund input from government and innovative output. There are also negative contribution from the openness of cities and foreign direct investment, which indicates that presently more innovative achievements in Jiangsu come from independent research and development rather than relying on technology spillovers from foreign direct investments. Finally, future policies about enhancing the research and development input scale, encouraging local human capital, executing more fiscal and direct capital supporting tools, and upholding liberal trade policies as high-quality international export-oriented economy are suggested.

KEYWORDS
innovative performance, environmental regulation, foreign direct investment, panel data, Jiangsu Province

1 Introduction

Reports from the 19th CPC National Congress point out that China's economy has shifted from a stage of high-speed growth to one that adheres to the philosophies of high-quality development, which is the most important assertion for China's current economic development. This, in turn, has propelled China to become the world's second largest economy. On one hand, the development strategy of prioritizing heavy industry has promoted China to rapid economic growth. On the other hand, this development has brought about increasingly serious environmental problems.

With the rapid development of China's economy especially in the industrial sector, it was confronted with the unprecedented pressure of energy consumption and environmental protection. According to the 2020 Bulletin on China's Ecological Environment, 135 of 337 cities at and above the prefecture level exceeded excessive air quality, which accounted for 40.1 percent of the total number of cities. It has become a common social prerogative to strengthen environmental governance, reduce environmental pollution, and build a beautiful China with its natural patrimony intact. It is natural that the Chinese economy should steer towards green sustainable development (Khan et al., 2021; Abbass et al., 2022; Ma et al., 2022). It is worth noting that "peak carbon dioxide emissions" and "carbon neutrality" have been popular terms in the Chinese Communist Party's annual government work report, frequently emphasized by social media in these recent years (Wan et al., 2021; Wu, 2022; Zeraibi et al., 2022).

Other previous studies on the dynamics between ecology and society focused on the tradeoff of industrial development and environmental protection by implying the private costs and social benefits of industrialization (Shao et al., 2020; Jiang et al., 2021). As for the definition of environmental regulation, according to the public interest theory, in order to solve the market failure caused by pollution, the government needs to meet public needs through environmental regulation. From the experience of various countries, the common policies of environmental regulation mainly include: prohibition, concession; price rate and quantity limit; product, technical production and performance standards limitation; subsidies; information provision; property right and right definition (Chen, 2016). Points about the relationship between environmental regulation and technological innovation can be divided into three main categories: Firstly, the traditional view that environmental regulation will raise the total cost of dealing with the waste discharging by forcing firms to increase financial investment on environmental governance, thus leading to insufficient input in research and development ultimately lowering the international market competitiveness (Kneller and Manderson, 2012). The second category is the optimistic idea initiated by Esty and Porter (2005) where they point out that because of the faulty static view of environmental regulation, 'innovation offset' will bring competitive advantages for those firms who innovate continually and will create absolute advantages for innovative firms over their overseas competitors (Porter and Van der Linde, 1995). The last category holds that environmental regulation will, to some extent, improve the allocation of economic resources through what's called the "offset effect".

The relationship between environmental and technological innovation is non-linear and the mediators are multiple. Whether there is, ultimately, technological progress depends on the environmental regulation intensity, type, firm property structure, time, and geographic attributes (Jaffe, 1993; Brunnermeier and Cohen, 2003; Jahanger et al., 2022). The relationship of innovation with stricter environmental regulation in industries has been an unavoidable theoretical and practical problem, which to this day remains largely unexplored.

Among the Chinese thirty-four administrative areas, Jiangsu province is one of the fastest-developed and pioneering region. Geographically, Jiangsu province is divided into three parts: Southern, Middle, and Northern Jiangsu. Southern Jiangsu includes the five cities of Nanking, Suzhou, Wuxi, Changzhou, and Zhenjiang. Middle Jiangsu meanwhile includes the cities of Yangzhou, Taizhou, and Nantong. Lastly, Northern Jiangsu includes the five cities of Xuzhou, Huaian, Yancheng, Lianyungang, and Suqian. During the early years of the Reform and Open policy, Jiangsu province experienced an economic miracle that has propelled it to a middle-income level region of a developed country, with almost 10,000 USD per capita in 2012. According to the national statistical yearbook, its gross domestic product value totaled to around 11,636.4 billion Renmingbi yuan in 2021, ranking as the second highest among provinces nationwide. Many researchers ascribe its success to its international strategy of cooperating with foreign enterprises where it can get enormous funds, more advanced technology, mutual benefits of international trade, and selling channels (Luo et al., 2016; Wang and Li, 2020; Xi et al., 2022). In 2006, Jiangsu provincial government proposed the strategy of building an innovative province, vigorously developing an innovative economy, and transforming economic development from mainly relying on material input to mainly relying on innovation driven, which is the only way for Jiangsu to promote scientific development. At present, Jiangsu has obvious regional differences in the level of economic development, scientific and technological resources, innovation awareness and other aspects. Therefore, when formulating the development strategy of innovative economy, we should not only consider the commonness of innovative economic development in Jiangsu, but also take into account the individuality of innovative economic development in different regions of Jiangsu, which requires comprehensive and in-depth investigation, research and theoretical analysis (Li, 2014). Given these circumstances, this paper focuses on two questions: What is the relationship between innovative performance and environmental regulation in Jiangsu province? To which extent do these factors will influence the innovative dependent variable? Accordingly, future developing suggestions related to industrial reform in Jiangsu will be given based on the ensuing empirical research. Based on the previous research results, this paper intends to use panel data to empirically analyze the influencing factors and differences of innovation output in 13 prefecture level cities and three regions in Jiangsu (Southern Jiangsu, Central Jiangsu and Northern Jiangsu), in order to objectively understand the actual situation and regional differences of Jiangsu's innovative economic development, and provide a scientific basis for the strategic choice and mode choice of Jiangsu's innovative economic development.

