How exports affect green technology innovation in small and medium-sized enterprises? Evidence from Chinese companies listed on the growth enterprise market

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Abstract: Using matched data from China Stock Market and Accounting Research (CSMAR) and Wind databases, this paper explores the impact of exports on the green technology innovation (GTI) of small and medium-sized enterprises (SMEs). The mechanisms are analyzed through a two-way fixed effects model. First, exports contribute significantly to GTI of SMEs. Second, exports mainly contribute to GTI of SMEs by attracting government subsidies and increasing firms' environmental awareness. Third, from the perspective of heterogeneity, exports significantly positively impact GTI of SMEs especially in medium- and low-technology industries and in eastern China. The impact of exports on GTI is also examined by replacing core variables, modifying the sample for robustness testing, and utilizing both urban river density and distance from the center of the city to the nearest port as instrumental variables for endogeneity test. With the continuous development of international import and export trade, enterprises increase GTI research and development by attracting government subsidies, improving the quality of disclosed information, and increasing environmental awareness.

Keywords: Green technology innovation; SMEs; Export

1 Introduction

In September 2020, at the general debate of the 75th United Nations General Assembly, General Secretary Xi Jinping declared that China would adopt more vigorous carbon reduction policies and measures. Carbon dioxide emissions were stipulated to peak by 2030 and carbon neutrality was projected to be achieved by 2060. This declaration implies that China will make every effort to promote the comprehensive green transformation of its economic and social development, and unswervingly take the path of green, low-carbon, circular, and sustainable development. In 2021, the State Council issued the "Carbon Peak Action Program by 2030", which stipulates the in-depth implementation of green manufacturing projects, the vigorous promotion of green design, the improvement of the green manufacturing system, and the provision of important support for the realization of the "dual carbon" goal. Green innovation refers to the strategic behavior of enterprises to actively incorporate environmental awareness and responsibility into their daily production and operation; such enterprises reduce environmental pollution and create new market opportunities via green technology innovation (GTI), products, and processes. The increase of GTI also requires enterprises to consider environmental performance, improve their resource utilization efficiency, and realize the necessary means of sustainable development, applying the double externality characteristics of environmental protection and innovation. On the one hand, GTI can reduce total pollutant emissions directly. On the other hand, GTI also conveys the advantages of innovative activities that can comprehensively promote ecological protection as well as scientific and technological progress (Liu et al., 2023; Chen et al., 2006); moreover, GTI also emphasizes the unity of economic, social, and ecological benefits, and is characterized by high uncertainty and high risk (Jin et al., 2022). While pursuing economic benefits, green sustainability has become a focus of attention for all sectors. However, with the higher development rate of China's import and export of goods and services trade and the intensification of competition among enterprises, problems of ecological resource constraints and environmental pollution are worsening, despite advances in promoting China's urbanization and industrialization construction. The "Global Environmental Performance Index Report 2018" states that China ranks 120th out of 180 countries and regions globally in terms of the level of environmental performance of its economic development. Consequently, the issue of green and sustainable development needs to be urgently addressed.

Since the reform and opening up, China has always adhered to the basic state policy of opening up to the outside world and has grasped new opportunities for the development of economic globalization. At the beginning of the reform and opening up, China's import and export volume of goods trade was only 20.64 billion USD, 9.75 billion USD of which was export trade, accounting for less than 1% of the global goods trade volume at the time. In 2009, China's total export trade reached 1.2 trillion USD, ranking first in the world; in 2013, China ranked first in the global trade in goods, and in the same year, China also ranked first in the world in terms of innovation patent applications; in 2021, China's import and export of goods reached 39.1 trillion yuan. During the 40 years since the start of the reform and opening up, the total value of China's import and export of goods trade increased from 20.64 billion USD to 4.10 trillion USD, with an average annual growth rate of 14.5%. The proportion of global import and export trade increased from 0.77% to 11.48%, far exceeding the growth rate of the world economy in the same period. China's ranking of trade in goods in the world changed from 30th place before the reform and opening up to first place today.

Chinese companies are rapidly expanding their exports, and this rapid economic growth is mainly driven by exports. Growth enterprise market (GEM) small and medium-sized enterprises (SMEs) are small and mainly engaged in high-tech business with high growth capacity. At the same time, China extends preferential treatment to specialized, special, and new SMEs, which are defined as those with "specialization and refinement characteristics and novelty". In 2022, the State Intellectual Property Office and the Ministry of Industry and Information Technology jointly issued the "Several Measures on Intellectual Property Rights to Assist the Innovative Development of Specialized and New SMEs". These rights support specialized and new SMEs by applying the priority examination policy of intellectual property rights (such as patents), and by helping SMEs to obtain rights efficiently. Moreover, the pilot policy of carbon emission trading incentivizes enterprises in polluting industries in pilot areas to participate in GTI activities, which plays an important role in promoting SME exports and GTI. Export is beneficial for polluting enterprises to maintain a high level of GTI research and development (R&D) as well as green patent applications and acquisitions, so that they can secure market shares and maintain a leading position in the same type of industry (Popp, 2006). Exporting enterprises often face more stringent green standards in their trade import and export businesses, and are confronted with greater demand for green products, stronger market competition, and higher standards imposed on product health and quarantine regulations and other green trade barriers. Therefore, it is important to examine whether exporting promotes GTI in the context of the current "dual carbon" goal.

Enterprise GTI is the core driving force for adaptations to the development needs of the new era and for promoting high-quality economic development (Ba et al., 2022; Anu et al., 2023). The literature related to GTI mainly explored corporate motivation factors in terms of the digital economy (Shen & Tan, 2022), environmental regulation (Chen & Chang, 2022), demand factors, cost factors, advanced infrastructure (Wang et al., 2023), and competition (Matray, 2021). In terms of the digital economy, Chinese enterprises currently rank among the world's top patent applications and authorizations, and have made considerable breakthroughs in process innovation (Nambisan, 2017), model innovation (Autio et al., 2018), and product innovation (Ghasemaghaei & Calic, 2020). These breakthroughs will have clear dual effects on improving the quantity and quality of GTI (Ramzan et al., 2023). In terms of environmental regulation, although regulation-driven green innovation decreases the short-term rate of return, it emphasizes the innovation process of low energy consumption, low pollution, and low emissions, thus mitigating the problem of ecological degradation (Jin et al., 2022; Ali et al., 2020). Therefore, in the long run, environmental regulation can not only help enterprises to overcome the problem of green barriers faced by exports, but also gain a positive image and reputation thus enhancing their long-term competitive advantage (Testa et al., 2011). According to Porter's Hypothesis, based on the market status quo, environmental regulation can realize "innovation compensation" (Porter & Van de Linde, 1995), and the accumulation government environmental regulation can effectively resolve the constraints imposed by exports on enterprise GTI. In terms of cost orientation, a lower export costs can optimize the allocation of funds and increase investment to improve the GTI capacity of enterprises (Kesidou & Demirel, 2012). From the perspective of competitive advantage, despite constraints imposed by the regional policy system, high risk, and high uncertainty enterprises face when carrying out GTI (Pacheco & Dean, 2015), they will imitate the GTI strategy of the same type of enterprises in the process of digital transformation to maintain their competitive advantage. The results of GTI R&D can unlock the competitive advantage of product differentiation to a certain extent and can also

alleviate the negative externality problem in the production process, thus effectively solving the conflict between China's economic development and pollution, and realize important strategic support for the sustainable development of enterprises (Huang & Li, 2017).

Based on the New-New Trade Theory of the Melitz model, the economic effect of export on the GTI of enterprises can be realized in two ways: the self-selection effect and the export learning effect. The self-selection effect suggests that the cost of exporting can only be borne by high-productivity firms, and that high productivity determines firms' participation in exporting (Melitz, 2003). The export learning effect suggests that export enterprises can directly access the latest product information when participating in trade exchanges in the international market. Consequently, these enterprises can continuously obtain new knowledge in the process of cooperation (Bai et al., 2017; Wang & Ma, 2018), realize foreign knowledge inflow through the demonstration imitation effect and competition effect (De Loecker, 2013), and master competitors' advanced management experience and technology (Mendoza, 2010). Furthermore, the export learning effect is more significant for direct exporters than for indirect exporters. However, "export-induced innovation" is also contradicted by the fact that even if exporting firms can unlock "induced technology upgrading" through the export learning effect, this may be merely an investment made to cater to foreign buyers (Dai & Yu, 2013); thus, such innovation cannot be characterized as an improvement in firms' independent innovation capacity and green innovation awareness (Bustos, 2011).

The existing literature has mainly explored the influencing factors of corporate innovation from the perspectives of productivity, digital economy effect, and environmental regulation, which provides strong lessons and references for subsequent research. Existing studies have focused on the impact of exports on GTI in the context of macroeconomic development, while ignoring how exports may affect GTI in the special group of SMEs. Therefore, (1) in this paper, the financial statement data of GEM SMEs from the China Stock Market and Accounting Research (CSMAR) database are selected and merged with related data obtained from the Wind database to systematically examine the role of export on GTI of SMEs. (2) The mechanistic roles of subsidies and environmental awareness are examined through a mediated effects approach. (3) As most of the existing literature focused on technological innovation while ignoring the heterogeneity of innovation dimensions, this paper adds dummy variables to the heterogeneity analysis for breakthrough and incremental GTI to explore their heterogeneity separately.

