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RESEARCH ARTICLE

Green innovation efficiency measurement and its influencing factors in specialized and new enterprises

Mengxue Li[1], Ruiyan Gao[1], Yaguai Yu[1,2*], Xiyi Li[3], and Qizhe Mao[4]

[1]Business School, Ningbo University, Ningbo, Zhejiang, China
[2]Donghai Academy, Ningbo University, Ningbo, Zhejiang, China
[3]Yangming School, Ningbo University, Ningbo, Zhejiang, China
[4]State Tobacco Monopoly Administration, Zhoushan, Zhejiang, China
2411010150@nbu.edu.cn, 226000079@nbu.edu.cn, yuyaguai@nbu.edu.cn, 236003247@nbu.edu.cn, lushe1999@126.com

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ABSTRACT

Based on data from 40 Specialized and New Enterprises (SNEs) in Zhejiang from 2017 to 2021, green innovation efficiency (GIE) is assessed by Charnes–Cooper–Rhodes and super-Slack-Based Measure models, and influencing factors of GIE are analyzed using the Systematic Generalized Method of Moments Dynamic model to address the improvement of GIE in SNEs. The conclusions include: (i) the GIE is declining from 2017 to 2021 and could be improved in the future, especially for SNEs in Zhejiang. (ii) As for influencing factors, research and development investment, industry-university-research collaboration, and government support have positive effects, while enterprise scale has a negative effect of restraining the development of green innovation of SNEs in Zhejiang. Therefore, several countermeasures, including establishing sound scientific research mechanisms, forming cooperation mechanisms among enterprises, research institutes, and colleges and universities, strengthening government support, and improving the government's subsidy policy, are being put forward. Scientific basis and practical guidance are provided to enhance the green innovation capability of enterprises and the formulation of relevant policies by the government.

1. Introduction

Since the 20th century, the excessive exploitation of fossil fuels such as coal, oil, and natural gas has significantly promoted socio-economic development while also causing notable negative impacts on the natural environment, leading to increasingly severe global warming issues. In June 1988, American meteorologist James Hansen proposed the theory of global warming at a joint hearing of the United States Congress, which subsequently garnered widespread attention. With the long-term consumption of energy, essential goods have faced severe shortages. As one of the largest carbon dioxide emitters in the world, China's carbon dioxide emissions reached 10.523 billion tons in 2021, ranking first globally.[1] To achieve sustainable economic development in China, the upgrading of industrial structure and transformation of the development model are imminent.[2] In the context of reducing carbon dioxide emissions, China has already taken several measures, such as implementing pilot carbon trading policies. The dual-carbon strategy proposed by President Xi Jinping at the 75th session of the United Nations General Assembly in 2020 aimed to achieve a comprehensive green transformation of economic and

*Corresponding Author

social development, while also promoting sustainable social development.[3] The introduction of the dual carbon strategy presents unprecedented opportunities and severe challenges for Chinese enterprises. Chinese enterprises need to seize the historical opportunity of carbon peaking and carbon neutrality, accelerate the adjustment of energy structure and industrial structure, build a green, low-carbon, and circular development industrial system, and set an example for the country to accomplish its carbon peaking and carbon neutrality goals.

As the forefront of China's technical independence and self-improvement, SNEs always emerge as crucial catalysts for high-quality development, crucial stabilizers for the new development pattern, and the backbone of an inventive country. Green innovation theory, rooted in the integration of ecological economics and innovation studies, emphasizes that enterprises should achieve technological breakthroughs, process optimization, and product upgrading while reducing environmental pollution and resource consumption, thereby balancing economic benefits with ecological sustainability. This theory highlights the dual attributes of innovation: resource efficiency and environmental friendliness. It coincides with the four characteristics of specialization, refinement, uniqueness, and novelty of SNEs. Firstly, in terms of specialization, these enterprises focus on specific industrial chains or product segments, enabling them to concentrate resources on green technology research and development (R&D) in niche fields. For example, specialized manufacturing enterprises can develop energy-saving technologies for core components, aligning with green innovation's emphasis on resource optimization in specialized links. However, their narrow business scope may also limit the scale of green innovation investment, creating a tension between specialized advantages and resource constraints. Secondly, for refinement, which is characterized by sophisticated production management and high-quality standards, these enterprises are more likely to integrate environmental factors into process optimization. Refined management systems can reduce waste emissions during production, directly contributing to green innovation's process-oriented environmental benefits. Yet, excessive pursuit of short-term efficiency may prioritize cost control over long-term green technology investment, hindering the transformation of refinement into green innovation momentum. Thirdly, for uniqueness, enterprises with unique technologies or product functions can differentiate themselves through green innovation, enhancing market competitiveness. This aligns with green innovation's differentiation strategy in environmental markets. As shown in a study by Li and Xiao[4] based on green patent data from listed firms, technological differences formed by firms through green innovation can be transformed into competitive advantages in the marketplace in the context of environmental regulation, and this path of differentiation is in line with the policy orientation as well as providing firms with sustained incentives to innovate. However, the high specificity of unique technologies may increase the difficulty of applying green innovation results across industries, limiting their spillover effects. Fourthly, for novelty, which focused on technological and institutional innovation, these enterprises are inherently inclined to adopt new environmental technologies and models. Their innovative vitality matches green innovation's demand for breaking traditional high-pollution patterns. Nevertheless, the uncertainty of novel technologies may lead to higher R&D risks, reducing enterprises' willingness to invest in green innovation, especially when facing market fluctuations. Against the backdrop of China's dual carbon strategy, green innovation has become a critical path for enterprises to achieve sustainable development. As the key driving force of technological autonomy, the integration of green innovation theory has the characteristics of specialization, refinement, uniqueness, and novelty. Such characteristics align with the synergistic development trend of digitalization and greening, and the coupling and coordination of the two can provide important support for the innovation and development of SNEs, which not only determine their competitiveness but also affect the overall efficiency of regional green development.[5] However, existing studies have not systematically explored how these unique characteristics moderate the mechanisms of green innovation efficiency (GIE), making it necessary to establish a targeted analytical framework to fill this gap.

At present, although several studies have focused on GIE of enterprises, they mostly focus on the GIE of ordinary small- and medium-sized enterprises (SMEs), the manufacturing industry as a whole, or specific industries, and there is less systematic research targeting the special group of SNEs. In addition, although some of the studies involve the influencing factors of green innovation, they are mostly analyzed from a single perspective and combined with the traditional data envelopment analysis (DEA) model or the three-stage DEA model, and do not sufficiently consider the impact of non-desired outputs in green innovation, such as pollutant emissions, on the measurement of efficiency. Consequently, focusing on SNEs, the evaluation indices of GIE are selected to measure their innovation ability and green development. GIE is evaluated using the undesirable slack-based measure (SBM) model, and influencing factors affecting GIE are analyzed using the systematic generalized method of moments (GMM) dynamic model. Finally, for SNEs, suggestions are provided based on an accurate evaluation of GIE, while providing leadership and demonstration for the green development of SMEs and filling gaps in existing research in this field.