2 Literature review

2.1 Mechanisms of environmental regulation influencing innovative behaviors

The concept of innovation was put forward by Schumpeter to explain the economic cycle and growth. His idea about innovation as a new design or adjustment of production function in different firms and industries. Innovation was not seen solely in a scientific notion; it is a certain new form of productive force, driven by profit orientation of different enterprises to promote social and economic sustainable development (Schumpeter and Backhaus, 2003). Some developing countries try to carry out innovative policies to overcome the deteriorating effects on environment, aiming at the win-win of environmental protection and economic development (Jiang et al., 2013). With more stringent public environmental regulations, many authors discuss the direct and indirect effects environmental regulations will impose on innovative institutions (Zhang, 2018).

The direct effects of environmental regulations are two-fold: the positive offset effect and the negative compensation effect. On one hand, when governments issue strict environmental policies to control emissions of wastewater, gases, or solid waste, firms with revenue-cost considerations can take two kinds of feasible strategies: first is to increase fund budget to realize the technological progress effect, while the other is to enhance productivity through improving production process or adjust the proportion of productive factors. Under these circumstances, firms can derive net profit due to increase of revenue despite additional environmental regulation costs. To protect the environment, government departments will give some financial and fiscal support to firms in certain industries, eliminating the fund constraint of innovative need. Meanwhile, as new policies inclined on reflecting the realistic social and environmental cost are carried out, some privileges for cleaner resources and more advanced materials applications will foster greener technological innovation.

On the other hand, the negative effects caused by environmental regulation consisting of crowding-out effects of innovative fund and investments. Because of the limited financial fund each firm possesses, putting some of these into dealing with the environmental regulation results in the remaining funds turning fewer. Classic firm theory tells us that stricter environmental regulation brings financial burden on firms, hence they gradually lose their comparison advantages and may move to locations with loose environmental regulations. This pushes developing countries and regions to bear the brunt of pollution-intensive industries, crowding out local investment and innovative orientation inputs.

Some of the indirect effect of environmental regulation include foreign direct investment (FDI), the technological spillover effect, size effect of large-scale firms, innovative effect of human capital, and the return of equity ratio—all of which will, to some extent, influence the innovative efficiency of firms. Environmental regulation changes the investment site as conducive for technological absorption, with administrative policies cater to international capital. In open economies, attracting FDI of higher quality has been the common strategy for developing countries. FDI does not only bring the adequate innovative domestic investment to assuage the lack of funds, it also imparts modern managerial philosophies and advanced technologies in these economies (Jiang, 2004).

The spillover effect of FDI under environmental regulation may be diversified. Explanations such as the pollution heaven hypothesis assume that as severe environmental regulation will increase the cost of compliance of foreign firms, they will divert to regions with weaker environmental regulation to conduct business (Baumol and Oates, 1988). Domestic firms lacking innovative funds will crowd out some employee training and R&D expense to pay for the stricter environmental regulation cost, leading the absorption of FDI technological to be weaker.

As environmental regulations get stricter with the increasing worldwide appeal of the "cleaner and greener life," some local governments will enhance the environmental standard for foreign enterprises seeking permission to investment by setting barriers for pollution-intensive firms, instead welcoming capital-intensive and technology-intensive enterprises.

Environmental regulations will also influence the effects of technological innovation on human capital. Technological progress has been the fundamental basis for modern economic growth characterized by better machines and better human resources equipped with better education and technical skills. On one hand, accumulation of adequate human capital is a motivation to promote technological capacities through the adoption of new technology needs to match the capabilities of human capital quality. The higher quality and amount of human capital a country possesses, the more pronounced the technological progress that ensues. On the other hand, acquirement, absorption and convertibility of human capital urges enterprises to create technological innovation that is goods-based. This is manifests as new technologies that are combined with human capital and sold to consumers with added economic value (Solow, 1957).

2.2 Factors influencing innovative efficiency

The streams of existing literature on innovation efficiency are mainly discussed in different levels: countries, regions or cities, or enterprises and various types of companies. Higher level of economic development, population increase, and industrial structures will have a significant influence on innovative efficiency improvement (Fan et al., 2020; Wan et al., 2022). Based on innovative efficiency decomposition, Li et al. (2021) point out that cities with better human capital, higher science and technology investment, and education expenditure have a more positive significance on municipal ecological efficiency.

Similarly, Chen et al. (2020) illustrate that education investment and innovation talents have a U-shaped relationship with urban eco-efficiency. In contrast, capital investment and innovation performance have an inverted U-shaped relationship. Li et al. (2018) used non-parametric DEA model to check the relationship between environmental regulation and technical innovation in Xi'an. The results show that the "Porter hypothesis" does not prove tenable.

Meanwhile, in the Yangtze River Economic Belt region, green technological innovation improves the region's eco-efficiency due to the energy rebounds from the compliance cost and the innovative compensation effects. Therefore, there is a "race to the top" phenomenon in some developed regions in Eastern parts of China and a likewise "race to the bottom" phenomenon in the Western part under-developed regions of China (Zhang and Lv, 2018; Liu et al., 2020).

