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THE EFFICIENCY OF FINANCING AND R&D IN TECHNOLOGY-BASED SMES AND IMPACT OF FINANCIAL REGULATION

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Abstract. Technological innovation is a long-term activity with highly unpredictable returns on investment, which makes SMEs with information problems and lack of collateral value be vulnerable to financing constraints when engaging in innovation activities. This study incorporates financing and R&D activities into the evaluation of innovation efficiency and further considers the impact of financial regulation as an external factor in technology-based SMEs in China. This study puts forward a three-stage dynamic DDF-DEA model to explore the overall innovation efficiency as well as the efficiency of each stage in technology-based SMEs by dividing the innovation process into three stages, namely the financing stage, R&D stage and operating stage. The study reveals that the overall efficiency of innovation are higher in non-coastal areas of China than in coastal areas. Non-coastal regions have higher efficiency in the financing and operating stages, while coastal regions have higher efficiency in the R&D stage. Strengthening financial regulation could improve the financing and R&D efficiency both in coastal and non-coastal areas, but it has different effect on the operating efficiency in coastal and non-coastal areas. The results of this study could provide some reference for China and other emerging economies to formulate policies in improving the efficiency of financing and R&D.

Keywords: financing efficiency, R&D efficiency, innovation, SMEs, financial regulation, three-stage dynamic DDF-DEA.

JEL Classification: G28, G32, D22, O31, B41, C67.

Introduction

Technological innovation is the primary driver of economic development, and it is inextricably linked to capital and financing. Financial institutions and organizations play a critical role in the financing process of technology-based enterprises. For example, Korean financial institutions allow small and medium-sized enterprises (SMEs) to use their patents and technologies for loan applications based on the value evaluation of these intellectual properties.

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Many Japanese commercial banks have also established specialized institutions and products to improve financial services for technology-based enterprises (China National Intellectual Property Administration, 2019).

China's financial system is less effective than that of developed countries in promoting technological innovation. There are still many issues in China's financial system at present. Firstly, technology-based enterprises and particularly technology-based SMEs, are frequently plagued by a lack of funding. Technology-based SMEs play a key role in China's technological innovation system, contributing more than 70% of the achievements (Shen, 2021). Although these SMEs have intellectual property rights and technology, their tiny size has made it difficult for them to secure enough loans. Secondly, there may be discrepancies in the efficiency of the financial system in supporting innovation in different regions of China. For example, the abilities of financing and innovation vary greatly between urban and rural areas, as well as coastal and non-coastal areas in China, due to the differences in economic development.

This paper selects coastal and non-coastal areas for comparative analysis. There is a huge gap in the development of the financial industry between urban and rural areas in China. Innovation resources are also mainly concentrated in urban areas. Therefore, the level of innovation is much lower in rural than that in urban areas. The research value of comparative analysis between urban and rural areas is relatively low. However, in the innovation process, it is difficult to judge which areas has higher efficiency in financing and research and development (R&D) activities between coastal and non-coastal areas in China. The coastal areas are more developed and richer in financial and technological resources compared with the non-coastal areas, however, the costs of human and material resources are also higher in coastal areas. Therefore, this does not mean that the financing and R&D efficiency of enterprises in coastal areas of China must be higher than that of enterprises in non-coastal areas in the innovation process. Further study need to be carried out on researching which group have higher efficiency of financing and R&D between coastal and non-coastal areas.

The primary purpose of this study is to incorporate financing, R&D and operating activities into the evaluation of innovation efficiency and further consider the impact of financial regulation on the entire innovation process in technology-based SMEs. Increasing the effectiveness of the financial system in supporting technological innovation has become an important mission for every country. Despite some studies have attempted to open the black box of the innovation process (Wang et al., 2016; Feng et al., 2021), researches on the internal mechanisms of innovation is still insufficient, especially do not take into account the financing and R&D activities at the same time. In addition, financial regulations play an important role in the process of financial activities supporting technological innovation. The financial system could stimulate technological development, the transformation of technological achievements, and the development of high-tech industries through a variety of arrangements for financial instruments, financial policies, and financial services (Zhao et al., 2009). However, these arrangements must be carried out under strict regulation. Strengthening the regulation of financial institutions and enterprises in the financial market is conducive to reducing risks (Kou et al., 2022) and maintaining the stability of the financial market (Jungo et al., 2022). Most previous literature on the efficiency of innovation in technology-based SMEs ignored the impact of financial regulation. Therefore, by analyzing the efficiency of the entire process of innovation in SMEs, this article could help us understand the efficiency of financing and R&D in technology-based SMEs in different regions of China and explain the reasons of why there is a difference between coastal and non-coastal areas. What's more, the intensity of financial regulation is added to the Direction Distance Function-Data Envelopment Analysis (DDF-DEA) model as a non-discretionary variable in this study to investigate the different impacts of this external factor on the innovation efficiency in technology-based SMEs in coastal and non-coastal areas of China. On the basis of the results of this study, we could make specific recommendations for China and other emerging economies to improve the efficiency of the financial system in supporting technological innovation.