2. Literature review

Although green innovation as an important path to promote sustainable development has received widespread attention in the academic community, the fragmentation and subjectivity of its measurement methods still constrain the scientific and policy guidance value of the research. Ernest and David[6] proposed the concept of green innovation in 1994, which refers to products, technologies, innovation efficiency, and processes that can achieve the goal of reducing, eliminating, or avoiding environmental pollution while saving resources. However, in relevant domestic and international research, scholars have yet to establish a unified standard for measuring green innovation. In several important studies, green innovation is measured using questionnaires. Due to the high cost of surveys, scholars subsequently began using input–output data related to innovation to measure green innovation. The company's R&D investment can reflect its importance in innovation. Generally speaking, the more a company invests in R&D, the more it values innovation. Therefore, R&D investment can be used to reflect a company's level of innovation. For example, Lee et al.[7] used green R&D expenditures to measure green innovation, while Wang and Chen[8] used R&D investment in energy consumption to measure green innovation. As a result of innovation activities, innovation output can also reflect the level of innovation within a company to some extent. The quantity of corporate green innovation activities was measured by Tao et al.[9] using the number of invention patent applications. They then created a patent knowledge breadth index to characterize the quality of green innovation activities.

Although the current research on the impact of enterprise characteristics on green innovation has accumulated abundant results, most of them focus on the linear correlation between financial targets and R&D inputs,[10] with the cognitive limitation of focusing on economic rationality and neglecting system interaction. Existing literature generally reduces green innovation to rational decision-making under a cost-benefit game, overly relies on the direct impacts of financial performance or a single innovation input, but neglects the dynamic coupling mechanism of internal and external factors. For example, although financial status can explain short-term resource constraints, it cannot reveal the role of non-financial factors, such as management's environmental values and organizational culture, in shaping the direction of green innovation. The positive correlation between up-front environmental costs and patent outputs may also conceal deep-seated contradictions, such as technological path dependence and policy subsidy heterogeneity. Regarding the research on the impact of a company's characteristics on green innovation, numerous scholars, both domestically and internationally, have proposed and validated their viewpoints from different angles. Due to the high cost of green innovation for enterprises, the financial status of the enterprise and its initial R&D expenditures will affect the implementation of green innovation activities. Zhang and Zhang[11] found that the expected economic benefits and profitability of enterprises have a significant impact on green innovation. Brunnermeier and Cohen[10] indicate that the initial environmental costs invested by enterprises are positively correlated with the output of green patents, meaning that the higher the environmental costs, the more green patents enterprises produce. Zhang and Wang[12] verified the donation of R&D investment to corporate green technology innovation by simulating the dynamic changes in green technology innovation, and the incentive effect continuously strengthened over time. Wang et al.,[13] from the perspective of public scientific research institutions, found that green R&D interventions can raise the standard of enterprises' green innovation and broaden the boundary of green innovation; the higher the intensity of green R&D cooperation, the stronger the green innovation driving effect.

Green innovation efficiency is the most elementary component of green innovation research and a crucial statistic for assessing the judicious distribution of innovation resources. From the standpoint of green growth, Zhang and Zhu[14] assessed the technological innovation efficiency of China's industrial businesses in 2009. Based on the results, environmental factors help different provinces become more efficient at technological innovation. Qian et al. determined the GIE of several Chinese regions using a two-stage DEA model. According to empirical findings, Chinese firms' two-stage GIE is poor and, on the decline, with notable variations in GIE among regions.[15]

There are generally the following two methods to gauge GIE: non-parametric estimation and parametric estimation. The former is represented by the DEA model proposed by Charnes, Cooper, and Rhodes in 1978, while the latter is mostly represented by Stochastic Frontier Analysis. Afterwards, Chung was the first to introduce unexpected outputs into the DEA model and proposed the directional distance function.[16] Fare et al.[17] later proposed using the Malquist–Luenberge index method to measure super-efficiency. As traditional DEA does not consider slackness in input–output, resulting in biased efficiency values, Tone[18] proposed the SBM model in 2001, which subsequently provided a better evaluation of decision-making units and ranked the evaluations. Based on the SBM model, he proposed the super-SBM model.

Existing research on the pathways of corporate green innovation is relatively scarce, and the research content is quite fragmented. Overall, several scholars approach the topic from the perspective of influencing factors, while a few scholars use case studies. Peng[19] analyzed the mechanism by which green economic development promotes innovation from a theoretical perspective, and discussed the main paths for promoting innovation through green economic development based on practical foundations and international experience. Zhang[20] conducted a case study on Chenming Paper, systematically exploring the specific paths for the green innovation upgrade of state-owned manufacturing enterprises from the perspective of high-quality development. The study found that the green innovation of Chenming Paper involves three upgrade paths: (i) green technological innovation; (ii) green organizational innovation; and (iii) green industrial chain innovation.

At present, although the academic field has conducted research on various types of enterprises and industries in terms of innovation and green development, there is still a lack of research on the impact of green innovation on SNEs. The existing relevant research presents a fragmented and insufficiently in-depth and systematic situation, which makes it difficult to comprehensively and accurately reveal the multi-dimensional, complex relationship and key influencing factors involved in the process of green innovation of SNEs. There is limited research on how specialized, sophisticated, and creative businesses affect green innovation. Using a three-stage DEA model, Fu and He[21] discovered that the innovation efficiency of SNEs is comparatively poor. After eliminating environmental factors and random disturbances, technical efficiency improves, while scale efficiency significantly decreases, but the overall innovation efficiency remains relatively low. With carbon neutrality as a backdrop, Yu et al.,[22] using a three-stage DEA model and a systematic GMM model, discovered that while not high overall, green financing efficiency of construction industry enterprises is on the rise, and that the financial environment, as well as government and financial market, have a major favorable effect on green financing efficiency. At the same time, Yu et al.[23] discovered that the construction industry's green financing efficiency still has a lot of room for improvement, depending on the four-stage DEA model. SMEs in our nation are reflected in SNEs. Slater and Angel[24] examined the effects of environmental rules on technological innovation in SMEs. Gong et al.[25] proposed that due to market failure in environmental allocation, the government must support green technology innovation of SMEs from a macro perspective, providing encouragement and support through laws, regulations, and policies. Zhou et al.[26] pointed out that green technology innovation, green manufacturing, and green marketing are essential paths for SMEs to achieve sustainable technological innovation. Since specialized, sophisticated, and innovative enterprises are primarily in the manufacturing sector, Li[27] elaborated on green innovation in manufacturing as early as 2005, believing that the purpose of green innovation in manufacturing is to save energy and reduce consumption. Horbach[28] found that the enhancement of green technology can strongly promote the green innovation environment in the manufacturing industry. The beneficial effects of internet finance on the green technology innovation of manufacturing firms were investigated by Yu et al.[29] based on the mediating function of financing. Li et al.[30] found that knowledge search and reconstruction have a significant role in promoting green technology innovation in specialized SMEs, in which the incentive effect of technical knowledge search is stronger. Ling and Ji[31] found that enterprise digital transformation can significantly promote green technology innovation in manufacturing enterprises based on different life cycles of enterprise development. Based on green technology innovation as an important channel, Zhang and Liu[32] found that digitalization input is a crucial practice in promoting green upgrading in the Chinese manufacturing industry.

3. Conceptual definition and measurement of green innovation efficiency in SNEs

Based on the systematic GMM dynamic model, this paper measured GIE of SNEs using the DEA model, conducted a comprehensive evaluation of the measured results, characterized the GIE in each region, and decomposed the influencing factors of GIE, to put forward the suggestions of SNEs in China for future enhancement of their GIE. To ensure the accuracy and effectiveness of the calculation results for the GIE of SNEs, it is necessary to define the estimation method for both efficiency and the parameters involved.