To identify the existence of GTI in SMEs, it is important to explore the effect of exports on GTI. In terms of theoretical significance, (1) by studying the effect of exports on GTI of SMEs, the theoretical system of SMEs' GTI can be deepened, and the influence mechanism of exports on SMEs' green technology R&D and product R&D can be explored. (2) This research direction is of great importance for disclosing how SMEs can enhance their own value through GTI under international market competition. Such knowledge can uncover further understanding of the relationship between GTI and the competitive advantage of enterprises, thus providing a theoretical basis for enterprises to formulate sustainable development strategies. From a practical perspective, (1) exports can lead enterprises to develop in a more environmentally friendly and sustainable direction, promote the efficient use of resources, and reduce the burden on the environment. These achievements will help to realize the goal of sustainable development, enhance international competitiveness, and achieve higher market share and profits. (2) Practical research can provide a reference for governments to formulate policy measures with the goal to promote GTI in SMEs, such as providing financial support and tax incentives to further promote the development of the

green economy. (3) SMEs may need to collaborate with other firms and research institutions in other countries in the export process to promote technology and knowledge exchange as well as cooperation to jointly promote the development of GTI.

The possible marginal contributions of this paper are as follows. (1) In the empirical part, this paper innovatively chooses urban river density and distance from the center of mass of a city to the nearest port as instrumental variables for exporting. These metrics alleviate the problem of endogeneity in empirical studies, enabling more precise assessments of the intensity of the role of exports on GTI in SMEs. (2) In terms of research content, this paper explores the impact mechanism of export on SMEs' GTI from the perspective of government subsidies and firms' environmental awareness, thus enriching the path of the effect of exports on firms' GTI. (3) In terms of research dimensions, GTI is categorized into breakthrough and incremental innovations, to categorize and explore the effect of exports on different dimensions of GTI.

2 Theoretical Analysis and Research Hypotheses

2.1 The role of exports in GTI of SMEs

Enterprise innovation is based on the market demand development trend to improve the development of the export business (Su et al., 2017), R&D of production and operation of products that match market demand, optimization of their own resources, and social resources allocation, including institutional innovation, technological innovation, and management innovation. However, to widen the competitive gap and expand exports, enterprises rely excessively on the export learning effect, resulting in a lack of effective protection of intellectual property rights. Strengthening the intellectual property protection system will not only enhance the enterprise's innovation consciousness, but also weaken the status quo of imitation (Xue et al., 2021). In recent years, China has gradually increased the protection of intellectual property rights. GTI can help companies gain the competitive differentiation advantage, while at the same time playing a role in improving the surrounding environment. Because the GTI cycle is long and the inputs and risks are high, whether exporting impacts the GTI of SMEs depends on whether the benefits and risks faced by firms in undertaking export expansion can motivate them to undertake GTI. If the gains from exporting are high, firms will conduct further export expansion or use funds for their product scale production process. Without external shocks, i.e., green hidden trade barriers or domestic related environmental regulation policies, it is less likely that firms will spontaneously engage in GTI.

For exporters, the core product has the highest export value. Because export itself requires considerable financial support, when enterprises encounter strong pressure from external competition or hidden green trade barriers, they will adjust the proportion of corporate funds in the original arrangement and allocate more funds to GTI patent R&D to pursue a long-term competitive advantage. Green trade barriers are extensive and covert, thus restricting and prohibiting the import of foreign products based on protecting the ecological environment, natural resources, and the health and growth of plants and animals. When both an enterprise's exports and business revenue increase, to alleviate the green trade barriers the enterprise has faced or may face, or to address the competitive pressure of GTI originating from enterprises in the same industry, the enterprise will allocate funds to GTI R&D. Based on the above analysis, the following hypothesis is proposed:

Hypothesis 1: Exports are good for promoting green technology innovation in small and medium enterprises.

2.2 The role of exports in GTI of SMEs through government subsidies

The government will promulgate many preferential policies to encourage the development of enterprises, one of which is government subsidies. There are three main types of government subsidies, i.e., financial allocations, financial interest subsidies, and tax rebates. Among them, there are two main ways of financial interest rate subsidies. Firstly, government finance will pay the subsidized interest rate funds directly to beneficiary enterprises, which includes the government's support for the development of SMEs by providing subsidized interest rates for loans to SMEs. Secondly, the government finance allocates the subsidized interest rate funds directly to lending banks, which provide loans to enterprises, such as funds for poverty alleviation, at policy preferential interest rates below market rates.

An increase of enterprise export makes the government increase the subsidy. Growing exports of enterprises have led to the emergence of environmental problems, such as the treatment of sewage and raw materials as well as fuels in the operation of industrial enterprises. Environmental regulation can be compensated by innovation (Porter & Van der Linde, 1995), and the government has formulated a series of environmental regulation policies to benefit its root causes (Chen & Chang, 2022), calling on firms to focus on the ecological environment. Government subsidies are also one of the sources of corporate R&D investment, and the amount of government subsidies received by SMEs can be identified from the firms' regular announcements of non-operating income. The increase in export volume of enterprises will increase the severity of competition in the international market, and the problem of green trade barriers becomes more common. To encourage the growth of SMEs, local governments will be attracted to provide subsidies for enterprises, thus increasing their subsidy income.

Increased government subsidies promote GTI in SMEs. At present, hidden green trade barriers among countries inhibit enterprises from exporting; therefore, enterprises must strengthen their own GTI technology and product development. According to the economy of scale, export enterprises need to scale up production to obtain additional profits and reduce production costs through the economy of scale. This process needs to control R&D investment expenditure. Therefore, increasing enterprise exports will increase their GTI ability through government subsidies.

Hypothesis 2: Government subsidies are an important way to promote green technology innovation in small and medium enterprises through exports.

2.3 Exports act on GTI in SMEs through environmental awareness

GTI can promote ecological protection and technological progress (Umar & Safi, 2023). In recent years, the term "environmental protection" has appeared more frequently in national policies and government reports, and corporate reports are no exception. Environmental awareness is measured based on the number of environment-related terms mentioned in corporate reports and the ratio of the number of environment-related terms mentioned to the total number of words in corporate reports. These metrics reflect the degree of awareness for environmental pollution and awareness of environmental protection in the business process.

Exports increase the environmental awareness of enterprises. The relationship between environmental regulation and exports has become a focus of academic attention. First, the international trade market is becoming more dynamic; the number of new enterprises increases year by year and competition in the industry is becoming increasingly fierce. In China, the degree of competition in the same industry varies. The specific market environment affects the ability of an enterprise to operate, its industry behavior, and the level of environmental performance of its

operations. Therefore, whether an enterprise invests in environmental protection or not must be formulated according to the specific market environment as well as operating conditions. Under China's environmental regulations, the resource waste and environmental damage generated as a result of business operations have led to increased competition in the same industry. Among GEM-listed enterprises, the market power of SMEs tends to be balanced, exports increase, and enterprises are more willing to invest capital in environmental protection to improve their market share and gain long-term competitive advantage through GTI as well as green transformation and upgrading. Second, the improvement of enterprises' export business capacity incentivizes them to disclose more environmental information to diversify their green production and to increase their market share on larger scale trade barriers. This causes low capacity and low efficiency enterprises to withdraw from the international trade market because of export hindrance; they improve social recognition and establish a good image while fulfilling their social responsibility. Therefore, an increase of enterprise exports will promote SMEs to increase their ecological awareness.

Increased environmental awareness among enterprises leads to GTI activities. Industry competition plays an important role in the environmental awareness of firms. With increasing competition in various industries, the business risks faced by firms also increase and increased environmental awareness facilitates GTI activities by SMEs. The reasons are presented as follows: First, enterprises in more competitive industries will seize any opportunities that may enhance their competitiveness and expand their markets, and their disclosure of information about the environment will increase. Compared with corporate financial data, environmental information disclosure will more likely attract strong attention, as public life is closely related to the environment, and the behavior of various industries related to the environment will be supervised and analyzed by relevant interest groups. The export competition of enterprises can stimulate the public to pay attention to the environment. Second, when the frequency of environmental awareness statements in work reports increases significantly, enterprises will pay more attention to the development of GTI, and the number of patent applications and licenses related to GTI will increase. Then, enterprises will improve public trust and gain competitive advantages by increasing the transparency of environmental disclosure.

Hypothesis 3: Export improvement promotes green technology innovation in small and medium enterprises by increasing environmental concern.

The outline of this study is demonstrated in **Figure 1**.