This study offers three important contributions. Firstly, this study proposed the three-stage meta under exogenous dynamic DDF-DEA model, which can make up for the shortage of the one-stage and two-stage functions, explain more complex and comprehensive internal mechanisms, solve the problems of the heterogeneity of the production technology level and further consider the effect of exogenous variables. Secondly, financing, R&D investment, technological achievements and the earning of enterprises are included in one model at the same time. We could explore the efficiencies of each stage as well as the overall efficiencies of innovation by dividing the technological innovation process into three stages: financing stage, R&D stage and operating stage. Thirdly, the intensity of financial regulation is added into the DDF-DEA model as an exogenous variable to investigate the influence of this external environmental factor and further propose the recommendations on how the financial system could improve its efficiency in supporting technological innovation.

The rest of the paper is organized as follows. Section 1 gives the literature review. Section 2 introduces the research model and the overall methodology. Section 3 presents the empirical results. And the final section provides the conclusion and implication.

1. Literature review

Innovation is the primary reason for enterprises to make profits and maintain the continuity of operation in the market competition. The literature review is reorganized from three perspectives: the relationship between financing and innovation efficiency, the relationship between R&D and innovation efficiency, and the impact of financial regulation on the production efficiency of various activities in enterprises, such as financing, R&D and innovation.

Researchers believe that easy access to financing would have a significant impact on the innovation efficiency of enterprises. Schumpeter (1934), the founder of innovation theory, first proposed the important role of financing in corporate innovation. He considers that a necessary condition for carrying out innovation is that the enterprises must have sufficient funds. After obtaining the funds in the financial market, enterprises would put some observable indicators, such as R&D expenditure and R&D personnel into the R&D process to obtain technological achievements. The financing behavior of companies will significantly increase their current R&D investments and subsequent technological performances. And this positive impact will change as companies' financing constraints and technological innovation undergo tremendous changes (Liu et al., 2021b). Easy access to equity and debt financing is particularly vital for companies, especially young innovation companies that lack reputational capital and have serious information asymmetries with external financial institutions (Colombelli et al., 2020). Easily accessible loans for young innovation companies may increase their reliance on formal financing mechanisms instead of collateralizing the intangible value generated through innovative activities. For many technology-based enterprises, external equity financing can meet their needs better than debt financing (Belo et al., 2019).

The information asymmetry between technology-based enterprises and financial institutions is the main reason that influences their financing efficiency. Financial institutions believe that technology-based enterprises, especially those in the early stage of development, have low security and credibility and are likely to be unable to afford to pay the mortgage (Brancati, 2015; Alam et al., 2019; Møen, 2019). Therefore, they are cautious about granting loans to these companies. Researchers also found that banks lack expertise in the technical field and the assets that technology-based enterprises can provide to banks as collateral are also limited. The information asymmetry is more prominent when the bank's loan decision is related to the enterprise's innovation project in comparison to other types of projects (Bustos-Contell et al., 2019). The researchers propose that the credit constraints faced by technology-based enterprises could be solved in the following two ways. On one hand, banks could rely on some external information and technical assistance to alleviate the problem of information asymmetry between them and technology-based enterprises. Financial institutions such as banks can use government R&D grants as a quality signal of a enterprise's R&D projects, so as to alleviate information asymmetry with these enterprises (Wu et al., 2021). The application of financial technology in commercial banks can also alleviate the pre- and post-loan risk associated with credit activities (Pan et al., 2021; Zhang et al., 2022). On the other hand, technology-based enterprises can also turn to external equity financing. External investors, such as venture capital firms, can further improve companies' innovation capabilities and market-based returns of innovation outputs by identifying technology-based enterprises with development potential and providing them with investment funds (Shinkle & Suchard, 2019).