3.1. Conceptual definition of green innovation efficiency in SNEs

3.1.1. SNEs

To be specific, the term "SNEs" means the enterprises that possess development characteristics of specialization, refinement, uniqueness, and novelty. Specialization includes several meanings, such as focusing on one industry, specializing in a few products, concentrating on serving one type of customer, and specializing in certain regions,[33] as well as possessing specialized technology, specialized teams, unique resources and specialized market groups,[34] and a comparative advantage in a specific link of the industry chain. Refinement includes refined production, management, and services, generating high-quality products and services to occupy a comparative advantage in the segment. It requires SMEs to build a scientific and orderly internal system, including a customer service system, a business management system, a personnel management system, a financial management system, etc., to ensure that customers have a good experience.[35] Uniqueness, such as unique technology, function, and appearance,[36] provides corresponding unique products and services tailored to different consumer groups. Novelty includes new products, processes, market mechanisms, management mechanisms, etc., specifically regarding enterprise technological innovation, institutional innovation, and standard innovation.[37] Therefore, SNEs refer to SMEs with the characteristics of specialized, refined, unique, and novel. The scale of the enterprise conforms to the provisions of the national "Classification Standard for Small- and Medium-sized Enterprises."[38]

3.1.2. Green innovation efficiency

The goal of green innovation is to address environmental issues, accomplish particular environmental protection objectives, and promote sustainable development. This includes energy conservation, pollution avoidance, waste recycling, and other enterprise green product and process innovation, along with organizational management support and innovation execution. Green innovation is a form of innovation aimed at achieving sustainable development. While sustainable development represents the purpose and direction, innovation serves as the means to reach it. Innovation drives economic growth and facilitates the transition toward sustainable development, while sustainable development, in turn, sets the requirements for innovation, demanding that it moves in a sustainable direction. Green innovation has the public nature of research, content diversity, process complexity, and externality of results, which is significantly different from traditional innovation.

Efficiency is the extent to which resources are fully utilized under certain technological conditions to maximize the benefits of production, that is, resource allocation efficiency, to measure the ratio of different inputs to outputs.[39] Based on the definition of efficiency, it can be derived that GIE is a comprehensive index that evaluates regional green efficiency, considering both innovation inputs and environmental losses. This is specifically reflected in improving the efficiency of resource elements in product development, promoting economic development by emphasizing ecological protection, and considering undesired outputs, such as comprehensively considering energy loss and pollutant discharge. While emphasizing environmental protection, it is also crucial to pay attention to the effectiveness of allocating innovation resources and ensure that there is a corresponding quality in the number of innovation outputs rather than just emphasizing or seeking more innovation inputs.

3.2. Measurement scheme for green innovation efficiency of SNEs

3.2.1. Green innovation efficiency and data envelopment analysis

Data envelopment analysis is a unique tool developed by Charnes et al.[40] in 1978 based on linear programming. It is primarily used to assess the productivity of departments. When there are many inputs and outputs, their ratio can be used to measure efficiency. It is typically used as an indicator to assess performance between organizations, regardless of the influence of the dimension. DEA will measure the efficiency of the decision-making unit. The principle of efficiency measurement is to project the decision-making unit, using multiple inputs and outputs, onto the DEA production frontier. The production frontier is a generalization of the production function to the multi-output situation. It is an optimal solution set composed of the Pareto optimal solutions to achieve the minimum input and maximum output. Combined with the linear programming approach, it is mainly used to measure the efficiency of decision-making units with complex production relationships and reduce the role of subjective influence by comparing the size of the weights. This method is widely used in the efficiency measurement of decision-making units with multiple inputs and outputs. Ultimately, it measures the efficiency value of all production units by the standard of the production frontier and provides an improvement program for inefficient units.

In the evaluation process, the DEA model does not assign weights to input and output indicators in advance; the weights are generated automatically by the model. Compared with a multi-criteria decision analysis model, it ensures the objectivity of evaluation and avoids the influence of subjective factors on the evaluation results. Within a limited framework, DEA is the optimal method for measuring efficiency.

3.2.2. Green innovation efficiency evaluation with Charnes–Cooper–Rhodes and super-slack-based measure models

We selected the super-SBM model that considers the input–output slack problem. Compared to the ordinary DEA model, the super-SBM model takes into account the relaxation factor when addressing the radial problem, rendering it more refined in dealing with the efficiency problem. It reveals the change rule of returns to scale under specific conditions and provides an in-depth understanding of the crowded and weakly crowded states of returns to scale. For the multi-input single-output system, it provides guidelines for dynamically determining the returns to scale of the decision unit. For the multi-input multi-output economic system, the model gives detailed conditions for determining changes in returns to scale of some inputs and outputs.

Green innovation efficiency of SNEs was measured and analyzed using the Charnes–Cooper–Rhodes (CCR) model with fixed constant returns to scale in the DEA method. By applying SNEs as decision-making units, the potential boundary of GIE of these businesses was created. It was assumed that there were n decision-making units in the production system, and each decision-making unit used m kinds of inputs, produced s kinds of expected outputs, which were denoted as $x \in R^m$, and $y \in R^s$, and were defined as matrices X and Y, as shown in Equations (1) and (2).

$$X = (x_1, x_2, \Lambda, x_n) \in R^{m\times n} \tag{1}$$

$$Y = (y_1, y_2, \Lambda, y_n) \in R^{s\times n} \tag{2}$$

The scale benefit of the CCR model remains unchanged, and it is primarily used to evaluate the overall efficiency of decision-making units. The ratio type was used as the evaluation index, which was more in line with the practical significance. Based on this, this study applied the CCR model to evaluate the static GIE of SNEs. The model is shown in Equations (3) and (4).

$$\min \left[\theta - \varepsilon \left(\sum_{j=1}^{m} s^- + \sum_{j=1}^{s} s^+ \right) \right] \tag{3}$$

$$s.t. \quad \begin{cases} \sum_{j=1}^{n} x_j\lambda_j + s^+ = \theta x_0 \\ \sum_{j}^{n} x_i\lambda_j - s^- = y_0 \\ \lambda_j \geq 0,\ s^+ \geq 0,\ s^- \geq 0 \end{cases} \tag{4}$$

where θ is the efficiency value of the decision-making unit, whose value is between 0 and 1. x is the input variable, y is the output variable, and s^- and s^+ are the slack variables of input and output, respectively. λ is a non-negative weight variable. When $\theta = 1$, it indicates that the enterprise is on the frontier of GIE in that year, and the outputs of its green innovation activities relative to the inputs have reached the level of optimal comprehensive efficiency.

3.3. Measurement of green innovation efficiency of SNEs

3.3.1. Sample selection and data sources

This study selected the SNEs in Zhejiang as the research sample. As of September 2022, there were 86 SNEs in Zhejiang, most of which are manufacturing companies. The sample companies cover a range of materials, biology, medical care, information, and other fields, which are representative to a certain extent. However, considering the accessibility of the data as well as the lack of