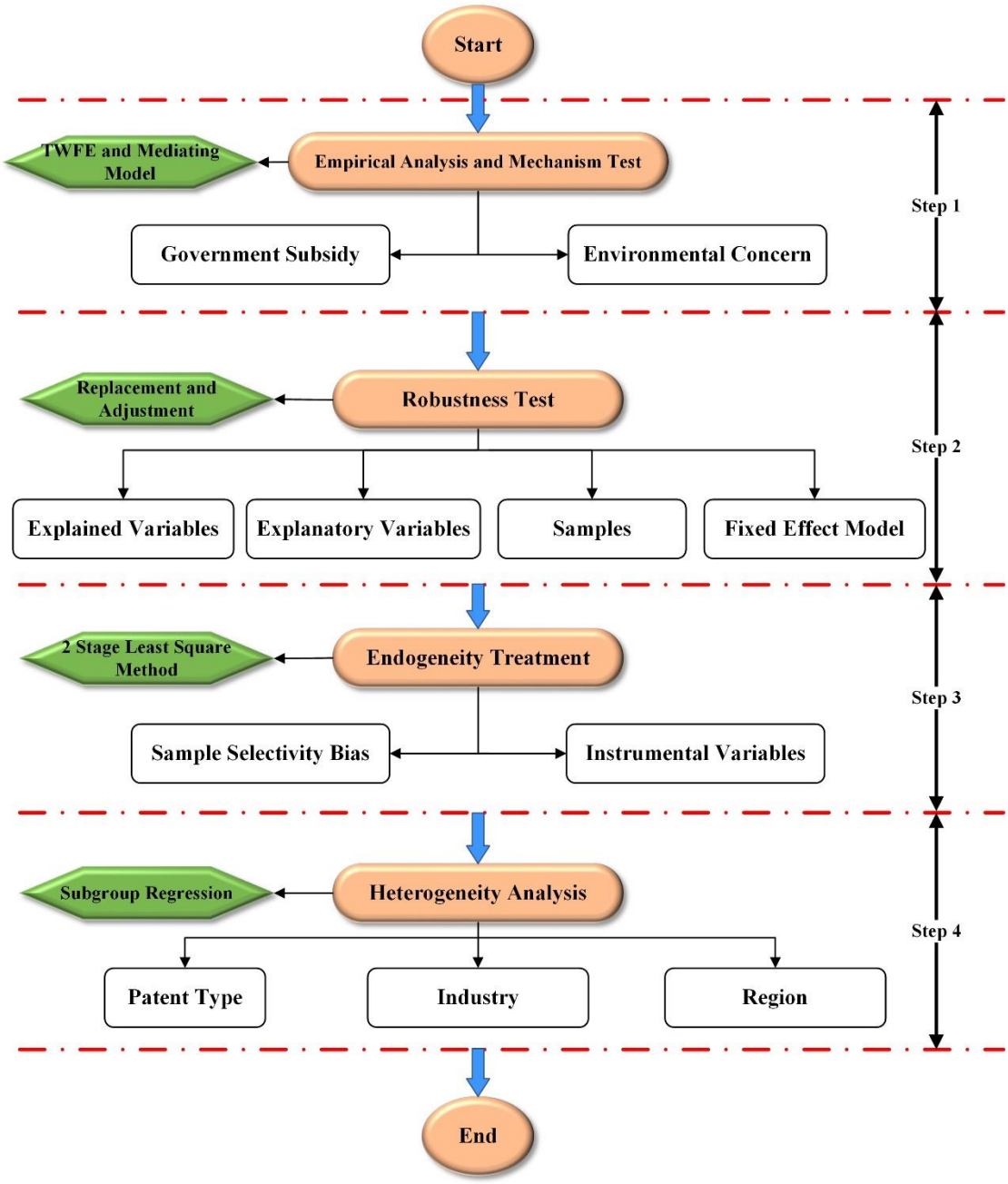

Figure 1. Research outline.

3 Research Design

3.1 Sample selection and data sources

There are two main reasons for choosing GEM listed companies as research sample:

First, SMEs are mostly manufacturing, industrial, and other polluting enterprises, and their production, sales, and export emissions have a large impact on the surrounding environment. Therefore, GEM SMEs are used as research sample to explore whether SMEs focus on GTI investment and whether SMEs impact local GTI through exports.

Second, using the "Regulations on SME Classification Standards (2017)" as a reference, most GEMs are SMEs, and Chinese SMEs play an important role in driving domestic economic growth and creating social employment opportunities. Since 2003, the average annual growth rate of the Chinese national economy has reached 9.5%, and the development rate of the individual private economy is much higher than the national economic growth rate.

The data interval used in this paper ranges from 2012 to 2020, and the enterprise level is divided into two parts: financial statement data of GEM SMEs and data related to corporate green patent innovation. Financial data of GEM listed companies are obtained from both the CSMAR database and WIND database, and corporate innovation data are obtained from the CSMAR database of R&D innovation of listed companies, the State Intellectual Property Office, and the patent search system of the State Intellectual Property Office of the People's Republic of China. City-level data are obtained from the National Bureau of Statistics and the China City Statistical Yearbook. In reference to common practice in the existing literature, these data are processed as follows: (1) Because of differences in the upper and lower limits and other aspects, companies that are specially treated as *ST, ST, and delisted during the sample period are excluded; (2) because of the special characteristics of the financial industry and differences in accounting treatment methods, financial enterprises are also excluded; (3) outliers that appear in the variables (Yu, 2015) and enterprises with less than eight employees are excluded; (4) enterprises with asset-liability ratios greater than 100 that face serious operating losses or huge compensation and are not suitable as samples for this research and are therefore excluded; (5) to eliminate the influence of extreme values on the research results, the original continuous data are processed with an upper and lower 1% tail reduction. After screening all data, panel data of 681 enterprises with 4649 observations were finally obtained.

3.2 Model setting

Before conducting empirical tests, the White test was firstly used to confirm the existence of heteroscedasticity and a p-value of 0.000 was obtained, which rejected the null hypothesis of homoscedasticity. Therefore, heteroscedasticity robust standard errors should be included in the regression. The presence of heteroscedasticity means that the traditional Hausman test cannot be used and a robust Hausman test is used instead with a p-value of 0.000. Thus, a two-way fixed effects model is selected as the econometric model in this paper to empirically test the role of corporate exports on GTI in GEM SMEs. Year and industry fixed effects are controlled and the benchmark model is shown as Equation (1).

$$lszl_{i,t} = \alpha_0 + \alpha_1 \ln\_exp_{i,t} + \alpha_2 Control_{i,t} + \mu_i + \lambda_t + \gamma_c + \varepsilon_{i,t} \quad (1)$$

Where, i denotes the firm and t denotes the year. The explanatory variable $lszl_{i,t}$ denotes the total amount of green patents obtained by firm i in year t; $\ln\_exp_{i,t}$ denotes the export value of firm i in year t, and the natural logarithmic form is used because of the large amount. $Control_{I,t}$ denotes the control variables, including firm's age to market, firm size, asset liquidity, urban population, urban environmental regulation, firm value, gearing ratio, intangible assets, share of primary shareholders, share of secondary shareholders, share of value added in secondary industry, and firm profitability. As firm exports are disturbed by time-varying municipal characteristics, to mitigate the omitted variable problem, μ_i denotes firm fixed effects, γ_c denotes year fixed effects, and λ_t denotes industry fixed effects, all three of which are used to control for factors that vary across firms, over time, and by industry, respectively. ε_{it} denotes the random error term.

Therefore, the coefficient denotes the degree of influence of firm exports on GTI in GEM SMEs, which is the core variable examined in this paper.

3.3 Variable description

3.3.1 Explained variables

GTI in SMEs (lszl) is used as explanatory variable, and although the innovation behavior of firms can be obtained directly from the data in the form of the amount of R&D investment, this metric is considered a sunk cost and cannot be used to assess the true innovation capacity of firms (Hall et al., 2000). Therefore, this variable is used to indicate the innovation capacity of firms through their innovation outcomes, i.e., the number of patents (Hirshleifer et al., 2013). The data are obtained from the CSMAR database of R&D innovation of listed companies and the State Intellectual Property Office, and are measured using the number of green patents of firms plus one to take the logarithm (Brunnermeier & Cohen, 2003). The year of patent granting is used as the year of patent output. The ratio of the number of utility model patents to the total number of corporate patents is used to measure the value of GTI in the robustness test, and the number of green invention patents obtained plus one (logarithmically transformed) is used to measure corporate green breakthrough innovation (Invention). The number of utility model patents obtained plus one (logarithmically transformed) is used to measure corporate incremental innovation (Non-Invention).

3.3.2 Explanatory variables

The export value of GEM listed companies (ln_exp) is used as explanatory variable. The data are obtained from the CSMAR database, and the export amount of listed companies is classified and filtered to finally obtain the export amount of different companies. Overseas operating income of GEM listed companies is used as the explanatory variable for the robustness analysis.

3.3.3 Control variables

Control variables are selected based on established literature (Bu et al., 2020; Dong & Wang 2019; Hutton et al., 2009). The firm-level control variables are firm's market age (age) using the current period end year - year of firm establishment; firm size (size) of R&D investment to assess the level of technological innovation development of the firm; firm asset liquidity (liqu) is the ratio of current assets to current liabilities (in logarithmic form); firm value (ln_tbq) is the logarithmic measure of the firm Tobin's Q value to express the firm's social (ln_tbq) and is measured by the logarithm of the firm's Tobin's Q value, which expresses the firm's social value creation ability; gearing (lev) is measured by the ratio of total liabilities to total assets, where moderate indebtedness allows the firm to have more abundant funds for the development of innovative activities (Meuleman & De Maeseneire, 2012); intangible assets (ia) is measured by the proportion of intangible assets to total assets; the first shareholder and the second shareholder are both executives, whose overseas experience, long-term orientation, and other factors substantially impact corporate GTI. This can influence the business development, expressed by the shareholder's shareholding ratio; corporate profitability (oi) is expressed by the corporate operating profit ratio, which is the proportion of main business income to total profit.

City-level control variables are city population (ln_pop) in the form of city year-end population (in logarithmic form); city environmental regulation (ln_so2) is measured using city-level emissions per unit of economic output (in logarithmic form); and industrial structure (second) is the of city-level value-added secondary industry as a share of city GDP.