Many studies view innovation as a production process that converts inputs to outputs, and research the influence of R&D activities on the innovation efficiency. Firstly, the usage of an enterprise's own R&D resources is the primary factor that determines the innovation efficiency. The scale of R&D investments and companies' attention to R&D activities are the major reasons affecting the innovation efficiency of enterprises (Barasa et al., 2019). A number of studies have demonstrated that there is a positive relationship between the R&D intensity and technological innovation outcomes of enterprises (Conte & Vivarelli, 2014; Baumann & Kritikos, 2016; Zhang et al., 2019). However, more R&D investments by an enterprise could not guarantee increased innovation outputs. Yang et al. (2020) find that R&D resource misallocation might lead to innovation inefficiency. And they propose that enterprises could tackle this problem by increasing the input factors of R&D with a higher output elasticity by adjusting the factor-biased level of technological innovation. Aside from the scale of R&D investments, the length of time for R&D investments and whether there is any interruption in the time span of R&D activities would also have an impact on enterprises' innovation results. R&D activities show positive dynamic returns, but the growth rate of these positive returns is decreasing. Disruption of R&D investments in enterprises is typically accompanied with a range of adjustment expenses, such as the cost of firing or rehiring trained personnel, losing proprietary information or innovative ideas and sunk costs (Beneito et al., 2015; Kang et al., 2017; Xiang et al., 2020). As a result, R&D-intensive enterprises might opt to protect their R&D investments by selling operating and financial assets (Liu et al., 2021a). Many studies also emphasize the critical significance of effective R&D collaboration in improving innovation efficiency. Different types of R&D cooperation exhibit distinct features and have different effects on innovation efficiency. Based on the different performances of these cooperation methods, managers could build collaborative innovation strategies and cooperation models that are appropriate for the company's development according to the actual needs of the company (Lee et al., 2019; Feng et al., 2022).

Furthermore, many efforts have been made to prove the importance of financial regulation on improving the production efficiency of enterprises. Johnston (2013) takes the United States as an example to illustrate that seeking efficiency without concentrating on regulation will lead to increasing deregulation and ultimately have numerous adverse effects. Financial regulations are established to reduce financial and economic instability without jeopardizing the economic contributions of financing institution to economic development (Rizwan et al., 2018). Financial regulation will not distort or stifle behaviors that are beneficial to enterprises' long-term operations. On the contrary, it could assist enterprises dealing with the difficulties they face in their daily operations more efficiently (Hlaing & Kakinaka, 2018). Generally, the net benefit of regulation for both micro- and macro-level, direct and indirect, is positive, justifying the existence of regulation itself. The public interest theory of regulation proposed by Kern (2019) suggests that governments could take policy and regulatory interventions to deal with negative externalities generated by market distortions and regulatory arbitrage. Effective financial regulation could improve the production efficiency of enterprises by eliminating systemic risks (Kou et al., 2022), enhancing asset quality and capital levels (Igan & Mirzaei, 2020), limiting unsustainable bank credit expansion (Gupta & Kashiramka, 2020), and preventing financial instability (Anarfo et al., 2020; Jungo et al., 2022). Thus, financial regulation is unquestionably important to maintain a fair playing field inside and between financial systems, ensure the soundness and resilience of banking systems and protect the orderly running of businesses. Financial regulation, whether macro-regulation aimed at preventing systemic financial risks, or micro-regulation focusing on the compliance and risk exposure of specific financial institutions, could enhance the stability of financial system and create favorable external conditions for improving the efficiency of enterprises (Kou et al., 2022).

2. Method

2.1. The framework of evaluating efficiency with DDF-DEA model

DEA is a linear programming model that could assess the Decision Making Unit (DMU) using Pareto's optimal solution instead of establishing the efficiency frontier using a predefined function. Therefore, it is widely used in the literature on efficiency evaluation. To analyze the relative efficiency relationship between DMUs, Charnes et al. (1978) propose the CCR model and Banker et al. (1984) propose the BCC model of DEA. Since CCR model and BCC model are radial estimate methods, Tone (2001) propose Slacks-Based Measure (SBM) model on the basis of the non-radial measurement model. Chung et al. (1997) propose the idea of the output-oriented DDF-DEA. DDF-DEA is widely used in efficiency measurement because it can cope with the decrease in inputs and the increase in outputs at the same time. Färe and Grosskopf (2010) as well as Chen et al. (2015) establish a non-directed direction distance function. This function is superior to others because it could provide a more reasonable and reliable estimation result. At the same time, DEA also allows the evaluation of different stages in the entire process. Färe et al. (2007) propose the network DEA model, which considered that the entire production process is made up of many secondary production technologies. These secondary production technologies could be seen as sub-decision making units (Sub-DMU), and seek the best solution through classic CCR and BCC modes. Tone and Tsutsui (2009) subsequently propose the weighted slack-based measures network DEA model. This model uses the linkage among decision making units as the analytical basis for the network DEA model, and then uses the SBM model to identify the optimal solution. More and more literature has been devoted to study the multi-stage production process and its efficiency evaluation in recent years. The multi-stage DEA can also apply dynamic methods to this model. By introducing carryover to connect DMUs of different stages in different periods, this model can evaluate DMUs in different periods. Therefore, many researchers have added dynamic analysis to the multi-stage model (Tone & Tsutsui, 2014; Li et al., 2019; Zhang et al., 2019; Li et al., 2020; He et al., 2021; Feng et al., 2021).