Table 1. List of SNEs in Zhejiang

Security codes	Security abbreviations
002006.SZ	Zhejiang Jinggong Integration Technology Co., Ltd.
002112.SZ	San Bian Science & Technology Co., Ltd.
002214.SZ	Zhejiang Dali Technology Co., Ltd.
002522.SZ	Zhejiang Zhongcheng Packing Material Co., Ltd
002686.SZ	Zhejiang Yilida Ventilator Co., Ltd.
002849.SZ	Zhejiang Viewshine Intelligent Meter Co., Ltd.
002860.SZ	Hangzhou Star Shuaier Electric Appliance Co., Ltd.
002915.SZ	Zhejiang Zhongxin Fluoride Materials Co., Ltd.
003017.SZ	Zhejiang Dayang Biotech Group Co., Ltd.
300076.SZ	Ningbo Gqy Video & Telecom Joint-stock Co., Ltd.
300587.SZ	Zhejiang Tiantie Industry Co., Ltd.
300604.SZ	Hangzhou Changchuan Technology Co., Ltd.
300611.SZ	Zhejiang Meili High Technology Co., Ltd.
300643.SZ	Hamaton Automotive Technology Co., Ltd.
688611.SH	Hangzhou Kelin Electric Co., Ltd.
300718.SZ	Zhejiang Changsheng Sliding Bearings Co., Ltd.
300853.SZ	Hangzhou Shenhao Technology Co., Ltd.
300582.SZ	Inventronics (Hangzhou), Inc.
603040.SH	Hangzhou XZB Tech Co., Ltd.
603089.SH	ADD Industry (Zhejiang) Co., Ltd.
300234.SZ	Zhejiang Kaier New Materials Co., Ltd.
300283.SZ	Wenzhou Hongfeng Electrical Alloy Co., Ltd.
300306.SZ	Hangzhou Everfine Photo-E-Info Co., Ltd.
300351.SZ	Zhejiang Yonggui Electric Equipment Co., Ltd.
300357.SZ	Zhejiang Wolwo Bio-Pharmaceutical Co., Ltd.
300401.SZ	Zhejiang Garden Biopharmaceutical Co., Ltd.
300412.SZ	Zhejiang Canaan Technology Limited
300488.SZ	Est Tools Co., Ltd.
300548.SZ	Broadex Technologreen Innovation Efficiency Co., Ltd.
300553.SZ	Hangzhou Jizhi Mechatronic Co., Ltd.
603321.SH	Zhejiang Meilun Elevator Co., Ltd.
603520.SH	Zhejiang Starry Pharmaceutical Co., Ltd.
603607.SH	Zhejiang Jinghua Laser Technology Co., Ltd.
603657.SH	Jinhua Chunguang Technology Co., Ltd.
603701.SH	Zhejiang Dehong Automotive Electronic & Electrical Co., Ltd.
603757.SH	Zhejiang Dayuan Pumps Industry Co., Ltd.
688039.SH	Zhejiang Goldensea Hi-Tech Co., Ltd.
603311.SH	Hangzhou IECHO Science & Technology Co., Ltd.
688296.SH	Zhejiang Heda Technology Co., Ltd.
300163.SZ	Ningbo Xianfeng New Material Co., Ltd.

data for some enterprises, the final determination includes only 40 companies. The specific company samples are listed in Table 1.

First of all, in terms of industry representation, SNEs in Zhejiang cover a wide range of key industrial fields, including auto parts, the electrical industry, and equipment manufacturing. Among the 40 enterprises we selected, for example, the automobile parts industry included Meilun Elevator (603321.SH) and Hamaton Automotive Technology (300643.SZ); the electrical industry included Jinggong Integration Technology (002006.SZ) and Kaier New Materials (300234.SZ); and the equipment manufacturing industry included Danyuan Pump Industry (603757.SH) and Hangzhou XZB Tech (603040.SH). These enterprises were distributed in different industrial fields, fully demonstrating the overall industry structure and diversified characteristics of SNEs in Zhejiang Province. Second, we paid special attention to the diversity of sizes in selecting these 40 sample firms to ensure that the sample truly reflected the size distribution of the entire group. For example, there were medium-sized enterprises, such as Dehong Automotive Electronic & Electrical (603701.SH) and Jinghua Laser Technology (603607.SH), as well as small or start-up enterprises, including Wenzhou Hongfeng Electrical Alloy (300283.SZ) and Hangzhou Everfine Photo-E-Info (300306.SZ). There were also large-scale enterprises, such as Starry Pharmaceutical (603520.SH) and Changsheng Sliding Bearings (300718.SZ). In addition to industry and size, we also carefully considered other key characteristics, such as a company's innovation capability, R&D investment, and market position, to ensure that the sample fully reflects the diversity of the group as a whole. For example, in terms of innovation ability, Wolwo Bio-Pharmaceutical (300357.SZ), and Canaan Technology (300412.SZ) possess significant R&D strength and innovation ability in their respective fields; for R&D investment, Hangzhou Changchuan Technology (300604.SZ), and Inventronics (300582.SZ) have continued to increase R&D investment and promote technological innovation and product upgrading; and in terms of market position Jinggong Integration Technology (002006.SZ) and Dali Technology (002214.SZ) exhibit high visibility and competitiveness in both domestic and international markets.

Collectively, these 40 enterprises are broadly representative in terms of industry, scale, and other major features, and truly reflect the overall strength and diversity of SNEs in Zhejiang.

According to the scope and availability of data, this paper selected information from 40 SNEs in Zhejiang from 2017 to 2021. Most of the data were obtained from the "China Urban Statistical Yearbook," the Wind Database, and the Science and Technology Department websites of each city. The collected data were then preprocessed by removing outliers and filling in missing values, which improved the quality and usability of the data. Among these, the linear interpolation approach was used to adjust for certain incomplete data. Linear interpolation is a simple and easy-to-implement method. Due to its simplicity, the computational cost of linear interpolation is relatively low, which is suitable for real-time applications or data processing scenarios that require frequent updates.[41]

3.3.2. Selection of green innovation efficiency index of SNEs

The "input index" and "output index" categories were chosen as the first-level indexes for evaluation when selecting the input–output index system to assess the GIE in Zhejiang SNEs. Simultaneously, considering the availability of data and the scientific basis of the indexes, we evaluated the environmental and innovation variables based on the research findings of previous studies.[42,43]

Among input indices, such as labor and capital inputs, the total number of employees and the R&D personnel of enterprises were chosen as indicators of labor input, according to the custom of Yan and Zhang.[39] The capital input was selected as a measure of R&D capital stock and net fixed assets of enterprises, and the annual changing rate of R&D investment input of enterprises was added as a significant reference for the capital input.[42] The method used to calculate the R&D capital stock of an enterprise was the perpetual inventory method.[43] The specific formula is shown in Equation (5).

$$RD_{it} = K_{i(t-1)} + (1-\delta)\, RD_{i(t-1)} \tag{5}$$

where RD_{it} is the R&D capital stock of an enterprise i in year t, $RD_{i(t-1)}$ is the R&D capital stock in year $t-1$, $K_{i(t-1)}$ is the R&D investment input after discounting in the early year $t-1$ (the discount rate used here was 8%), and δ is the depreciation rate of the R&D capital stock. We assumed that the R&D capital stock at the beginning of the period could be expressed with Equation (6), and the rise in the ratio of the R&D investment inputs K and the R&D capital stock were equal.

$$RD_{i0} = K_{i0}/\delta + g \tag{6}$$

where g is the average growth rate of K. The data used in this paper range from 2017 to 2021, and a 15% depreciation rate was applied to R&D expenditures, which is the value according to most previous studies.

Output indexes, according to Wang et al.,[43] the revenue from new product sales was generally chosen as the economic output indicator. However, since enterprises did not disclose this indicator, the main business income of listed companies was used as the alternative indicator, referring to the practice of Qu et al.[44] The green innovation output indicators in the existing literature generally used the number of patent applications or authorizations directly, and rarely applied green patents to measure green innovation output directly. The current study obtained and screened patents according to the "Green List of International Patent Classification" issued by the International Intellectual Property Office. Due to the delay in granting patents, it often took 1–2 years from the application to the granting of a patent. Therefore, the number of green patents awarded can better represent the level of green innovation compared to the number of green patent applications. The authorized green patents were accurately screened in the following three steps: firstly, the international patent classification numbers of seven major green technology fields, such as alternative energy production, energy efficiency improvement, and waste management, were extracted from the list of the International Intellectual Property Office, and the scope of the target patents was locked through the combination of classification number search.