3.3.4 Mediating variables

To further explore the mechanism of how export influences the GTI of SMEs, this paper uses government subsidies (subsidy) and indicators reflecting enterprises' environmental concerns as channel variables. Government subsidies are obtained using the CSMAR database of enterprises' regular announcements of non-operating income. When the economic development prospect is poor, enterprises will increase the amount of tax they pay, and will thus receive more government subsidies in the following year. The number of words related to environmental protection (cp) such as carbon dioxide emissions, sulfur dioxide, haze, and pollution as well as the proportion of the number of words related to environmental protection to the total number of words in the report (cpzb) in the enterprise work report are used to reflect the enterprises' environmental protection awareness; a greater frequency of words related to environmental protection indicates that these enterprises pay more attention to environmental protection.

Descriptions of all variables are provided in **Table 1**.

Table 1. Variable description.

Variable Type	Variable Symbols	Variable Name	Variable Definition
Explained variables	lszl	GTI	Ln (total number of green patents + 1)
Explanatory variables	ln_exp	Enterprise export capacity	Exports of GEM-listed companies
	lnfexp		Overseas operating revenue of GEM-listed companies
Control variables	age	Business age	Current period-end year - year of business establishment
	size	Enterprise size	Total enterprise assets are logarithmically transformed
	ln_pop	City population	City population (logarithmically transformed)
	liqu	Fluidity	Current assets / current liabilities
	ln_tbq	Tobin Q	Take logarithms and define enterprise value creation
	ia	Intangible assets	Corporate intangible assets / total assets
	gd1	First shareholder	Corporate first shareholder shareholding / total shares
	gd2	Second shareholder	Shareholding of the second shareholder of the enterprise / total shares
	lev	Gearing ratio	Total liabilities as a percentage of total corporate assets
	second	Industry structure	Urban secondary industry value added / GDP
	ln_so2	Environmental regulation	Urban sulfur dioxide emissions (logarithmically transformed)

	oi	Operating margin	Enterprise main business income / total revenue
Intermediate variables	subsidy	Government subsidies	Enterprises regularly announce non-operating income
	cp	Environmental keywords	Environmental glossary in enterprise work reports
	cpzb	Environmental word frequency	Environmental glossary in work report / total words in report

4 Empirical Analysis

4.1 Descriptive statistics

Table 2 provides descriptive statistics of the variables in this paper. The explanatory variable GTI (lszl) of GEM listed companies has a minimum value of 0, a maximum value of 3.258, and a mean value of 0.376. These values indicate that the innovation ability of Chinese GEM listed companies is generally low and there is room for further development. The export values of different companies show that a large difference exists in export delivery business between companies, with a minimum of 11.41 and a maximum of 21.98.

Because samples shorter than one year are excluded, the minimum age of enterprises listed is 1 year, and the maximum is 10 years; the gap of enterprise size is small, as most SMEs were examined, with a mean value of 7.644, a minimum value of 6.149, and a maximum value of 9.792. The minimum value of the urban population level is 5.353 and the maximum value of 7.313. The standard deviation of enterprise asset liquidity is 0.702 with a mean value of 0932. The enterprise value (ln_ tbq) varies widely, with a minimum value of 0.0396 and a maximum value of 2.072. Enterprise intangible assets (ia) has a minimum value of 1484 and a maximum value of 217,324, which represents a large difference in the proportion of intangible assets among different enterprises. The maximum and minimum values of the shareholding ratio of the first and second shareholders vary widely, indicating that there are many differences in the shareholding of executives in enterprises. Enterprise asset and liability ratio (lev) has a mean value of 0.323, a maximum value of 0.740, and a minimum value 0.0502. Enterprise industrial structure (second) has a minimum value of 0 and a maximum value of 60.46. Environmental regulation (ln_so2) has a standard deviation of 1.412, indicating that the difference between different enterprises emissions is small. Enterprise profitability (oi) has a mean value of 0.887 and a standard deviation of 0.269.

Enterprises receiving government subsidies (subsidiy) has a minimum value of 5.635, a maximum value of 18.39, and an average value of 15.00; these values indicate that most enterprises receive little in government subsidies, which is probably because of differences in the refund time of value added tax. The maximum and minimum values of environmental vocabulary (cp) and environmental word frequency (cpzb) of enterprise work reports show little difference. This result shows that the business development process of environmental concerns is small, indicating that the level of environmental protection awareness in the process of business development is low.

Table 2. Descriptive statistics.

	Average value	Standard deviation	Minimum value	Maximum value	Sample size
lszl	0.376	0.758	0	3.258	4,666
ln_exp	17.87	2.145	11.41	21.98	4,563
age	4.421313	2.62418	1	10	2,834
size	7.644	0.800	6.149	9.792	3,144
ln_pop	6.696	0.510	5.353	7.313	1,816
liqu	0.932	0.702	-0.312	2.923	3,145
ln_tbq	0.746	0.446	0.0396	2.072	3,059
ia	54,961	41,326	1,484	217,324	3,131
gd1	31.06	13.67	8.480	76.92	3,639
gd2	11.43	6.510	1.610	31.51	3,628
lev	0.323	0.170	0.0502	0.740	3,059
second	33.82	18.58	0	60.46	2,201
ln_so2	9.868	1.412	6.886	12.39	2,084
oi	0.887	0.269	-0.794	1.283	3,145
subsidy	15.00	1.919	5.635	18.39	2,113
cp	3.617	0.350	2.565	4.407	3,887
cpzb	0.00605	0.00175	0.00256	0.0104	3,887

4.2 Regression results of export on GTI of SMEs

Table 3 reports the results of the baseline regressions, where Column (1) presents the results without controlling for firm, year, and industry fixed effects. The empirical results show that the estimated coefficients are significantly positive at the 1% level when the control variables are not included, suggesting that exports have a significant promoting effect on GTI in SMEs. This implies that an increase in firm exports promotes firms to carry out GTI, which in turn increases the number of green patents of firms. While still not including control variables, Column (2) controls for firm, year, and industry fixed effects so that the results are not affected by changes in the firm itself, the industry it is in, and time. The results indicate that exports promote GTI in SMEs, and the estimated coefficient is significantly positive at the 5% level. In Column (3), control variables such as age at IPO, firm size, and asset liquidity are added to the regression on the basis of controlling for firm, year, and industry fixed effects. The estimated coefficients are still significantly positive at the 5% level, and each 10% increase in exports is associated with a 21.7% increase in the firm's GTI capacity, i.e., its number of green patents. The greater the export capacity of the enterprise, the higher the total number of green patents, which is more conducive to the enterprise to overcome the green trade barriers of target exporting countries. This also improves the competitiveness of the enterprise. First, this result contrasts with existing studies where trade openness has a significant negative impact on regional GTI and this inhibitory effect is characterized by a nonlinear evolution of decreasing marginal efficiency (Han et al., 2023). Second, the existing literature mostly focused on A-share listed companies (Kesidou & Demirel, 2012; Wang & Ma, 2018) when exploring the impact of exports on environmental innovation; this paper explores the impact of the exports of SMEs on GTI and conducts a mechanism test through government subsidies and environmental concerns. Finally, the following analysis of this paper replaces the explained variables to categorize different types of GTI and the explanatory variables; municipalities and years of stock market

crashes are excluded to adjust the sample size, and the "industry × year" high-dimensional fixed-effects model is applied to conduct a robustness test. The result shows that exports have a significant positive impact on corporate GTI.

On the one hand, for SEMs, although the trade barriers between many countries resulting from the World Trade Organization principles have been eased, there are still hidden green trade barriers in many countries. In the export market for environmental protection, sustainability requirements are high. The existence of such unwritten rules imposes the need for export enterprises to invest funds into GTI and R&D for the sake of their own export business development and the innovation of resources. On the other hand, China preferentially treats specialized SMEs over manufacturing enterprises. A-share listed firms that have been studied in the literature, and the results motivate SMEs to enhance their GTI conceptual choices to reach international market standards and satisfy customer demands (Su et al., 2017). In international markets, GTI by SMEs not only enhances their brand image but also enables them to gain sustainable competitiveness. For the government, an increase in enterprise exports is conducive to enhancing the market share of Chinese companies, thus increasing China's share of trade in the international market. To attract advanced technology from abroad and alleviate the hindrance of green barriers from abroad, the Chinese government will increase measures to promote GTI among enterprises. As a result, the total number of green patents obtained by companies increases significantly.

Table 3. Baseline regression results.