The classic DEA methods generally presume that all producers have the same level of production technology when evaluating efficiency. However, the assessed DMUs usually have distinct levels of production technologies due to the differences in geographical positions, national policies, and socioeconomic conditions. Battese et al. (2004) and O' Donnell et al. (2008) apply the concept of meta-frontier to the efficiency estimation of DEA. Firstly, estimating the meta-frontier through all group samples. Secondly, the DMUs are split into groups, and the group frontier of each group is estimated separately. Finally, using the distance between the meta frontier and the group frontier to evaluate whether the production technology level used by the group samples is close to the potential production technology level of the meta frontier. The indicator reflecting the distance between the group frontier and the meta frontier is the technology gap ratio (TGR).

The innovation process includes a series of complicated activities, such as financing, research, development, demonstration, deployment, and commercialization (Kou et al., 2020). Some studies have begun to open the black box in the traditional DEA model, and used two-stage DEA models to evaluate the efficiency of innovation in different countries or enterprises (Wang et al., 2016; Feng et al., 2021). However, their studies on the internal mechanisms of innovation is still incomprehensive. To solve this problem, we propose a three-stage meta under exogenous dynamic DDF-DEA model to evaluate the efficiency of innovation in technology-based SMEs in China. The framework of the input-output relationship of each stage to evaluate efficiency in innovation process is shown in Figure 1.

This study divides the innovation process into three stages. The first stage is the financing stage, the second stage is the R&D stage and the third stage is the operating stage. Schumpeter (1934), the founder of innovation theory, proposes that technological innovation is to

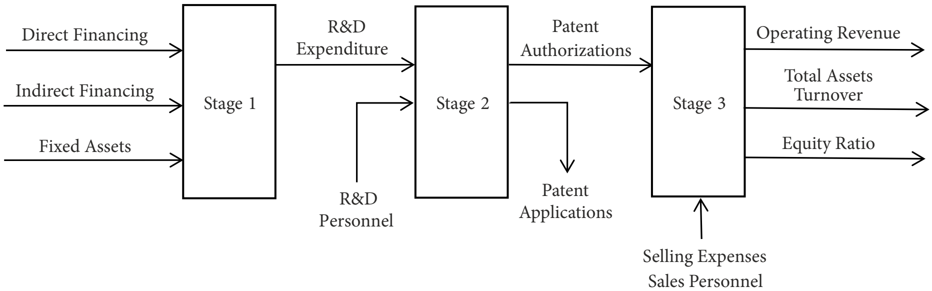

Figure 1. The framework of a three-stage innovation process

introduce new combinations of production factors and conditions into the production system. A necessary condition for carrying out these activities is that the enterprises must have sufficient funds. After obtaining the funds in the financial market, enterprises will put some observable indicators, such as R&D expenditure and R&D personnel into the R&D process to obtain technological achievements. It is also worth noting that innovation is a process that can generate profits. Only technological achievements that can create profits and improve the performance of enterprises are effective in the technological innovation process.

The three-stage meta under exogenous dynamic DDF-DEA model proposed in this paper refers to the DDF model proposed by Färe and Grosskopf (2010) and Chen et al. (2015), and further considers the concept of the dynamic network DEA model proposed by Tone and Tsutsui (2014), as well as the concept of the meta frontier model proposed by O'Donnell et al. (2008). Furthermore, the issue of exogenous variables is also considered on the basis of those previous studies. The three-stage function could make up for the shortage of the one-stage and two-stage functions, and solve the problems of the heterogeneity of the production technology level. The specific description of the three-stage meta under exogenous dynamic DDF-DEA model is as follows.