Secondly, the patent title and abstract are supplemented with green technology keywords, such as hydrogen fuel, biodiesel, and smart grid, for secondary checking, and setting the condition of "legal status=authorized" to retain only the authorized patents that have passed the examination of the State Intellectual Property Office, to avoid the interference of the lag period of 1–2 years from application to authorization. Finally, the data uniqueness and classification accuracy are ensured through de-duplication and manual sampling. In addition, this paper also selected the ratio of enterprise R&D expenses to operating income and operating profit as an important measurement basis of economic output indicators. The construction of the specific index system is shown in Table 2.

3.3.3. Analysis of the results of green innovation efficiency measurement of SNEs

This paper adopts the DEA method and utilizes MaxDEA software (MaxDEA 5.2, MaxDEA software Ltd., China) to evaluate and decompose the GIE of 40 SNEs in Zhejiang. The general GIE of SNEs and its decomposition items are shown in Table 3.

First, comprehensive technical efficiency (CRS) is a comprehensive indicator that reflects the ability of decision-making units to allocate and utilize resources. According to the measurement results, the CRS of SNEs in the years 2017–2021 were 0.807, 0.773, 0.779, 0.724, and 0.704, respectively, with an overall downward trend. This indicates that the allocation and utilization of innovation resources by the SNEs have declined, and there is still some room for upward movement.

Second, pure technical efficiency (VRS) reflects the part affected by enterprise management and technology. The VRS in the years 2017–2021 were 0.973, 0.919, 0.880, 0.852, and 0.836, respectively. The average values of scale efficiency in the years 2017–2021 were 0.829, 0.841, 0.885, 0.850, and 0.842, respectively. The scale and VRS in each year were greater than the CRS, but neither has reached the optimal level, resulting in a low level of GIE. Therefore, it is necessary to focus on improving the management and technical level, as well as the scale efficiency of SNEs.

3.3.4. Analysis of the reasons for the results of green innovation efficiency measurement of SNEs

Further analysis of the reasons for the low level of GIE shows that, from the perspective of green patent output, 33% of the sample enterprises have no green patent output, which is an important reason that leads to the low level of GIE within listed companies in China. In addition, under China's current environmental regulation policy, enterprises will actively conduct green innovation activities only when the cost of violating the environmental regulation policy is much greater than the cost of innovation activities. Otherwise, to chase short-term profits, enterprises often choose to accept economic sanctions, such as environmental taxes for polluting the environment, rather than conducting innovation activities, and therefore lack the incentive to implement green innovation.

Besides, there are many other reasons affecting the low level of GIE within the listed companies of SNEs in Zhejiang, such as insufficient scale of R&D expenditures and R&D personnel, as well as inefficient resource allocation. The declining trend of CRS presented by SNEs throughout 2017–2021 may be the result of China's overall downward adjustment of economic growth rate under the new normal, with elevated inputs accompanied by insufficient demand on the output side, which hinders efficiency.

The overall GIE of SNEs in Zhejiang is low. It has been declining in recent years, and few of the enterprises are in a state of inefficiency. Moreover, VRS and scale have not reached the optimal level, which is the main cause of the low level of GIE. The GIE is also declining throughout 2017–2021, which may be due to the overall downward adjustment of China's economic growth rate under the new normal, resulting in insufficient output demand, and may also be related to the COVID-19 pandemic in recent years. The epidemic led to shrinking market demand and supply chain disruptions, resulting in cash flow constraints for SNEs, which ultimately limited R&D investment. R&D investment, as a positive influence on GIE, directly impacted the financial support of green technology R&D and the resulting transformation capacity. At the same time, enterprises need to cope with the uncertainty of the contraction of the scale of possible involuntary or idle resources, which leads to a further decline in the efficiency of resource allocation. Moreover, to maintain their survival, environmental protection inputs, which

Table 2. Green innovation efficiency index system of SNEs

Target layer	Initial level index	Second-level index	Third-level index	Unit
Green Innovation Efficiency	Input index	Capital input	Net fixed assets of enterprises	Yuan
			Annual rate of change of R&D investment input of enterprises	%
			R&D capital stock of enterprises	Yuan
		Labor input	Total number of employees	Person
			Total number of R&D personnel of enterprises	Person
	Output index	Technical output	Number of granted green patents	Piece
		Economic output	Ratio of enterprise R&D expenses to operating income	%
			Ratio of enterprise R&D expenses to operating profit	%
			Revenue from the main business	Yuan

Abbreviation: R&D, Research and development.

Table 3. Green innovation efficiency of SNEs in Zhejiang

Year	Green innovation efficiency CRS	VRS	Scale
2017	0.807	0.973	0.829
2018	0.773	0.919	0.841
2019	0.779	0.880	0.885
2020	0.724	0.852	0.850
2021	0.704	0.836	0.842
Average	0.757	0.892	0.849

Abbreviations: CRS, comprehensive technical efficiency; VRS, pure technical efficiency.

Table 4. The control variables involved in the current study and their definitions

Variable type	Variable name	Variable abbreviation	Variable definition
Explained variable	Green innovation efficiency	GIE	Comprehensive technical efficiency
Explanatory variable	R&D investment	RD	R&D expenditure investment
	Enterprise scale	ES	The logarithm of the total assets
	Industry-university-research cooperation	COORP	The total number of jointly authorized green inventions and utility model patents
	Environmental protection investment intensity	ENVIR	Total expenditure on environmental protection
	Government financial support	GOVNM	Government grants / operating revenue
Control variable	Ownership concentration	LHD	The shareholding ratio of the largest shareholder
	Net operating cash flow	Profit	The operating profit margin disclosed in the annual report
	Asset-liability ratio	Lev	The debt-to-asset ratio disclosed in the annual report
	Board size	DN	Total number of board members

did not have a significant positive impact, may be scaled down due to the short-term pressure of epidemics, making it even more difficult to support GIE.

3.4. Theoretical foundations and research hypotheses

3.4.1. Research and development investment

The inflow of R&D capital provides ample financial support for technological R&D, as well as the transformation of research results, enhancing

Table 5. Descriptive statistical table of variables involved in this study

Variables	n	Average value	Standard deviation	Maximum value	Minimum value
GIE	200	0.757	0.372	1.914	0.109
RD	200	17.385	0.680	19.680	15.800
ES	200	20.956	0.599	22.310	18.920
COORP	200	14.490	21.826	151.000	0.000
ENVIR	200	188854.800	769446.100	5067438.000	0.000
GOVNM	200	0.014	0.013	0.087	0.000
LHD	200	0.321	0.140	0.900	0.000
Profit	200	0.150	0.200	0.561	−1.115
Lev	200	0.293	0.159	0.705	0.048
DN	200	7.635	1.323	9.000	0.000

Abbreviations: COORP, Industry-university-research cooperation;
DN, Board size;
ENVIR, Environmental protection investment intensity; ES, Enterprise scale;
GIE, Green innovation efficiency; GOVNM, Government financial support;
Lev, Asset-liability ratio;
LHD, Ownership concentration; Profit, Net operating cash flow;
RD, research and development investment.