	(1)	(2)	(3)
	lszl	lszl	lszl
ln_exp	0.0780***	0.0273**	0.0527**
	(6.0716)	(2.2209)	(2.1770)
age			-0.1568***
			(-5.1739)
ln_pop			0.5826
			(1.3175)
size			0.1021
			(1.0550)
liqu			0.0518
			(0.7468)
ln_tbq			0.2296***
			(2.6783)
ia			-0.0000
			(-0.8009)
gd1			0.0121*
			(1.7637)
gd2			-0.0064
			(-0.5516)
lev			0.0687
			(0.1817)
second			-0.0046
			(-1.2847)

ln_so2			-0.0155
			(-0.3819)
oi			-0.0282
			(-0.3606)
Constant	-1.0104***	-0.3055	-5.1001
	(-4.4016)	(-1.4343)	(-1.5065)
Observations	4,563	4,563	1,132
R-sq	0.0255	0.0715	0.0665
Corporate fixed effects	NO	YES	YES
Year fixed effects	NO	YES	YES
Industry fixed effects	NO	YES	YES

Note: ***, ** and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

4.3 Mechanism analysis

Implementing the above theories, to further study the influence path of exports on GTI of SMEs and test whether exports affect the development of GTI of enterprises through intermediate channel variables, this paper uses the intermediary effect test method (Wen et al., 2014). The intermediary effect model with government subsidies as the intermediary variable is established, and the model is shown in Equations (2) and (3):

$$subsidy_{i,t} = \beta_0 + \beta_1 \ln\_exp_{i,t} + \beta_2 Control_{i,t} + \mu_i + \lambda_t + \gamma_c + \varepsilon_{i,t} \quad (2)$$

$$lszl_{i,t} = \delta_0 + \delta_1 \ln\_exp_{i,t} + \delta_2 subsidy_{i,t} + \delta_3 Control_{i,t} + \mu_i + \lambda_t + \gamma_c + \varepsilon_{i,t} \quad (3)$$

where the channel variable $subsidy_{i,t}$ denotes the amount of government subsidies received by firm i in year t, obtained from the CSMAR database where firms post their non-operating income; the other control variables remain consistent with the benchmark regression. Column (1) in **Table 4** shows the results of the benchmark regression without mediating variables, which are identical to the results shown in Column (3) in **Table 3**, indicating that exports have a facilitating effect on the development of GTI in SMEs. In Column (2), the estimated coefficient of ln_exp is significantly positive at the 5% significance level when government subsidies (subsidiy) are included as explanatory variable; this result indicates that an increase in firm exports is beneficial in attracting government subsidies. On the one hand, the increase in enterprise exports is conducive to achieving a trade surplus and improving international competitiveness, and thus the government is more inclined to provide subsidies to help enterprises invest in R&D; on the other hand, the increase in enterprise exports results in more severe industry competition and environmental problems are easily ignored. The increase in government subsidies is conducive to enterprises having sufficient funds to carry out GTI activities.

In Column (3), government subsidies are added to the baseline regression equation, and the results are significant at the 5% significance level, indicating that the presence of government subsidies results in an increase in enterprises' exports to promote their GTI activities. On the one hand, trade barriers between countries lengthen enterprises' export cycles. Although China has

signed many successful trade agreements, such as the Regional Comprehensive Economic Partnership Agreement, additional hidden green trade barriers still inhibit enterprises' exports; therefore, enterprises have to strengthen their own GTI and product development. According to the economy of scale, export enterprises have to scale production to obtain profit surplus and reduce production costs through economies of scale, a process that requires control of R&D input expenditures; on the other hand, the government will implement a series of measures to encourage enterprises to export, such as export credit, export tax exemptions, and subsidies. Because of these government subsidies, the problem of enterprise R&D funds is alleviated and funds are sufficient to support GTI activities; therefore, the increase of enterprise exports will improve their own GTI capability by attracting government subsidies.

Table 4. Intermediary effect model 1.

	(1)	(2)	(3)
	lszl	subsidy	lszl
ln_exp	0.0527**	0.1023**	0.0516**
	(2.1770)	(1.9751)	(2.0330)
subsidy			0.0014
			(0.0630)
age	-0.1568***	-0.0579	-0.1659
	(-5.1739)	(-0.7868)	(-1.3321)
ln_pop	0.5826	-0.2952	0.4843
	(1.3175)	(-0.3594)	(1.2847)
size	0.1021	0.4173**	-0.0006
	(1.0550)	(2.1105)	(-0.0075)
liqu	0.0518	0.3404**	0.0167
	(0.7468)	(2.4747)	(0.2096)
ln_tbq	0.2296***	0.1451	0.1477*
	(2.6783)	(0.8588)	(1.6792)
ia	-0.0000	0.0000	-0.0000
	(-0.8009)	(0.4927)	(-0.9217)
gd1	0.0121*	0.0044	0.0081
	(1.7637)	(0.2725)	(1.2709)
gd2	-0.0064	-0.0017	-0.0066
	(-0.5516)	(-0.0942)	(-0.7974)
lev	0.0687	1.8955**	0.1532
	(0.1817)	(2.1782)	(0.3702)
second	-0.0046	0.0127	-0.0043
	(-1.2847)	(0.8855)	(-0.8083)
ln_so2	-0.0155	-0.0090	-0.0096
	(-0.3819)	(-0.1128)	(-0.2103)
oi	-0.0282	0.0285	0.0121
	(-0.3606)	(0.2125)	(0.1311)
Constant	-5.1001	11.3528*	-3.5725
	(-1.5065)	(1.9635)	(-1.3730)

Observations	1,132	925	925
R-sq	0.0665	0.4551	0.0555
Corporate fixed effects	YES	YES	YES
Year fixed effects	YES	YES	YES
Industry fixed effects	YES	YES	YES

Note: ***, ** and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

Environmental awareness is used as a mediating variable and the model is shown in Equations (4) and (5). In Column (1) of **Table 5**, firms' awareness for environmental protection is treated as an explanatory variable. The estimated coefficient is significantly positive at the 1% significance level, indicating that an increase in firms' exports raises the awareness for environmental protection. On the one hand, the dynamics of the international trade market gradually increase, industry competition is intense. Any enterprise is in a specific market environment, which is related to the business capacity, industry behavior, and the level of performance of the business environment; therefore, the enterprise environmental protection investment must be formulated according to the specific market environment as well as prevailing business conditions. If exports increase, enterprises are more willing to invest funds in environmental protection through GTI, green transformation, and upgrading to improve their market share and obtain long-term competitive advantage; on the other hand, the increase in the export business ability of enterprises makes them tend to disclose more environmental information for a larger increase in market share. This diversifies the creation of green trade barriers, causing different enterprises to increase their environmental awareness.

Column (3) incorporates environmental concern into the regression equation and the estimated coefficients pass the 5% significance level test, indicating that environmental concern promotes firms' GTI activities. Companies in more competitive industries seize opportunities that may enhance their competitiveness and expand their markets; consequently, their disclosures in response to environmental information increase, which attracts more attention than corporate financial data. When the frequency of environmental awareness terminology in work reports increases significantly, companies will focus more on GTI development, and the number of patent applications and licenses related to GTI will increase.

$$cp_{i,t} = \beta_0 + \beta_1 \ln\_exp_{i,t} + \beta_2 Control_{i,t} + \mu_i + \lambda_t + \gamma_c + \varepsilon_{i,t} \quad (4)$$

$$lszl_{i,t} = \delta_0 + \delta_1 \ln\_exp_{i,t} + \delta_2 cp_{i,t} + \delta_3 Control_{i,t} + \mu_i + \lambda_t + \gamma_c + \varepsilon_{i,t} \quad (5)$$

Table 5. Intermediary effect model 2

(1)	(2)	(3)	(4)

	cp	cpzb	lszl	lszl
ln_exp	0.0286***	0.0002***	0.0559**	0.0552**
	(3.1100)	(3.8099)	(2.5408)	(2.5008)
cp			-0.1110	
			(-1.3176)	
cpzb				-14.6867
				(-0.8455)
age	0.0313	0.0006**	-0.1533	-0.1481
	(0.5913)	(2.3073)	(-1.2169)	(-1.1709)
ln_pop	-0.6921***	-0.0062***	0.5057*	0.4919
	(-5.4972)	(-10.1045)	(1.6588)	(1.5465)
size	-0.0183	-0.0001	0.1000	0.1004
	(-0.5840)	(-0.7646)	(1.3452)	(1.3485)
liqu	-0.0093	-0.0001	0.0508	0.0499
	(-0.3150)	(-0.9207)	(0.7210)	(0.7073)
ln_tbq	0.0053	-0.0000	0.2301***	0.2293***
	(0.1582)	(-0.1051)	(2.8648)	(2.8524)
ia	-0.0000	-0.0000	-0.0000	-0.0000
	(-0.2958)	(-0.1979)	(-0.7996)	(-0.7913)
gd1	0.0016	0.0000	0.0123**	0.0122**
	(0.6524)	(0.2165)	(2.0520)	(2.0272)
gd2	0.0067**	0.0000	-0.0057	-0.0062
	(2.0218)	(1.1214)	(-0.7203)	(-0.7818)
lev	-0.0390	-0.0007	0.0644	0.0580
	(-0.2567)	(-0.9963)	(0.1784)	(0.1604)
second	-0.0043**	0.0000***	-0.0051	-0.0041
	(-2.4334)	(3.9781)	(-1.2207)	(-0.9819)
ln_so2	-0.0498***	-0.0001	-0.0210	-0.0174
	(-2.7500)	(-1.4631)	(-0.4869)	(-0.4038)
oi	-0.0137	0.0000	-0.0298	-0.0281
	(-0.3720)	(0.0542)	(-0.3409)	(-0.3217)
Constant	7.9924***	0.0421***	-4.2129*	-4.4814**
	(9.2325)	(10.0256)	(-1.9458)	(-2.0509)
Observations	1,132	1,132	1,132	1,132
R-sq	0.3779	0.4433	0.0685	0.0673
Corporate fixed effects	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES

Note: ***, ** and * indicate 1%, 5% and 10% significance levels, respectively; standard errors are shown in parentheses.

5 Robustness Testing and Endogeneity Treatment

5.1 Robustness test

To further test the reliability of the estimation results, robustness tests are performed by replacing explanatory variables, adjusting the sample, and replacing the fixed effects in four different ways including time, firm, and industry fixed effects.

5.1.1 Replacing explained variables

In this paper, the explained variable GTI is replaced by the enterprise green patent share (lszb), which is expressed as the ratio of the number of green patents obtained by the enterprise during the accounting period to the total number of patents obtained by the enterprise in that same period. As shown in Column (1) of **Table 6**, enterprise export has a significant promoting effect on the enterprise green patent share, and the estimated coefficient is significantly positive at the 5% level. This result indicates that an increase of enterprise exports promotes the development of enterprises' GTI capability. In addition, the signs of the coefficients of other control variables are basically consistent with the benchmark regression results.