Resource endowment is both a curse and blessing for cities with different resources as it moderates the innovative development of cities (Zhang et al., 2022). From small and middle scale enterprises in European regions, over-investment is carried out in non-research and development innovation activities which causing low innovative output (Rexhäuser and Rammer, 2014; Teirlinck and Khoshnevis, 2022). As for the spatial spillover of eco-innovation effect (Yang and Liu, 2020), there exists a positive correlation between foreign capital utilization and degree of openness. Zeng et al. (2019) uncovered that regional absorptive capacity—especially for industrial R&D, government support, and FDI, also proved as the most critical factors that facilitate regional innovation in China and is revealed only in highly innovative cities, but not in less innovative ones. In this light, regional absorptive capacity in China unexpectedly serves as a self-reinforcing mechanism solely for highly innovative cities, which further advances the current understanding of the rising regional inequality of innovation in China.

From the literature review, it is found that most of the existing studies analyze the factors affecting enterprise or industry innovation from the micro perspective, while the analysis of regional innovation ability is mostly from the national macro level. There are few quantitative analyses and comparative studies from the regional level, especially those taking each region of Jiangsu Province as the research object. Therefore, the author uses the data of 13 prefecture level cities in Jiangsu Province. By constructing an econometric model, this paper discusses the factors affecting regional innovation output, and puts forward policy suggestions accordingly.

3 Method and data

3.1 Model

Knowledge Production Function (KPF) is the prevalent theoretical model to examine the relationship of technological innovation, knowledge production, and regional innovation. KPF was used to estimate different factors that would contribute to the final output in research and development (R&D) activities, in which output of R&D is viewed as function of the R&D input (Griliches, 1979). KPF has been proved to be effective in measuring both innovative performance and knowledge spillover effect (Bode, 2004). Jaffe (1989) used time series data to explore the spillover effect from university research to commercial innovation. It was found that new knowledge with commercial value is an important target that firms pursue. Hence, the modified Cobb-Dauglas knowledge production function model is as follows:

$$P_i = AK_i^{\alpha}L_i^{\beta}\epsilon_i \tag{1}$$

In formula (1), P variable indexes the patent number of companies that are registered and reflect the new knowledge created. Because of its objectivity, continuity and richness, scholars can use patent data as an effective tool for in-depth analysis and interpretation of innovation management problems, phenomena and laws in case studies. Usually, scholars measure innovation performance by patent quantity and quality. Patent quality can generally be measured by the following indicators or their comprehensive weighting: patent type, time interval from patent application to authorization, number of patent claims, patent maintenance time, number of patent citations, strength and depth of patent family (Sun et al., 2022). The K variable indexes the R&D fund input of firms, and the L variable indexes the financial input by universities. A is constant value, and $\mathcal{E}$ is the stochastic error. Based on current literature, factors influencing the innovative output are capital, human labor, and others, thus the Cobb-Dauglas production function is constructed as follows:

$$PN = A * RD^{\beta_1} * TP^{\beta_2} * GF^{\beta_3} * TL^{\beta_4} * FDI^{\beta_5} * OP^{\beta_6} * \epsilon \quad (2)$$

Here in formula (2), PN indexes the regional innovative performance, A is the constant, RD indexes the R&D input, TP indexes the human capital input, GF indexes the governmental supporting fund, TL indexes the financial loan in each city, FDI indexes foreign direct investment, OP indexes the economic openness of each city, and ϵ indexes the stochastic error.

In consideration of time dynamic effect in getting the natural logarithm disposal for formula (2), get the econometric model is therefore as follows:

$$\log PN_{it} = \alpha_{it} + \beta_1 \log RD_{it} + \beta_2 \log TP_{it} + \beta_3 \log GF_{it} + \beta_4 \log HC_{it} + \beta_5 \log TL_{it} + \beta_6 \log FDI_{it} + \beta_7 OP_{it} + \epsilon_{it} \quad (3)$$

In model 3, i indexes the city observational unit, t indexes each year time, α is the constant item, ϵ_{it} is the stochastic error term.

3.2 Augmented dickey-fuller unit root and co-integration tests

The disturbance term $\{\mathcal{E}_t\}$ is independent white noise, so the disturbance term has no autocorrelation. If $\{\mathcal{E}_t\}$ has autocorrelation, a higher-order lag term can be introduced. Suppose an appropriate lag period p is selected, so that the disturbance term $\{\mathcal{E}_t\}$in the following AR(p)model 4 is independent white noise:

$$y = \beta_0 + \beta_1 y_{t-1} + ... + \beta_p y_{t-p} + \gamma t + \epsilon_t \quad (4)$$

For the convenience of inspection, the above formula is converted into the following Eq. 5:

$$y_t = \beta_0 + \rho y_{t-1} + \gamma_1 \Delta y_{t-1} + \gamma_2 \Delta y_{t-2} + ... + \gamma_{p-1} \Delta y_{t-p+1} + \gamma t + \epsilon_t \quad (5)$$

In order to test whether there is a unit root, we can consider regression Eq. 5 and test the null hypothesis H_0: $\rho = 1$ $vs H_1$: $\rho < 1$.