Table 6. Pearson's correlation coefficient of all variables involved in this study

Variables	GIE	RD	ES	COORP	ENVIR	GOVNM	LHD	Profit	Lev	DN
GIE	1									
RD	0.153**	1								
ES	−0.133**	0.659**	1							
COORP	0.043	0.300**	0.342**	1						
ENVIR	0.182**	0.130	0.265**	−0.051	1					
GOVNM	0.324**	0.222**	0.040	−0.092	0.068	1				
LHD	−0.117	−0.308**	−0.269**	−0.220**	−0.060	0.030	1			
Profit	−0.188*	−0.076	−0.173*	−0.204**	0.044	0.240**	0.232**	1		
Lev	−0.049	0.252*	0.301**	0.150*	0.064	−0.231**	−0.046	−0.325**	1	
DN	0.127**	0.136	0.161*	0.039	0.194**	0.016	−0.117	−0.206**	0.075	1

Abbreviations: COORP, Industry-university-research cooperation; DN, Board size;
ENVIR, Environmental protection investment intensity;
ES, Enterprise scale; GIE, Green innovation efficiency;
GOVNM, Government financial support; Lev, Asset-liability ratio;
LHD, Ownership concentration; Profit, Net operating cash flow;
RD, Research and development investment.
**At level 0.01 (two-tailed), the correlation was significant; *At level 0.05 (two-tailed), the correlation was significant.

the resilience of innovation entities. During the innovation and R&D phase, the comparative advantage of innovation resources is obtained. The establishment of SNEs attracts R&D capital that flows toward these companies, facilitating close cooperation, resource complementarity, and information sharing among innovation entities, which promote regional green innovation division of labor and collaboration, ultimately improving the efficiency of green R&D and achievement transformation. The outflow of R&D capital follows the principle of maximizing profits by reconfiguring and optimizing idle resources within enterprises, thus avoiding resource waste and misallocation issues. Under the guidance of relevant policies, the upgrading of China's industrial structure takes the initiative to dock the construction of SNEs, prompting the flow of R&D capital and other innovative elements from high to low, thereby achieving the optimal allocation of innovative resources and enhancing corporate innovation rates. Therefore, the following hypothesis is proposed:

H1: R&D investment is significantly and positively related to the GIE of SNEs.

3.4.2. Enterprise size

Large companies, with advantages such as economies of scale and access to financing, tend to be more innovative. However, as the scale of enterprises expands, energy consumption and pollution also increase, which can offset the economies of scale and reduce the GIE. As most SNEs are SMEs, they are sensitive to changes in market demand, making it easy for them to specialize in a

Table 7. Regression results of influencing factors on green innovation efficiency of SNEs in Zhejiang

Variables	**Green innovation efficiency**	**Variables**	**Green innovation efficiency**
Constant term	4.618	GOVNM	0.326**
	(1.524)		(0.096)
RD	0.175**	LHD	−0.453
	(0.227)		(0.139)
COORP	0.107**	Lev	0.432
	(0.005)		(0.236)
ES	−0.830**	Profit	−0.133**
	(0.257)		(0.059)
ENVIR	0.102	DN	0.153
	(0.003)		(0.085)

Abbreviations: COORP, Industry-university-research cooperation; DN, Board size; ENVIR, Environmental protection
investment intensity; ES, Enterprise scale; GIE,
Green innovation efficiency; GOVNM, Government financial support;
Lev, Asset-liability ratio; LHD, Ownership concentration;
Profit, Net operating cash flow; RD: Research and development investment.
* and ** are significant at the level of 10% and 5%, respectively.
The standard error of the estimated coefficient is shown in parentheses

Table 8. Robustness test of influencing factors on green innovation efficiency of SNEs in Zhejiang

Variables	**Green innovation) efficiency (VRS value)**	**Variables**	**Green innovation) efficiency (VRS value)**
Constant term	2.352	GOVNM	0.827**
	(1.187)		(0.318)
RD	0.156**	LHD	−0.921
	(0.160)		(0.589)
COORP	0.117**	Lev	0.721
	(0.004)		(0.341)
ES	−0.726**	Profit	−0.125**
	(0.181)		(0.029)
ENVIR	0.042	DN	0.177**
	(0.002)		(0.060)

Abbreviations: COORP, Industry-university-research cooperation;
DN, Board size; ENVIR, Environmental
protection investment intensity; ES, Enterprise scale;
GIE, Green innovation efficiency; GOVNM, Government financial support;
Lev, Asset-liability ratio; LHD, Ownership concentration; Profit, Net operating cash flow;
RD, Research and development investment.
*and ** are significant at the level of 10% and 5%,
The standard error of the estimated coefficient is shown in parentheses.

specific aspect, forming a construction brand effect and a market advantage. Moreover, with the launch of the sharing platform, SNEs can easily form a construction enterprise community with a complete system and strong strength through the integration of resources and complementary advantages among enterprises, which in turn will help SNEs improve their green innovation ability and improve their GIE. Therefore, the following hypothesis is proposed:

H2: Enterprise scale (ES) is significantly and negatively related to the GIE of SNEs.

3.4.3. Industry-university-research Cooperation

As an innovative activity of the technology alliance, industry-university-research cooperation (COORP) is a process of realizing technological innovation by integrating internal and external technology and knowledge, and its cooperation degree covers two dimensions: breadth and depth. In the process of COORP and innovation, SNEs internalize the new knowledge acquired from partners, enabling their internal knowledge to be dynamically updated and accumulated to improve their technical capabilities, optimize resource allocation, and promote the improvement of GIE. Therefore, the following hypothesis is proposed:

H3: COORP is significantly and positively related to the GIE of SNEs.

3.4.4. Environmental protection input intensity

Enterprise pollution control requires the allocation of funds for environmental protection and the diversion of capital from production and operational activities to environmental protection activities, to comply with environmental protection policies. Environmental protection investment is merely a palliative measure for enterprise production and operation, and an environmental protection behavior that temporarily meets regulatory standards. When enterprises confront government environmental regulations, environmental protection investment becomes an incentive for them to undertake green innovation. Advanced and high-level production technology will gradually assume an important supporting role in enhancing the green production level of enterprises. Environmental protection investment will induce enterprises to implement green innovation. Generally, green innovation activities have a long cycle and require a longer time for preparation, design, R&D, etc., thus the effect of green innovation will not be manifested in a short period. In this study, the amount of environmental protection expenditures, including environmental protection, pollution control, and green environmental protection, is evaluated. Therefore, the following hypothesis is proposed:

H4: The correlation between environmental protection input intensity and the GIE of SNEs is not significant.

3.4.5. The extent of government financial support

Environmental regulations raise the non-productive costs of enterprises. Green innovation is characterized by substantial input, a long cycle, and uncertain output, which results in a lack of motivation for green innovation. Hence, the government is required to offer enterprises innovation support through incentives and compensation. At the stage of green technology R&D, enterprises need to allocate green innovation resources to conduct green R&D activities. However, environmental regulations might cause the crowding out of R&D funds. Therefore, enterprises need government financial support (GOVNM) to bridge the R&D funding gap and improve their enthusiasm for conducting green innovation activities. Therefore, the following hypothesis is proposed:

H5: The extent of GOVNM is significantly and positively related to the GIE of SNEs.

4. Influencing factors analysis on green innovation efficiency of SNEs in Zhejiang

4.1. Variable selection and model setting

4.1.1. Explained variable

The explained variables are the GIE of Zhejiang SNEs and the CRS of Zhejiang SNEs, measured in the previous chapter, and are directly adopted.