5.1.2 Replacing explanatory variables

The volume of corporate exports is replaced by overseas business income of GEM SMEs, which is obtained from the WIND database. According to Column (2) of **Table 6**, the estimated coefficient of the core explanatory variable ln_exp is positive and passes the 5% significance level test. This result indicates that corporate exports significantly contribute to corporate GTI.

5.1.3 Adjusting samples

This paper also uses adjusted samples for robustness testing. The results shown in Column (3) of **Table 6** indicate that after excluding the municipalities directly under the central government, the sample will be regressed. The municipality directly under the central government itself has a higher level of development and a superior trade environment; therefore, it pays more attention to the environment than other cities. The estimated coefficients of the core explanatory variables are significantly positive after excluding municipalities directly under the central government and pass the 5% significance level. The results in Column (4) show the regression of the sample after excluding the stock market crash; the core explanatory variables pass the 1% significance test and the estimated coefficients are higher than the baseline regression, indicating that the year of the stock market crash had a negative impact on corporate GTI.

5.1.4 Adjusting the fixed effects model

To mitigate the impact of macro-environmental changes on the results of baseline regression, a robustness analysis is conducted by controlling for firm, year, and industry fixed effects based on a higher-order joint fixed effects model of "industry*year". As shown in Column (5) of **Table 6**, the regression results are significantly positive at the 5% level, which still indicates the promotion effect of exports on GTI of SMEs; the baseline regression results are robust.

Table 6. Robustness tests.

	(1)	(2)	(3)	(4)	(5)
	lszb	lszl	lszl	lszl	lszl
ln_exp	0.0099**		0.0546**	0.0748***	0.0532**
	(2.0379)		(2.0527)	(2.6801)	(2.0909)
lnfexp		0.0531**			
		(2.1886)			
age	0.0080	-0.1570***	-0.1890	-0.1125	-0.0637
	(0.2838)	(-5.1880)	(-1.6223)	(-0.7766)	(-0.8451)
ln_pop	-0.0431	0.5764	1.1319*	0.3409	0.1232
	(-0.6457)	(1.3039)	(1.6943)	(1.0253)	(0.2693)
size	-0.0161	0.1004	-0.0021	0.1455	0.2177*
	(-0.9715)	(1.0352)	(-0.0204)	(1.5177)	(1.8328)
liqu	0.0094	0.0512	-0.0038	0.1023	0.1158
	(0.6009)	(0.7385)	(-0.0427)	(1.0550)	(1.4039)
ln_tbq	0.0067	0.2290***	0.2210**	0.3352***	0.2796***
	(0.3755)	(2.6734)	(2.1008)	(3.0962)	(2.7799)
ia	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(-1.4601)	(-0.7902)	(-0.6602)	(-0.6180)	(-0.7639)
gd1	0.0039***	0.0120*	0.0195**	0.0143**	0.0172*
	(2.9424)	(1.7493)	(2.4575)	(1.9756)	(1.8904)
gd2	-0.0011	-0.0065	-0.0200**	-0.0077	-0.0066
	(-0.6117)	(-0.5556)	(-2.1546)	(-0.7816)	(-0.4529)
lev	0.0746	0.0662	-0.0085	0.1261	0.2401
	(0.9256)	(0.1748)	(-0.0182)	(0.2606)	(0.5457)
second	-0.0015	-0.0045	-0.0038	-0.0027	-0.0095**
	(-1.6393)	(-1.2579)	(-0.5800)	(-0.5684)	(-2.1849)
ln_so2	-0.0097	-0.0151	-0.0208	-0.0187	-0.0165
	(-1.0143)	(-0.3715)	(-0.3009)	(-0.3541)	(-0.3167)
oi	-0.0108	-0.0275	0.0125	-0.0888	0.0306
	(-0.5534)	(-0.3519)	(0.1074)	(-0.6560)	(0.3517)
Constant	0.3374	-5.0581	-7.9210*	-4.4039*	-2.8192
	(0.7348)	(-1.4963)	(-1.7565)	(-1.9019)	(-0.8208)
Observations	1,132	1,132	586	806	1,132
R-sq	0.0410	0.0668	0.0864	0.0951	0.2258
Corporate fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES
Industry*Year FE	NO	NO	NO	NO	YES

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

5.2 Endogenous processing

5.2.1 Sample selectivity bias

Because of the existence of a sample self-selection problem of whether firms engage in R&D innovation, firms' behavior of conducting R&D is non-random following the combination of external economic environment and internal policy preference base. Therefore, this paper uses the Heckman two-stage model to overcome sample selectivity bias and to estimate the innovative R&D production of exporting firms. The first stage is the Probit model, which indicates whether a dummy variable enterprise carries out R&D investment (rd). This paper applies the following considerations: the enterprise green patent represents the results researched by the enterprise, and is an important reflection of the enterprise's own GTI ability; however, if the enterprise has no patent output, this does not mean that the enterprise did not carry out green input. Based on data availability, the amount of enterprise R&D investment is used as the explained variable; the inverse Mills ratio (IMR) is obtained by using the amount of enterprise R&D investment as explanatory variable. In the second stage, regression model analysis is conducted using the amount of enterprise innovation input as explanatory variable. The IMR index obtained in the first stage is incorporated into the second stage regression to overcome the problem of sample selection bias and estimate the innovation capability of the enterprise.

The first stage model is set up as follows:

$$\Pr\left(rd_{if_{i,t}}=1\right)=\delta_0+\delta_1\ln\_exp_{i,t}+\delta_2 Control_{i,t}+\mu_i+\lambda_t+\gamma_c+\varepsilon_{i,t} \quad (6)$$

The second stage model is set up as follows:

$$\mathrm{E}\left(Y_{f,t}|rd_{if_{i,t}}=1\right)=\delta_0+\delta_1\ln\_exp_{i,t}+\delta_2 IMR_{i,t}+\delta_3 Control_{i,t}+\mu_i+\lambda_t+\gamma_c+\varepsilon_{i,t} \quad (7)$$

where, $Y_{f,t}$ denotes the SME innovation capacity, measured by the amount of firm R&D investment; $IMR_{i,t}$ is the IMR obtained from the first stage regression of the Heckman model. The results of the first stage estimation are shown in Column (1) of **Table 7**, where the estimation results indicate the relationship between firm exports and SME innovation capacity, i.e., exports promote SME innovation inputs, and the estimated coefficient is significantly positive at the 5% level. The Heckman second stage estimation results are presented in Column (2), where the IMR rejects the original hypothesis at the 10% significant level. This result indicates the existence of sample selection bias and therefore the need for Heckman model testing. The core explanatory variables are significantly positive at the 1% level, suggesting that increased exports can significantly promote SME innovation inputs.

Table 7. Heckman two-stage regression results.

	First	Second
	L.rdif	ln_rd
ln_fexp	0.8495**	0.0348***
	(1.9711)	(3.3964)
imr		0.0527*
		(0.7554)
age	0.3646	0.0109
	(0.6743)	(1.0333)
ln_pop	-6.2317*	0.0062
	(-1.7178)	(0.0971)
size	-1.6315	0.7007***
	(-1.2998)	(21.5615)
liqu	-1.4630	0.0522
	(-0.8024)	(1.3827)
ln_tbq	1.8193	0.0905***
	(1.1860)	(3.1972)
ia	0.0005*	0.0000
	(1.7123)	(1.0467)
gd1	-0.0170	-0.0056**
	(-0.3670)	(-2.4448)
gd2	-0.1561	-0.0009
	(-1.5231)	(-0.2453)
lev	-4.2583	0.2077
	(-0.4267)	(1.1142)
second	0.0249	-0.0006
	(0.5741)	(-0.8082)
ln_so2	-1.2101	-0.0764***
	(-1.5496)	(-4.9818)
oi	-0.5288	0.0165
	(-0.2228)	(0.3428)
Constant	55.1996**	12.3973***
	(2.0108)	(24.4151)
N	845	1,121

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

5.2.2 Instrumental variables

In Column (1) of **Table 8**, urban river intensity is chosen as an instrumental variable for firms' export business to be regressed. Urban river intensity (river) data are obtained from the National Center for Basic Geographic Information, and this variable remains largely unchanged over time. As shown in Column (1) of **Table 9**, the value of the Cragg-Donald statistic for the weak instrumental variable test using urban river density as the instrumental variable is 21.070, which exceeds the critical value of 16.38 under 10% bias, i.e., the hypothesis of the weak instrumental

variable is rejected, and the original core variable has endogeneity problems. The instrumental variables were included in the regression equation as shown in Column (2) of **Table 8**. The regression results were significantly positive and passed the 5% estimation level test. This result shows that urban river density significantly contributes to the export expansion of local enterprises and is more conducive to promoting the development of GTI, i.e., the higher the density of urban rivers, the more local understanding of the impact of urban transportation on export convenience and the more enterprises tend to engage in export trade.

Table 8. Instrumental variable regression results.