In order to test whether there is co-integration relationship between variables, (Engle and Granger 1987) put forward the test method. Assuming that there is an auto-regressive distributed lag model relationship between X and Y sequences:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \epsilon_t \quad (6)$$

And its Error Correction Model (ECM) is:

$$\Delta y_t = \gamma_0 \Delta x_t + (\beta_1 - 1)(y_{t-1} - \varphi - \theta x_{t-1}) + \epsilon_t \quad (7)$$

The Δy_t in Eq. 7 is a stationary process, if there is no co-integration relationship between X and Y sequences, the left equation still keeps stationary, while the right error correction model can not be established.

3.3 Variables and data sources

3.3.1 Explained variable

In this study, yearly patent registered number is used to measure innovative performance. In China patents are designated into three categories: invention patent, practical new type patent, and the design patent. All three categories have distinct and specific definitions of originality and protective time spans. In the Jiangsu statistical yearbook, only two groups of patent data exist: one is the patent application number, while the other is the patent approved number. The second group of patent data has a stricter examination, and the final approved number of patents can be used to reflect the regional innovative capability (Table 1).

3.3.2 Explanatory variables

Environmental regulation (ER). Current literature suggests that there is no direct indicator to measure the intensity of environmental regulation. Some papers adopt quantitative indicators to measure this intensity. For example, GDP Per capita is used as an alternative index to environmental regulation only if, with the continuous rise of income level, environmental regulation is also stricter (Antweiler et al., 2001). The emission intensity of different pollutants is used as an index to measure the environmental regulation intensity of a country (Domazlicky and Weber, 2004). The operation cost of pollution control facilities is also measured, or the quantitative index of environmental governance cost is taken as the alternative or proxy variable (Zhang et al., 2011). There are some qualitative indicators such as urban environmental governance standards and environmental subsidy policies which are adopted to reflect the environmental protection process and the subsequent measures adopted.

This paper considers the different nature of available industries, along with the many indicators in the statistical yearbook. The lack of comparability between different industries and the relevant indicators must also be carried out by standardized processing. Therefore, this paper adopts the linear standardization method to deal with environmental regulatory indicators, and constructs a comprehensive reflection of the different industries.

The index system of pollution regulation intensity and its change measures the pollution emission intensity of various industries as the alternative index of environmental regulation. Usually, the higher the pollution emission intensity in a region, the more severe the environmental regulations in the region are, as well. By collecting the pollution discharge of wastewater, waste gas, and solid waste and the industrial output value of each industry, the pollution discharge value of the unit output value of each industry is calculated to demonstrate the environmental regulation intensity in each city.

Human capital. The level of human capital is an important factor that affects the technological innovation ability of enterprises. The technological innovation of enterprises needs high-level R&D personnel, and the technological innovation of enterprises is the embodiment of the creative achievements of core technicians. At the same time, in the development process of open economy, China has made full use of its strategic location and cost and business advantages by actively integrating into the international division system of labor, and effectively promoting the rapid development of economy through introduction, digestion, absorption, and re-innovation. Human capital is one of the indispensable variables that affects these different faces of economic development. The study uses the number of people engaged in scientific and technological activities to reflect the quality of human capital in each city.

R&D fund input. Sufficient R&D funds are a necessary condition for an enterprise's technological innovation. However, due to faults in China's financial market system and the high-risk characteristics of technological innovation, the external financing channels of enterprises are limited, and its reliance on internal funds makes it vulnerable as well. Higher profit margin can not only ensure that enterprises have enough retained earnings for technology R&D, but also encourages enterprises with higher profit margin to have good expectations for industrial development and invest more funds into R&D activities. The funds that support the R&D process include three different sources: the enterprise invests part of its own funds, banks support R&D activities or through technological transformation loans, and government financial support funds.

Foreign direct investment and the extent of economic openness. With the continuous advancement of economic globalization, the innovation and R&D process of foreign-funded enterprises is no longer limited to one country. The integration of technical and human resources around the world forms the sharing of technology, knowledge, and information, to achieve the purpose of complementary advantages and collaborative improvement of enterprises' technological innovation ability.

Today, the scale of China's investment attraction continues to expand, and foreign-funded enterprises have become an important part of China's R&D and innovation system. In this context, local enterprises should not only focus on improving their R&D capacity and absorption capacity, but also improve their technological innovation ability by strengthening R&D cooperation with foreign-funded enterprises. In addition, the flow of talent also contributes to the technology spillover of foreign-funded enterprises. Therefore, this paper selects the actual scale of foreign capital utilized in that year as the measurement index of FDI.

In the specific analysis process, to eliminate the dimension of variables, the indexes are logarithmicized. The study uses total import and export volume divided by GDP of each city to reflect their openness.

3.3.3 Data sources

With the availability of environmental pollution emission data, this paper selects the panel data of 13 prefecture level cities in Jiangsu Province from 2006 to 2020 for regression analysis. The sample data are mainly from Jiangsu's statistical yearbook from 2006 to 2020, Jiangsu Science and Technology Yearbook from 2006 to 2020, comprehensive evaluation results of statistical monitoring of scientific and technological progress of cities in Jiangsu Province from 2006 to 2020, and some patent data available at the website of Jiangsu Intellectual Property Office.

4 Results and discussion

To eliminate the influence of price factors on R&D fund investment and other indicators, the consumer price index is used to reduce the variables RD, GF, TL and FDI so that x = 100 (X*/PI) where: X represents the actual statistical index; X * indicates nominal

TABLE 1 Variables definition.