4.1.2. Explained variable

A total of five explanatory variables of Zhejiang SNEs are included in the study: (i) R&D expenditure is chosen to measure R&D investment; (ii) the logarithmic worth of the total assets of the enterprise in years 2017–2021 is chosen to measure the ES; (iii) the total amount of green invention and utility model patents jointly authorized in the years 2017–2021 is chosen to measure the degree of COORP; (iv) the total amount of environmental protection expenditures, such as environmental protection expenditure, pollution control expenditure, as well as greening and environmental protection fee, under the environmental and sustainable development item of the company's annual social responsibility report, environmental report, and sustainable development report are selected to measure the environmental protection investment intensity (ENVIR); (v) the ratio of the total amount of government subsidies publicized in the enterprise annual report to the business income is chosen to measure the degree of GOVNM.

4.1.3. Control variable

According to a previous study,[45] the degree of ownership concentration, net operating cash flow, asset-liability ratio, and board size are selected as the control variables for the study. The degree of ownership concentration creates a dual effect by affecting information transfer efficiency and decision-making checks and balances, which may either promote innovation investment by reducing agency costs or inhibit long-term green projects due to interest bias.[46] The asset–liability ratio constrains the allocation of innovation resources through the capital structure, and the pressure of high debt often forces firms to prioritize short-term gain projects and reduce long-term investments in green technology.[47] Board size has an inverted U-shaped relationship with innovation efficiency, while moderate size enhances decision-making expertise, but overexpansion leads to higher coordination costs and lower decision-making efficiency. In contrast, net operating cash flow may have an indirect effect by affecting the overall investment capacity of the firm. Together, these variables constitute the key governance affecting the GIE of SNEs. The specific definitions of the variables are presented in Table 4.

4.1.4. Model setting

To study the factors affecting GIE of SNEs in Zhejiang and provide suggestions for SNEs in Zhejiang to improve GIE, Equation (7) is established.

$$GIE = \alpha_0 + \alpha_1 RD + \alpha_2 ES + \alpha_3 COORP + \alpha_4 ENVIR + \alpha_5 GOVNM + \sum_j \alpha_j w_j + \varepsilon \tag{7}$$

where α_0 is a constant term, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$, and α_j represent the regression coefficients, w_j is the control variable, and ε is the possible residual term.

4.2. Regression analysis of influencing factors

4.2.1. Descriptive analysis

Four indicators—the lowest value, maximum value, average value, and standard deviation—are used to assess the particular circumstances of each variable before the antecedent regression analysis on the GIE of SNEs in Zhejiang. The results are shown in Table 5. It can be seen that the standard deviation of GIE of SNEs in Zhejiang is 0.372, indicating that the overall difference is small. The standard deviations of ENVIR and COORP in SNEs are remarkably large, which indicates significant variations in the degree of emphasis on environmental protection among SNEs.

Pearson's correlation coefficient is shown in Table 6. It can be seen that GOVNM, R&D investment, and COORP are positively correlated with GIE, while ES is negatively correlated with GIE. Meanwhile, correlation coefficients across all variables are lower than 0.5, indicating that there is no collinearity problem across the variables.

4.2.2. Correlation analysis

Table 7 presents the regression results of the model, indicating the effects of R&D investment, ES, COORP, ENVIR, and GOVNM on GIE of SNEs in Zhejiang. The five hypotheses raised previously were analyzed accordingly:

(i) The GIE is significantly positively correlated with R&D investment. Overall, the standardized regression coefficient for R&D investment measured by R&D capital stock is 0.175 and passes the 5% significance test, indicating that R&D investment promotes the improvement of GIE in SNEs. Therefore, H1 is verified. Under the influence of increasing R&D investment in enterprises, the enthusiasm of enterprises for scientific research also increases, which promotes technological innovation and positively affects the GIE in SNEs.[48] Therefore, enterprises should emphasize R&D investment to drive the positive incentive effect on technological innovation.

(ii) There is a significant negative correlation between ES and GIE. Overall, the regression coefficient value for ES is 0.83, indicating that every 1% increase in ES leads to a 0.83% decrease in GIE in SNEs. Therefore, H2 is verified. This shows that the existing ES is relatively reasonable for SNEs, and blind expansion will only hinder the allocation of its resources to meet the expansion needs, resulting in a decline in its innovation ability. If the green innovation ability is further enhanced, it will only result in a cost-squeezing effect, which is not conducive to improving GIE.

(iii) There is a significant positive correlation between COORP and GIE. Overall, the regression coefficient value for the COORP level is 0.107 and passes the significance test at 5%. If the level of COORP increases by 1%, GIE increases by about 0.107%. Therefore, H3 is verified. The breadth of cooperation expands, bringing more cooperation objects, forming a network circle of COORP R&D, obtaining more high-quality resources, prompting enterprises to obtain heterogeneous knowledge from cooperation objects and their existing homogeneous resources to produce complementary effects, stimulating internal R&D, increasing R&D efforts, achieving technological innovation, and improving GIE.

(iv) In Table 7, the coefficient of environmental input intensity in the regression results is not significant, which may be because most of the specialized enterprises are SMEs, and there is a contradiction between short-term cost crowding out and long-term technological forcing in the role of environmental inputs on green innovation. In the short term, environmental investment may consume funds that could have been used for green R&D, leading to a mismatch of resources between innovation and compliance, and there is a cyclical lag in the transformation of environmental investment into green innovation results. Simultaneously, the environmental investment of some enterprises may be allocated only to meet the requirements of policy compliance rather than based on the active investment of green technological upgrading, and a lack of synergies with R&D activities and cooperation between industry, universities, and research institutes, which makes it difficult to effectively transform environmental investment into green innovation, resulting in an insignificant effect in the regression model.

(V) Government financial support and the GIE are notably positively correlated. The regression coefficient value of GOVNM on the GIE is 0.326 overall, surpassing the 5% significance level. This means that GIE of SNEs increases by 0.326% for every 1% increase in GOVNM. Therefore, H5 is verified. Liu[49] found that government science and technology funding has a direct incentive effect on corporate green innovation. Through direct financial assistance and other methods, the government lowers the risk of technological innovation for businesses, promotes innovation activities to a certain extent, creates a favorable environment for innovation, and lessens the cost-cutting impact of green innovation.

4.2.3. Robustness test

To enhance the credibility of the conclusion, the core explained variable, GIE, is replaced with the VRS decomposition variable, and the BCC model is adopted to measure GIE for SNEs in Zhejiang. The results are shown in Table 8. It can be seen that whether the CRS decomposition variable in the CCR model or the VRS decomposition variable in the BCC model is used as the replacement variable of GIE, it is consistent with the results obtained in Table 7, that is, the regression coefficients of R&D investment, COORP, ES, and GOVNM are all significant at the 5% level.

As shown in Table 8, the regression coefficients of R&D investment, COORP, ES, and GOVNM are 0.156, 0.117, 0.726, and 0.827, respectively, which are all significant at 5% level. R&D investment, COORP, and GOVNM are positively correlated with GIE. There is a negative correlation between ES and GIE.

5. Conclusion and recommendations

5.1. Conclusion

Panel data are used from 40 SNEs in Zhejiang from 2017 to 2021 as a sample. The CCR input-oriented super-SBM model is employed to measure the GIE of these 40 SNEs. Subsequently, using the systematic GMM dynamic model, this paper finds that influencing factors, such as R&D investment, ES, COORP, and GOVNM, have an important impact on GIE. Previous studies have found that government subsidies can enhance the ability of enterprises in green technology innovation, as R&D investment is positively affected by government financial subsidies. While government subsidies can help to improve the green technology innovation ability of SNEs, this paper does not take R&D investment as a mediating variable, and by directly analyzing R&D investment and policy support, we focus more on these two core factors, and thus more accurately assess their role in enhancing GIE. The core explanatory variables are replaced to conduct tests, resulting in two conclusions.