	(1)	(2)
	River density	Port distance
ln_exp	0.3440***	0.4369**
	(2.9445)	(2.3909)
age	-0.0475**	-0.0565**
	(-2.4003)	(-2.3162)
ln_pop	0.0521	0.0621
	(0.5266)	(0.5128)
size	-0.1003	-0.1439
	(-1.1302)	(-1.1158)
liqu	0.2525***	0.2663***
	(2.7990)	(2.8686)
ln_tbq	0.0867	0.0979
	(0.9218)	(0.9059)
ia	-0.0000**	-0.0000*
	(-2.0131)	(-1.7310)
gd1	-0.0036	-0.0034
	(-1.2923)	(-1.0762)
gd2	-0.0185***	-0.0195**
	(-2.8671)	(-2.3966)
lev	1.3964***	1.2168**
	(3.0407)	(2.2071)
second	-0.0027	-0.0048
	(-0.5461)	(-0.7827)
ln_so2	-0.0093	0.0056
	(-0.2529)	(0.1267)
oi	-0.2198	-0.2257
	(-1.6138)	(-1.5284)
Constant	-5.0280***	-6.4651**
	(-2.7835)	(-2.3883)
N	1,132	1,110
R-squared	-0.4276	-0.7534

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

In Column (2) of **Table 8** the distance from the urban center of mass to the nearest port (gkhl) is chosen as the instrumental variable for firms' exports to be regressed. Because the nearest port distance is not time-sensitive, the nature of this metric as instrumental variable is ensured by forming an interaction term between the currency exchange rate between China and the USA and the nearest port distance from 2012 to 2020. Port distance data are obtained from China Customs, and the relevant exchange rates are obtained from the State Administration of Foreign Exchange. The results presented in Column (2) of **Table 9** show that the value of the Cragg-Donald statistic for the weak instrumental variable test using port distance as an instrumental variable is 11.373. This value exceeds the critical value of 8.96 under 15 bias, thus rejecting the hypothesis of a weak instrumental variable and the original core variable has endogeneity problems. The instrumental variables were included in the regression equation as shown in Column (2) of **Table 8**. The regression results are significantly positive and pass the 5% significance test.

Table 9. Descriptive statistics and tests for instrumental variables.

Instrumental variables	Urban river density	Port distance
Descriptive statistics of instrumental variables:		
Average value	0.4490559	13.17406
Standard deviation	0.295002	1.316784
Phase I weak instrumental variable test:		
Cragg-Donald statistic	21.070	11.373
Stock-Yogo weak ID test critical values	16.38 (10%)	8.96 (15%)
Endogeneity Test:		
Durbin-Wu-Hausman chi-sq test	28.19	154.77
P-value	0.0592	0.0000

6 Heterogeneity Analysis

6.1 Heterogeneity of patent types

Chinese patents are commonly divided into three types: invention patents, utility model patents, and design patents. Among these, invention patents refer to new technical solutions for products, methods, or improvements thereof; utility model patents refer to new technical solutions for the shape, structure, or combination thereof of products that are suitable for practical use; and design patents refer to new designs for products that are aesthetically pleasing and suitable for industrial applications. Based on data availability, in this paper, green invention patents (lsfm) plus one (logarithmically transformed) is defined as a firm's green breakthrough innovation, and utility model patents obtained plus one (logarithmically transformed) are used to measure a firm's incremental innovation (Brunnermeier & Cohen, 2003).

Column (1) of **Table 10** shows the regression result analysis of the impact of export on enterprises' green breakthrough innovation; Column (2) shows the regression result analysis obtained by testing the impact of export on enterprises' green progressive innovation using green utility model patents (lssy) plus 1 (logarithmically transformed) and the share of green utility model patents. The results show that exports significantly contribute to the number of green utility model

patents, i.e., green incremental innovation of enterprises. The estimated coefficient is significantly positive at the 1% level; the estimated coefficient of the share of green utility model patents is significant at the 10% level, indicating that exports can promote the development of green incremental innovation of SMEs. However, no significant promotion effect on green breakthrough innovation of enterprises was found.

Incremental innovation refers to non-core content innovation represented by product design, which represents a simple modification of the product's original foundation and does not significantly impact consumers' habits and consumption patterns. Breakthrough innovation, on the other hand, refers to fundamental changes to existing technologies, where processes are associated with learning new knowledge, huge time and monetary costs, and high technological risks, causing fundamental changes to consumers' lifestyles and habits. In recent years, the innovation ability of Chinese enterprises has been progressing, and the number of patent applications and licenses ranks among the top in the world; however, there is still the phenomenon of "stuck neck" of key technologies, and the problem of weight and light quality of patent output: breakthrough innovation products still need to be improved. In contrast, the impact of corporate exports on SMEs' green progressive innovation is stronger.

Table 10. Heterogeneity analysis (by patent type).

	(1)	(2)	
	Green breakthrough innovation	Green progressive innovation	
	lsfm	lssy	syzb
ln_exp	0.0156	0.0540***	0.0144*
	(0.7258)	(2.5931)	(1.7948)
age	-0.1852***	0.0120	-0.0016
	(-7.7905)	(0.5069)	(-0.2289)
ln_pop	0.4604	0.4249	-0.0156
	(1.2711)	(1.1974)	(-0.1863)
size	0.1810**	-0.0199	-0.0228
	(2.4836)	(-0.2429)	(-0.9180)
liqu	0.0312	0.0825	0.0007
	(0.6254)	(1.3659)	(0.0362)
ln_tbq	0.1820***	0.1417**	0.0130
	(2.8286)	(2.0610)	(0.6143)
ia	0.0000	-0.0000*	-0.0000
	(0.8685)	(-1.6627)	(-1.4550)
gd1	0.0138**	0.0034	0.0020
	(2.5024)	(0.6031)	(1.2109)
gd2	-0.0040	-0.0029	0.0024
	(-0.5202)	(-0.2906)	(0.6803)
lev	-0.0199	0.4139	0.1181
	(-0.0673)	(1.3619)	(1.1439)
second	-0.0028	-0.0016	0.0008
	(-0.9181)	(-0.5319)	(0.5862)

ln_so2	-0.0053	0.0150	-0.0045
	(-0.1464)	(0.4896)	(-0.3515)
oi	-0.1069	0.0834	0.0037
	(-1.5007)	(1.3505)	(0.1919)
Constant	-4.5625*	-3.7769	0.0015
	(-1.7428)	(-1.3389)	(0.0026)
Observations	1,132	1,132	1,132
R-sq	0.0648	0.0580	0.0208
Corporate fixed effects	YES	YES	YES
Year fixed effects	YES	YES	YES
Industry fixed effects	YES	YES	YES

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

6.3 Industry heterogeneity

The impact of exports on the development of GTI in SMEs may vary by industry. To measure the differences in the effects generated by industry, 26 industries that meet the requirements of the matched sample were selected from 40 industries. The classification criteria followed the Organization for Economic Cooperation and Development, and the selected 26 industries were classified into the following four categories: low-technology, medium-low-technology, medium-high-technology, and high-technology industries (Li et al., 2016). Column (1) of **Table 11** shows that exports inhibit the development of GTI capacity of SMEs in low-technology industries, and the estimated coefficient is significant at the 5% level; the results shown in Column (2) indicate that exports promote the development of GTI capacity of SMEs in low- and medium-technology industries, and the estimated coefficient is significantly positive at the 10% level. The results presented in Columns (3) and (4) indicate that exports have no significant effect on the development of GTI among SMEs in medium and high technology industries.

Firstly, low-technology industries mainly include textile industry, which has a negative effect on the impact of GTI on the export of enterprises in this industry. The main reason is the relatively simple production process of enterprises in low-technology industries. Usually, the initial raw materials can be simply processed for export, the technical requirements are low, and enterprises thus pay more attention to the competition of labor costs. Secondly, medium and low-technology industries are mainly plastic and rubber products, metal products, coal mining industries. This type of industry faces greater environmental pollution problems, encountering corresponding peer green competition and green trade barrier problems; therefore, to expand exports, SMEs in industries of this type have to consider their green sustainable development while operating their export business; therefore, exports play a role in promoting the development of GTI of enterprises. Thirdly, medium and high technology industries as well as high technology industries are two types of industries that mainly include transportation equipment, medical equipment, communication equipment, and other industries. In these industries, the product production process is more complex, and the learning effect of enterprises' export is larger; enterprises in these industries can obtain independent innovation ability in the learning process, and the new products and patents developed are mostly complex and have high technology content; more importantly, the products exported by these two

industries must follow strict health standards; therefore, there is no significant impact of export on enterprises' GTI development in these two industries.

Table 11. Heterogeneity analysis (by industry).