Variables	Variables design	Implications
Explained Variable		
PN	Numbers of patents	Including three types of patents in each city
Explanatory Variables		
ER	Environmental regulation	Industrial waste water discharging in each city
RD	Financial input of R&D	Research and development expenses for the whole city
HC	Human capital input	Number of people engaged in scientific and technological activities
GF	Governmental funding	Local finance general budget expenditure on government science and technology multiply the proportion of appropriations in fiscal expenditure
TL	Loan for technical innovation	Year-end loan balance of science and technology and technical transformation loan multiply the proportion of total loan
FDI	Foreign direct investment	Actual uses of the foreign investment amount of each city, converted into the RMB currency
OP	Openness	Total import and export volume divided by GDP of each city

TABLE 2 Descriptive statistical analysis of each variable.

Variable	Mean	Standard deviation	Minimum	Maximum	Observations
PN	15362.48	19517.26	107.00	138861.00	195
GF	20.63	29.01	0.57	216.28	195
RD	101.66	115.52	2.10	671.94	195
TL	4266.72	5134.00	195.54	34195.79	195
HC	36800.00	37800.00	2800.00	218400.00	195
ER	3.15	4.08	0.25	19.65	195
FDI	20.34	17.56	0.49	91.65	195
OP	0.41	0.50	0.02	3.50	195

TABLE 3 Unit root test of variables in Jiangsu Province.

Variables	Jiangsu Province		Southern Jiangsu		Central Jiangsu		Northern Jiangsu	
	ADF	LLC	ADF	LLC	ADF	LLC	ADF	LLC
ln (PN)	41.1110**	−4.7943***	7.6224	−2.1514 **	17.2448***	−2.9637***	6.3284	−1.3939 *
Δ ln (PN)	60.8516***	−10.0451***	13.1449	−5.7425***	18.1303***	−5.0624 ***	56.5669 ***	−6.0055 ***
GF	15.7831	−1.5146 *	0.0775	5.1718	2.6822	−2.2521 **	7.4974	−0.7364
Δ GF	55.0771***	−5.1288***	13.5480	−3.7070***	19.3384***	−9.0853***	12.5147	−4.8663***
RD	13.7107	3.0219	0.7271	2.4827	5.2417	1.9818	3.4540	2.3736
Δ RD	104.7016***	−7.4477 ***	57.6485***	−5.8713***	10.2639	1.9969	8.9760	−2.0820 **
ln (HC)	36.3547 *	−5.1950***	27.8817 ***	−2.9883***	6.1000	0.0535**	3.9971	−4.9461 ***
Δ ln (HC)	55.8596 ***	−15.9767***	67.5704***	−9.4728***	5.6547	−8.2299***	14.4949	−7.3091 ***
ln (TL)	28.1806	−1.1790	6.9197	−0.6493	5.3742	−1.6812**	3.5756	−1.1958
Δ ln (TL)	48.1221***	−5.9923***	7.3826	−2.3815***	54.8394 ***	−5.7439***	10.0394	−4.0453 ***
ER	44.1546**	−2.6098***	2.0384	2.7340	4.4275	−2.0175 **	2.2300	−0.8682
Δ ER	56.0468***	−5.5028***	2.0155	1.8961	13.8726**	−4.0282 ***	27.0976 ***	−5.3933***
FDI	57.4453***	−5.9104 ***	13.6366	−4.3681***	14.0245 **	−2.8393 ***	7.1554	−3.3078 ***
Δ FDI	95.4389***	−10.6492***	57.4212***	−8.2170***	13.7270**	−5.4686***	13.9333	−6.6254 ***
OP	13.2819	−2.4840***	24.9558***	−5.8268***	25.3075***	−2.8616 ***	7.3188	−1.0765
Δ OP	84.2348***	−6.8406***	64.2270***	−2.1067***	33.1527 ***	−5.3825 ***	37.1465 ***	−5.2927 ***

Note: ***,* *, *Mean significant at 1%,5%, 10% level.

statistical indicators; PI represents the measured consumer price index. Set year 2006 as 100. According to Jiangsu statistical yearbook 2007–2021, the above indexes are converted into the constant price level in 2006.

4.1 Description of variables

The descriptive statistical result of the explained and explanatory variables are given in Table 2. The unit of the PN variable is the number of patents, with a mean value of (15362.48). The unit of GF variable is RMB 100 million, with a 20.63 mean valye. The unit of RD variable is RMB 100 million, with a 115.52 mean value. The unit of TL variable is RMB 100 million, with a corresponding 4266.72 mean value. The unit of RD variable is number of working staff in R&D activities, with 4266.72 as its mean value. The unit of ER variable is 100 million tons, with 3.15 as its mean value. The unit of FDI variable is 100 million US dollar, with 20.34 as its mean value. The unit of OP variable is the percentage value of each city in different years, with a 0.41 mean value.

4.2 Unit root test

Traditional econometrics requires the stochastic process to be stable. That is, the expectation of each time in the time series is independent of covariance and time. If the stability premise is not satisfied, there will be false regression. Therefore, before calculating the panel data model, it is necessary to test the unit root of the relevant time series data to determine whether the variables are stable. In this study, three test methods are used to test the unit root of the panel data of Jiangsu Province, Southern Jiangsu, Central Jiangsu, and Northern Jiangsu respectively, including the Fisher Augmented dickey-fuller (ADF) test and LLC (Levin-Lin-Chu) test. See Table 3 for details.