Firstly, this paper evaluates the GIE of SNEs in Zhejiang province. Overall, the GIE of SNEs in Zhejiang is relatively low. From 2017 to 2021, the average value of the CRS of SNEs was 0.807, 0.773, 0.779, 0.724, 0.704, showing a general downward trend, and a small number of them were in the state of inefficiency, reflecting the decline in the level of the ability of the SNEs to configure and utilize the resources for innovation. There are spaces available to improve the GIE. Additionally, both VRS and scale efficiency fail to reach optimal levels. As emerging enterprises in recent years, GIE has not been much emphasized. However, this also indicates that there is still significant room for improvement in the GIE of SNEs in Zhejiang.

Second, the GIE in resource-based cities is examined. R&D investment and GIE are significantly positively correlated. SNEs should invest more in R&D to boost the effectiveness of their green innovation. Additionally, there is a strong negative correlation between the GIE in Specialized and New Enterprise and their size. For SNEs, maintaining the current ES rather than rushing to expand is more beneficial for improving their GIE. Furthermore, there is a significant positive correlation between COORP and GIE. For SNEs, strengthening their cooperation with other institutions can enhance GIE. Moreover, the GIE and GOVNM are significantly positively correlated. One efficient strategy to increase resource-based cities' GIE is to increase government funding. Lastly, the effectiveness of corporate green innovation may also be influenced by operating profit margin and board size, suggesting that the effectiveness of corporate green innovation may be connected to the operational capabilities and management of the business, which should be taken into consideration.

5.2. Policy recommendations

Considering the systematic GMM dynamic model, this paper finds that influencing factors, such as R&D investment, ES, COORP, and GOVNM, all have important impacts on GIE. Based on this, this paper suggests targeted policy recommendations from four aspects to provide help and reference significance for the improvement of GIE in SNEs.

Firstly, establish and improve a comprehensive research mechanism. Investment in R&D funding is a crucial guarantee for innovation. The enterprise innovation system should reasonably increase R&D funding, improve the efficiency of R&D funding utilization, and rely on issuing green innovation subsidy policies to guide social funds into the green innovation field, thereby enhancing the enterprise's innovation capability and economic development level. It is advisable to strengthen efforts to attract research talent, optimize incentive mechanisms, and broaden channels for talent introduction while increasing the number of personnel and effectively enhancing the innovation capability of enterprises.

Secondly, establish connections for cooperation between enterprises and research institutes, as well as between enterprises and universities. There is a significant positive correlation between COORP and GIE. Due to the spillover effects of green innovation, establishing a comprehensive cooperation and mutual assistance relationship is essential for enhancing the green innovation levels of SNEs and reducing the differences in GIE among these enterprises. It is vital to learn from the development experience of companies with high GIE to strengthen the flow of outstanding talent and enhance one's own GIE.

Thirdly, maintain a stable business scale. ES has a significant negative correlation with GIE. As the representatives of SMEs, SNEs have certain limitations in their expansion capabilities compared to large enterprises. Blind expansion only backfires, leading to a decline in their green innovation capabilities. Therefore, SNEs should focus on their strengths, leveraging their inherent advantages in market competition to gain a competitive edge, thereby further enhancing their innovation capabilities and improving their GIE. SNEs should focus on improving management efficiency, optimizing resource allocation, and reducing operating costs through the implementation of refined management to enhance the GIE. Besides, establishing an internal innovation incentive mechanism to encourage employees to suggest green innovation proposals and rewarding excellent innovation results to stimulate employees' enthusiasm for innovation can result in GIE improvement as well. During the process of expansion, the enterprise should give full consideration to enhancing GIE and avoid blindly pursuing scale expansion, which neglects the importance of green transformation.

Lastly, reform government subsidy schemes and bolster government assistance. One of the four factors with the most effective impact is government support, which is essential for improving the GIE. To enhance the innovation ability and leadership role of SMEs, the government should first improve its policy support capabilities and unleash the innovative vitality of businesses. Since businesses are the foundation, it is crucial to concentrate on resource allocation to consistently allocate scarce societal resources to green innovation in businesses while encouraging green transformation and industry upgrading through intense market rivalry. Additionally, it is sensible to encourage SMEs to increase research investment and establish research centers, guiding SMEs to conduct fundamental and cutting-edge R&D. Lastly, utilizing the signaling effect of government subsidies encourages further investment from investors and alleviates the financing pressure on enterprises, enhancing the GIE.

As one of the most economically active provinces in China, Zhejiang Province is representative of the development of GIE of SNEs in the country. Although the policy orientation, as well as external circumstances, such as technological innovation in Zhejiang Province, may be better than the average level of SNEs in China, resulting in the superior development of GIE of SNEs in Zhejiang, the policy recommendations are generally applicable, which can provide a path for the development of SNEs across the country.

5.3. Research limitations

SNEs cover a wide range of industries, and their development is affected by a variety of factors. The current study faces two limitations that require improvement.

This study primarily focuses on the two dimensions of input indicators and output indicators, and prudently selects key factors, such as R&D investment, ES, COORP, and GOVNM, for consideration. However, the influence of other factors, such as enterprise culture and management level, on GIE may be neglected. Additionally, external environmental factors, such as policy orientation adjustments, fluctuating market demand, and technological iteration speeds, may have far-reaching impacts on GIE. However, it is challenging to control and quantify these factors in the study. Furthermore, given that the sample selected for this study includes 40 SNEs with different characteristics in Zhejiang, different enterprises may not follow the same standards in data reporting and recording, which may increase the difficulty of comparing the data with each other. Therefore, it may affect the accuracy and reliability of the study results.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Mengxue Li, Ruiyan Gao
Formal analysis: Qizhe Mao, Mengxue Li
Investigation: Xiyi Li, Qizhe Mao
Methodology: Yaguai Yu
Writing–original draft: Ruiyan Gao, Mengxue Li
Writing–review & editing: Yaguai Yu

Availability of data

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AI Tools Statement

All authors confirm that no AI tools were used in the preparation of this manuscript.

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Mengxue Li *Born in August 2001, Bengbu, Anhui Province, P.R. China. A postgraduate student of Business School of Ningbo University, majoring in accounting.*
https://orcid.org/0009-0008-5924-0515

Ruiyan Gao *Born in August 2004, Huzhou, Zhejiang Province, P.R. China. Undergraduate student of Business School of Ningbo University, majoring in Economics.*
https://orcid.org/0009-0006-7790-9855

Yaguai Yu *Born in August 1976, Ningbo, Zhejiang Province, P.R.Chian. Professor of Ningbo University, Master's Supervisor, PHD. Research field focused in innovation of enterprise and corporate finance.*
https://orcid.org/0009-0005-0625-9923

Xiyi Li *Born in October 2004, Taizhou, Zhejiang Province, P.R.Chian. A 2023-level student at Yangming College of Ningbo University, majoring in Accounting.*
https://orcid.org/0009-0002-8771-3988

Qizhe Mao *Born in January 1999, Zhoushan, Zhejiang Province, P.R.Chian. An employee of the Tobacco Monopoly Bureau of Putuo District, Zhoushan City, Zhejiang Province, Engaged in discipline inspection work.*
https://orcid.org/0009-0004-0372-583X

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