	(1) Low-technology industries	(2) Low and medium-technology industries	(3) Medium and high-technology industries	(4) High-technology industry
	lszl	lszl	lszl	lszl
ln_exp	-0.4452**	0.0687*	0.0120	-0.0178
	(-2.4633)	(1.9198)	(0.4202)	(-0.2647)
age	3.1011	-0.0482	-0.1034***	0.1180
	(0.5770)	(-0.9349)	(-3.5080)	(1.6300)
ln_pop	-1.3304	0.2218	0.1127	0.2327
	(-0.4692)	(0.9287)	(0.7859)	(0.7223)
size	1.2447**	0.0404	0.2668***	-0.1595
	(2.0144)	(0.2107)	(3.1018)	(-0.7412)
liqu	0.6859	-0.5559**	0.0614	-0.0391
	(1.1847)	(-2.2342)	(0.6390)	(-0.1480)
ln_exp	0.2269	-0.1705	0.2556**	0.4327
	(0.3658)	(-0.7204)	(2.2696)	(1.5726)
ia	0.0000	-0.0000	-0.0000	-0.0000*
	(0.1203)	(-0.2490)	(-0.8006)	(-1.8264)
gd1	0.1024	0.0058	-0.0059	0.0091
	(1.4332)	(0.7717)	(-1.2295)	(0.7462)
gd2	-0.1133	-0.0103	-0.0076	0.0292*
	(-0.7431)	(-0.5781)	(-0.9766)	(1.6735)
lev	6.2272	-2.9265**	0.5482	0.5071
	(1.4347)	(-2.3889)	(1.1873)	(0.3464)
second	-0.0411	-0.0230**	-0.0021	-0.0008
	(-1.4519)	(-2.2398)	(-0.3628)	(-0.0863)
ln_so2	0.5974**	-0.1022	-0.0432	-0.0981
	(1.9964)	(-1.1419)	(-0.8490)	(-0.9680)
oi	0.8767	-1.1870***	0.0455	0.0974
	(0.8222)	(-3.2581)	(0.3177)	(0.1615)
Constant	-5.4862		-2.2340	0.0133
	(-0.5559)		(-1.5476)	(0.0045)
Observations	32	82	511	109
Corporate fixed effects	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES

Note: ***, ** and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

6.4 Regional analysis

In this paper, the examined cities are divided into three groups according to the regions they are located in: east, central, and west. The degree of influence of export of enterprises in these different regions on the GTI ability of enterprises is explored. The regression results are shown in **Table 12**. Column (1) presents a positive impact of exports on enterprises' GTI in the eastern region, and the estimated coefficient is significantly positive at the 10% level. The results shown in Columns (2) and (3) indicate that in the central and western regions, exports have no significant impact on the GTI of SMEs.

There is a large difference in economic development between the eastern and western regions of China. The export promotion effect is apparent in the eastern region. On the one hand, the eastern region has flat terrain, more rivers, convenient ports, a faster economic development than the western region, and the government focuses more on the development status of export enterprises. Because of the convenient infrastructure and supportive policy environment of the eastern region, enterprises generally have a good financial condition, which is conducive to their exports. On the other hand, the eastern region imposes stricter environmental requirements and more policies on environmental protection, and enterprises respond to the government's call to spend their R&D funds on green patent R&D, thus promoting the development of GTI of SMEs.

The effect of exports in the central and western regions on GTI of SMEs is not apparent. On the one hand, the central and western regions of China are at a disadvantage compared to the eastern regions in terms of facilities, environment, and taxation. This disadvantage is coupled with a high cost of attracting investment by local governments and a lack of clear exchange market effect for technology. This results in a loss of market, government funds are not sufficient to cover the expenses, and the subsidy preferences given to enterprises for innovation are reduced accordingly, which is not conducive to the development of GTI of SMEs. On the other hand, enterprises in central and western regions of China produce their export commodities far from port cities and export business is not highly developed; therefore, the development of local GTI capacity cannot be affected by their export business.

Table 12. Heterogeneity analysis (sub-regional).

	(1)	(2)	(3)
	Eastern region	Central region	Western region
	lszl1	lszl1	lszl1
ln_exp	0.0315*	0.0027	-0.0920
	(1.7472)	(0.0385)	(-1.3431)
age	-0.0021	0.1720	-0.0247
	(-0.1010)	(1.5663)	(-0.4754)
ln_pop	-0.0111	0.2776	0.2531
	(-0.1085)	(0.3719)	(0.6736)
size	0.0998	-0.2604	-0.1132
	(1.6218)	(-1.3912)	(-0.2972)
liqu	0.1087	-0.1106	0.3395
	(1.5492)	(-0.5120)	(0.8476)
q1	0.1782**	0.2480	0.0879
	(2.3411)	(1.0276)	(0.1518)

ia	-0.0000	-0.0000	0.0000
	(-1.4994)	(-0.6780)	(1.4592)
gd1	0.0022	0.0109	0.0209
	(0.5916)	(0.8950)	(1.3084)
gd2	-0.0036	-0.0120	0.0145
	(-0.5771)	(-0.5675)	(0.6280)
lev	0.4229	1.9379	4.6053**
	(1.2306)	(1.5841)	(2.4000)
second	-0.0021	-0.0162	-0.0182
	(-0.5402)	(-1.0145)	(-0.3942)
so2_	0.0038	-0.0735	0.1338
	(0.1096)	(-0.4128)	(0.7262)
oi	0.0034	-0.9100*	-0.9826
	(0.0390)	(-1.7275)	(-1.6167)
Constant	-1.4176	1.7669	
	(-1.4242)	(0.3184)	
Observations	953	112	67
Corporate fixed effects	YES	YES	YES
Year fixed effects	YES	YES	YES
Industry fixed effects	YES	YES	YES

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; standard errors are shown in parentheses.

7 Conclusion and Policy Implications

In international trade (both import and export), green trade refers to the efficiency, harmony, and sustainability as the goal of economic growth and social development. Green development has become an important trend, and many countries have developed green industries as an important initiative to promote economic restructuring. These developments highlight the concept and connotation of "green", and developing countries should be more responsible for energy saving and emission reduction. In the Fifth Plenary Session of the Seventeenth Central Committee, the need to adhere to the construction of a resource-saving and environmentally friendly society has been emphasized. This has been proposed as an important focus for accelerating the transformation of economic development, increasing ecological and environmental protection, improving the level of ecological civilization, and enhancing the capacity for sustainable development. In this context, it is important to explore the importance of exporting for GTI of SMEs. In this paper, the financial data of GEM SMEs from the CSMAR database and the WIND database are selected, studying the interval from 2012 to 2020. This study examined whether exports influence GTI of SMEs from a micro perspective.

The analysis shows that: First, export significantly positively impacts GTI of SMEs. The greater the export capacity of enterprises, the greater the total number of green patents, the more beneficial it is for enterprises to overcome the green trade barriers of target exporting countries and thus improve their competitiveness. This finding contrasts with existing studies in which trade

openness has a significant negative impact on regional GTI; this inhibitory effect is characterized by a nonlinear evolution with decreasing marginal efficiency (Han et al., 2023). The existing literature mostly focused on A-share listed companies (Kesidou & Demirel, 2012; Wang & Ma, 2018) when exploring the impact of exports on environmental innovation. However, in the present paper, the impact of the exports of SMEs on GTI is explored and a mechanism test is conducted through government subsidies and environmental awareness. By replacing explained and explanatory variables, changing the sample size (by excluding the municipalities directly under the central government) and the year of the stock market crash, and using the "industry*year" high-order joint fixed-effects model for robustness testing, export was found to have a significant positive impact on GTI of SMEs.

Second, there are two ways in which exporting affects GTI of SMEs. One is the attraction of government subsidies that can then be used to increase enterprises' R&D investment in GTI and enhance their innovation capacity; the other way is an increase of the attention to environmental protection in enterprises' work reports, which is used as a measure of enterprise awareness for green development that promotes their GTI development.

Third, exports can promote the gradual development of GTI of SMEs, but the effect on breakthrough GTI is not apparent; a suppressive effect was found on the green development of enterprises in low-technology industries, a significant promotion effect was found on the development of medium and low-technology industries, and the effect on the influence of medium-high and high-technology industries is not significant; a significant promotion effect was found on the green development of SMEs in eastern China, while the effect on the central and western regions is not significant. According to endogeneity analysis, where the reverse causality problem is examined using urban river density and urban center of mass to the nearest port distance as instrumental variables to mitigate the interference of endogeneity, the results are still significant. This endogeneity analysis effectively verifies the impact of exporting on GTI of SMEs.

Based on the above findings, the policy implications of this paper are as follows: First, at the national level, relevant environmental regulatory policies and early warning mechanisms for green trade barriers should be established. Relevant laws, regulations, and technical standards set up by trading partner countries should be actively collected to provide export SMEs with information and consulting channels. Such data can also assist these SMEs in obtaining the environmental protection and safety certificates required for export, thus improving their competitiveness. Second, the government can provide tax incentives to encourage enterprises to invest in environmental protection by reducing their cost of GTI. Measures can be the reduction of import tariffs on green technology and equipment or the granting of tax breaks for products that meet environmental standards, while promoting exports. Third, enterprises should actively utilize the preferential policies and R&D subsidies provided by the government, set up relevant departments to keep abreast of international environmental dynamics, make adjustments in a timely manner, and use the "export learning effect" to match more advanced green environmental protection standards and technologies. SMEs should also learn from relevant green production processes and organizational and management experiences, to strive for a long-lasting competitive advantage.

Further, this paper discusses the limitations of this research and provides an outlook to future research. The current research sample of this paper focuses on SMEs of listed companies in China, without focusing on developed countries and more microscopic enterprise samples. Moreover, this paper considers the impact of the export volume on GTI in terms of the scale, but without focusing

on the differences in the impacts of the type of export trade or the method of trade. In subsequent studies, further focus will be directed on the impact of the type of export trade of developed countries on GTI, as well as the quality of exports on GTI. The spatial effect of exports on green technology diffusion will be examined in conjunction with spatial econometric modeling.

Authors' contributions X.Y., H.X. and B.L. conceived and designed the experiments. J.W. and H.X performed the experiments. H.X. and Z.Q. analyzed the data and wrote the manuscript. All authors read and approved the final manuscript.

Funding We acknowledge the financial support from the Social Science Foundation of Jiangsu Province [23EYC001]; General Project of Jiangsu University Philosophy and Social Science Research [2022SJYB0102]; The Talent Introduction Research Start-up Fund Project of Nanjing University of Posts and Telecommunications [NYY222010].

Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare that they have no competing interests.

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