The time-varying behavior of the moment characteristics of time series reflects the non-stationary nature of time series. The processing method of non-stationary time series is generally to transform it into stationary series, to apply the method of stationary time series and study accordingly. The test of the unit root of the time series is the test of the stationarity of the time series. If there is a unit root in the non-stationary time series, this can be eliminated by the difference method to obtain the stationary series. For the time series with unit roots, they generally show obvious memory and volatility persistence. Therefore, the unit root test is the basis for the discussion of the existence test of co-integration relationship and the persistence of series volatility.

The results of unit root test of various variables in Jiangsu show that ln (PN) rejects the original hypothesis at the level of 10%, while FDI rejects the original hypothesis at the level of 5%, indicating that the two index sequences are 0-order single integers. However, GF, RD, lnHC, lnTL, ER, and OP in Jiangsu Province cannot reject the null hypothesis of unit root at the significance level of 10% (although some individual results pass a single test without difference). For their first-order difference, the results of the two test methods reject the null hypothesis of unit root at the significance level of 1%, indicating that the first-order difference of each sequence is a first-order stationary process. Therefore, according to the test results, GF, RD, lnHC, lnTl, ER and OP are all first-order stationary sequences, but ln (PN) and FDI are zero-order stationary sequences (see: Table 3).

TABLE 4 Results of Kao and Pedroni test.

	Kao test		**Pedroni test**	
Items	Statistic (t)	*p*-value	Statistic (t)	*p*-value
Jiangsu Province	−3.6782	0.001	−7.6884	0.0000
Southern Jiangsu	−2.6178	0.004	−8.0128	0.0000
Central Jiangsu	−4.7819	0.000	−5.6485	0.0000
Northern Jiangsu	−4.7182	0.000	−5.5698	0.0000

4.3 Co-integration analysis

Because there are non-stationary variables in the panel data model, it is necessary to conduct co-integration test on the model to judge whether there is said relationship between each variable. This prevents the occurrence of pseudo regression. This paper will use the Kao ADF test and Pedroni test method to co-integrate the panel.

It can be seen from Table 4 that the Kao and Pedroni test of each variable rejects the original hypothesis at the significance level of 1%.This indicates there is a co-integration relationship between each variable. Additionally, Westerlund test for co-integration is done, the null hypothesis is "No co-integration", we check the Jiangsu province data in Stata, the *p*-value is 0.01 (the statistic value is 2.11), so we accept the alternative hypothesis "Some panels are cointegrated".

4.4 Panel data regression results

Before setting the model, it is necessary to consider that there may be a test of inter group contemporaneous correlation in panel data. Consider the null hypothesis is that "there is no component synchronization correlation". If this original assumption is true, the correlation coefficient of different individual disturbance terms calculated according to the residual should be close to zero. If these correlation coefficients are arranged into a matrix, namely "correlation matrix of residuals", the diagonal elements of the matrix should not be far from zero. According to correlation matrix of residuals, it can be tested by Breusch-Pagan LM test. In Table5, based on 15 complete observations, the chi2 (78) value is 204.81, the *p*-value of Breusch-Pagan LM test of independence is zero, therefore, it strongly rejects the null hypothesis of "no contemporaneous correlation" and believe that there is cross sectional dependence.

For ordinary panel data, neighboring cities may interact through trade or investment, resulting in cross-section related problems. There are mainly two ways to deal with the heteroscedasticity between groups or the simultaneous correlation between groups in which the disturbance term exists. One is to continue to use OLS method to estimate the coefficient and only correct the standard error, that is, through the panel corrected standard error method. The other is to assume the specific form of heteroscedasticity or auto-correlation, and then use the feasible generalized least square (FGLS) method to estimate. In this paper, considering the existence of intra group auto-correlation, inter group heteroscedasticity or contemporaneous correlation, the cross-sectional time-series FGLS regression method is used for estimation, and the results are shown in Table 6.

Considering the abnormal value influence, the observed values of variables at the 1st and 99th percentiles of their

TABLE 5 Results of correlation matrix of residuals.

	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10	e11	e12	e13
e1	1.00												
e2	0.68	1.00											
e3	−0.36	−0.24	1.00										
e4	−0.24	0.16	0.03	1.00									
e5	−0.20	0.41	0.33	0.38	1.00								
e6	0.64	0.65	−0.33	0.38	0.05	1.00							
e7	−0.64	−0.26	0.27	0.52	0.53	−0.22	1.00						
e8	−0.60	−0.45	0.53	0.00	0.21	−0.60	0.57	1.00					
e9	0.44	−0.13	0.12	−0.49	−0.46	0.22	−0.46	−0.14	1.00				
e10	0.16	0.28	0.10	0.27	0.10	0.54	0.04	0.00	0.08	1.00			
e11	0.77	0.61	−0.06	−0.04	0.07	0.67	−0.47	−0.63	0.38	0.07	1.00		
e12	0.18	0.36	0.32	0.08	0.62	0.32	0.30	0.13	0.18	0.14	0.51	1.00	
e13	0.83	0.67	−0.36	−0.16	−0.08	0.77	−0.58	−0.56	0.50	0.32	0.73	0.34	1.00

Note:each number refers to a city,1-Nanking; 2-Wuxi; 3-Zhenjiang; 4-Suzhou; 5-Nantong; 6-Yangzhou; 7-Yancheng; 8-Xuzhou; 9-Huaian; 10-Lianyungang; 11-Changzhou; 12-Taizhou; 13-Suqian.

TABLE 6 Regression results of innovation output.

Sample	Jiangsu province	Southern Jiangsu	Central Jiangsu	Northern Jiangsu
GF	−0.0019 (−1.23)	0.0063* (1.68)	−0.0415*** (−3.85)	0.0039 (0.37)
RD	0.0008 ** (2.23)	−0.0020 (−1.81)	−0.0071** (−2.05)	−0.0121*** (−2.79)
ln (HC)	0.4377*** (12.98)	0.5366*** (6.00)	1.3632*** (5.95)	0.1647** (2.25)
ln (TL)	1.0216 *** (22.50)	0.5007*** (6.42)	1.5258*** (10.33)	1.6051*** (10.27)
ER	0.0117 ** (3.25)	−0.0968*** (−2.94)	0.0832*** (4.61)	−0.0128 (−0.49)
FDI	−0.0029 ** (4.07)	0.0052 (1.31)	−0.0032 (−0.34)	0.0076 (0.90)
OP	−0.1180*** (−1.05)	0.0178 (−0.22)	4.4571*** (4.48)	−0.0053 (−0.03)
constant	0.5251 (−3.42)	4.7112*** (7.7)	−4.0347*** (−4.55)	−3.3822*** (−3.40)
Wald chi2	2298.20	417.71	1454.40	368.62
Observation	195	75	45	75

Note: ***, **,* represent the significant levels of 1%, 5%, and 10% respectively, z statistics in parentheses.

distribution are windorized. From the regression results (Table 6), it can be seen that the variables affecting the level of technological innovation in various regions are different from the expected symbols.

The regression results of Jiangsu Province are significantly different from those of Northern, Central and Southern Jiangsu. This could be explained by the following:

(1) Government funding for science and technology. From the perspective of Jiangsu Province, this variable has no significant role in promoting innovation output, which is only significant at the 10% significance level in southern Jiangsu and 1% significance level in Central Jiangsu, but it does not pass the test in Northern Jiangsu. In southern Jiangsu, every 1% point increase in government science and technology allocation promotes the increase of innovation output by 0.00063% points. This shows that the Jiangsu provincial government attaches great importance to the role of scientific and technological innovation in economic development. However, government financing has invested a lot in promoting scientific and technological innovation, which has produced good results such as significantly improving the local level of scientific and technological innovation, pushing for further optimizing the structure. In Northern Jiangsu, the equation did not pass the significance test, which may be due to the low overall financial level of Northern Jiangsu and the limited financial support for the development of the innovative economy. Governmental subsidies are an important support for technological innovation of

polluting enterprises, but it is often difficult to meet the financial needs of technological innovation. Therefore, enterprises can take the ways of technological innovation R&D shares, purchase insurance for technological innovation activities, joint financial institutions, insurance companies and R&D institutions to carry out technological innovation, and use modern financial tools to provide financial support for technological innovation (Zhou and Guo, 2022).

(2) Independent R&D investment of enterprises. This variable has a significant positive effect on innovation output in Jiangsu, where every 1% point increase in R&D input level can promote the increase of innovation output by 0.0008% point. From a sub-regional perspective, the R&D input level has a significant negative impact on the innovation output of Northern and Central Jiangsu. This may be due to the crowding out effect of enterprise funds. R&D activities crowd out the normal operation of enterprises, which significantly hinder the progress of local scientific and technological levels and improve the strength of independent innovation in the long run.

(3) Investment of scientific and technological personnel. This variable has a certain promoting effect on innovation output. That is, every 1% point increase in the input level of scientific and technological personnel can promote the increase of innovation output by 0.4377% points. This is mainly because Jiangsu Province has rich research and teaching resources and many research talents, which provide favorable conditions for the development of scientific and technological innovation activities in Jiangsu. From a sub-regional perspective, the input of scientific and technological personnel has obvious positive significant role in promoting the innovation output of Southern Jiangsu, Central and Northern Jiangsu. The possible reason is that Jiangsu province is rich in science and education resources, and the successful implementation of R&D talent incentive policies in Southern, Central and Northern Jiangsu. In recent years it has led to the increasing number of scientific and technological talents in whole Jiangsu province, which is conducive to the improvement of local scientific and technological output. Enterprises should also create a good innovation atmosphere within the organization, formulate various incentive measures to fully mobilize the enthusiasm of employees for innovation, so as to promote green innovation and sustainable development of enterprises (Xing and Yu, 2019).

(4) Loans for scientific and technological transformation of financial institutions. In Jiangsu's experience, the science and technology output elasticity of this variable is 1.0216, and its positive effect on innovation output is significant at the level of 1%. In terms of sub-regions such as in Northern, Southern or Central Jiangsu, the impact of financial institution loans on independent innovation in each region has reached the significance requirement of 1%. Indicating that at present, financial science and technology loans have a significant role in promoting technological innovation in Jiangsu, and that local financial resource endowments have an important impact on enterprise innovation activities.

(5) Environmental regulation. From the regression results, environmental regulation has a positive and significant impact on Jiangsu's regional innovation, given that it passed the 5% significance level test. Every 1% increase in regulation intensity will positively promote the innovation level of the whole province by 0.0117% points. From the consequences of environmental regulation, Central Jiangsu region has achieved a positive "Porter effect". However, it has not passed the significance test in Southern and Northern Jiangsu, which may be closely related to the degree of industrialization in these sub-regions. In the domestic empirical research on local environmental regulation and foreign direct investment, most studies believe that the difference of local environmental regulation is the main reason for the regional difference of foreign direct investment. Chen. (2009) believes that the loose environmental regulation strategy of local governments has made China a "pollution refuge" for multinational polluting enterprises. Strict environmental regulation inhibits the inflow of foreign capital, or forces high energy consuming and high polluting enterprises to migrate to other regions, thus making regions with weak environmental regulation standards become "pollution havens" (Xue and Huang, 2021). Spatareanu (2007) believes that reasonable environmental regulation policies can optimize the level and structure of foreign direct investment.

(6) Influence of foreign direct investment. With Jiangsu, FDI has a negative effect on its innovation output, and passes the significance test at the level of 5%. From a sub-regional perspective, FDI does not show a significant effect on three part. All regions should continue to introduce policies to improve the quality of foreign investment and realize the technology spillover of FDI.

(7) Openness. From the perspective of Jiangsu Province, this variable has a certain negative effect on science and technology output. That is, every 1% point increase in openness will reduce innovation output by 0.1180% points. In terms of sub-regions, South Jiangsu and Norther Jiangsu have not passed the significance test, hence the openness of each region does not has a clear impact on scientific and technological output. This may be explained by the scientific and technological content and the economic added value of Jiangsu's import and export products being relatively low. The increase of import and export does not promote scientific and technological innovation, but instead hinders the progress of science and technology.

5 Conclusion and policy implications

Based on the theory of knowledge production function, using the panel data of 13 prefecture level cities in Jiangsu from 2006 to 2020 and based on the processing method of panel time series, the study constructs the measurement model of the influencing factors of innovation output in Jiangsu Province and analyzes the impact of R&D investment, environmental regulation, FDI, and other factors on innovation output in Jiangsu Province. Future policies can be carried out from following recommendations:

(1) Formulate a system of simultaneous growth of science and technology investment and fiscal revenue and strive to ensure that the growth rate of science and technology investment is higher than that of fiscal revenue. Financial investment in science and technology focuses on supporting basic, social welfare and cutting-edge technology research. Attach importance to the scientific research capacity building of public welfare industries and establish a stable support mechanism for scientific research of public welfare industries.

Priority should be given to funding key R&D projects with good market prospects. Strive to create a guiding environment conducive to enterprises' independent investment in R&D and drive social funds to continuously invest in the field of scientific and technological R&D. Promote enterprises to increase R&D investment. For enterprises whose R&D investment accounts for a certain standard of sales revenue in the current year, implement tax relief or give certain financial subsidies. Increase support for enterprises with R&D institutions, and cultivate innovative enterprises and a number of large enterprises and groups with strong independent innovation ability through the construction of enterprise R&D institutions and major project support. This makes enterprises truly become the main body of innovation and R&D investment.

(2) Improve the quality of human capital investment and the ability of science and technology transformation. The study found that due to the quality of the enterprise's own human capital and the ability to transform scientific and technological achievements, the investment in human capital may increase while the enterprise's technological innovation level does not change or even decline. The main reason is that the investment in human capital is of "quantity" and lack of "quality." Therefore, the enterprises should improve the level of introducing talents or human capital investment, so that human capital can effectively transform science and technology into productivity. The enterprises themselves can establish the vocational training and incentive mechanism supporting the enterprise to provide an efficient platform for high-level human capital. At the same time, a perfect talent introduction and assessment system shall be formulated to strictly check whether the introduced talents match the needs of the enterprise to avoid "redundant innovation attempts" and waste resources.

(3) Formulate appropriate environmental regulation measures. Presently, China is in an opportunity period of economic transformation and industrial upgrading. The formulation of appropriate regulatory measures is conducive to the effective development of technological innovation activities, to ensure the health and sustainable development of the economy. The impact of environmental regulation on technological innovation depends not only on the severity of environmental regulations, but also on the specific environmental regulation measures it implements "controlled" environmental regulation tools such as environmental standards and emission quotas lack sufficient incentives for enterprises due to their strong compulsion. The "incentivizing" environmental regulation tools such as emission trading and environmental subsidies provide continuous incentives for enterprise technological innovation, which is conducive to improving the innovation ability of enterprise pollution control. Therefore, the government needs to take differentiated environmental regulation measures according to the level of economic development, the degree of environmental pollution and the practical characteristics of different industries in different regions.

For areas with serious environmental pollution and pollution intensive industries, policymakers can adopt "controlled" environmental regulation tools to reduce the intensity of pollution emission, while for areas with less environmental pollution and technology intensive industries, policymakers can flexibly use sewage charges, user charges, and emission trading and other measures to encourage enterprises to innovate pollution control technology and production technology, and improve enterprises' pollution control ability and production efficiency.

(4) Choose foreign direct investment according to local conditions. The study also shows that the relationship between foreign direct investment and the technological innovation level of enterprises in Jiangsu Province is not significant. The main reason is that the absorption capacity of foreign direct investment and receiving enterprises is misplaced, and the threshold effect is obvious, which makes enterprises absorb foreign direct investment. This however does not effectively transform into productivity, or foreign investors' willingness to share technology with accepted enterprises, hence local enterprises are limited to the low end of the production chain.

Therefore, enterprises should selectively introduce foreign direct investment, not ignore environmental pollution for short-term interests, and introduce foreign direct investment for sustainable development from a long-term perspective. At the same time, enterprises should investigate the matching degree between their own enterprises and foreign-funded enterprises and introduce them targeted. The most fundamental point is that enterprises should strive to improve their ability of digestion, absorption and secondary innovation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JD designed the paper outline and wrote the main manuscript, SX made the revisions, checked the manuscript and will correspond with editors and other readers.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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