2.2. Three-Stage Meta Under exogenous dynamic DDF-DEA model

Assume that due to different management types, resources, regulations, or environments, all manufacturers (N) are composed of decision-making units ($N = N_1 + N_2 +....+ N_g$) of g groups. Suppose there are three stages in each t time periods $\left(t=1,\ldots,T\right)$. In each time period, there are three stages, including financing stage, R&D stage and operating stage. The financing stage has M inputs $x_{ij}^t\left(i=1,\ldots,m\right)$ to generate D intermediate products $z_{dj}^t\left(d=1,\ldots,D\right)$ and K desirable outputs $o_{kj}^t\left(k=1,\ldots,K\right)$. R&D stage using D intermediate products $z_{dj}^t\left(d=1,\ldots,D\right)$ and Q inputs $w_{qj}^t\left(q=1,\ldots,G\right)$, to generate S desirable output $y_{sj}^t\left(s=1,\ldots,S\right)$ and E intermediate products $u_{ej}^t\left(e=1,\ldots,E\right)$ at the same time. Operating stage using E intermediate products $u_{ej}^t\left(e=1,\ldots,E\right)$ and B inputs $f_{bj}^t\left(b=1,\ldots,B\right)$ to generate L desirable output $n_{lj}^t\left(l=1,\ldots,L\right)$. $c_{hj}^t\left(h=1,\ldots,H\right)$ is the carry-over factor and V are exogenous variables $p_{vj}^t\left(v=1,\cdots,V\right)$. The inputs in the first stage are direct financing and indirect financing and the output is R&D expenditure. R&D expenditure is also the link between the first stage and the second stage. The inputs in the second stage is R&D personnel, the output is the number of patent applications. The link between the second stage and the third stage is the number of patent authorizations. The inputs in the third stage are selling expenses and sales personnel, and the output is operating revenue, total assets turnover and equity ratio. Carry-over is the fixed asset.

x_{ij}^{t}: Direct financing and indirect financing.

o_{kj}^{t}: R&D expenditure.

z_{dj}^{t}: R&D expenditure (link between the financing stage and R&D stage).

w_{qj}^{t}: R&D personnel.

y_{sj}^{t}: Patent applications.

u_{ej}^{t}: Patent authorizations (link between the R&D stage and operating stage).

f_{bj}^{t}: Selling expenses and sales personnel.

n_{lj}^{t}: Operating revenue, total assets turnover and equity ratio.

c_{hj}^{t}: Fixed assets.

p_{vj}^{t}: Financial regulation.

Under the meta frontier, the decision unit can choose the final output that is most favorable to its maximum value, so the efficiency of the decision unit under the common boundary can be solved by the following linear programming procedure.

(a) Objective function

Overall efficiency:

The efficiency of the DMU is:

$$\max \text{MFE} = \sum_{g=1}^{G}\sum_{t=1}^{T}\gamma_{tg}\left(w_{1g}^{t}\theta_{1g}^{t} + w_{2g}^{t}\theta_{2g}^{t} + w_{3g}^{t}\theta_{3g}^{t}\right). \tag{1}$$

S.T.

Financing stage

$$\sum_{g=1}^{G}\sum_{j}^{n}\lambda_{jg}^{t}X_{ijg}^{t} \le \theta_{1g}^{t}X_{ipg}^{t}\ \forall i,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\lambda_{jg}^{t}z_{djg}^{t} \le \theta_{1g}^{t}z_{dpg}^{t}\ \forall d,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\lambda_{jg}^{t}o_{kjg}^{t} \ge \theta_{1g}^{t}o_{kpg}^{t}\ \forall k,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\lambda_{jg}^{t} \le 1$$

R&D Stage

$$\sum_{g=1}^{G}\sum_{j}^{n}\mu_{jg}^{t}Z_{djg}^{t} \le \theta_{2g}^{t}Z_{dpg}^{t}\ \forall d,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\mu_{jg}^{t}y_{sjg}^{t} \ge \theta_{2g}^{t}y_{spg}^{t}\ \forall s,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\mu_{jg}^{t}w_{qjg}^{t} \le \theta_{2g}^{t}w_{qpg}^{t}\ \forall g,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\mu_{jg}^{t}u_{ejg}^{t} \le \theta_{2g}^{t}u_{epg}^{t}\ \forall e,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\mu_{jg}^{t} = 1$$

Operating Stage

$$\sum_{g=1}^{G}\sum_{j}^{n}\rho_{jg}^{t}u_{ejg}^{t} \le \theta_{3g}^{t}u_{epg}^{t}\ \forall e,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\rho_{jg}^{t}f_{bjg}^{t} \le \theta_{3g}^{t}f_{bpg}^{t}\ \forall b,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\rho_{jg}^{t}n_{ljg}^{t} \le \theta_{3g}^{t}n_{lpg}^{t}\ \forall l,\forall t$$

$$\sum_{g=1}^{G}\sum_{j}^{n}\rho_{jg}^{t} = 1$$

$$\lambda_j^t \geq 0 \;\forall j, \forall t \quad \mu_j^t \geq 0 \;\forall j, \forall t \quad \rho_j^t \geq 0 \;\forall j, \forall t. \tag{2}$$

The exogenous variables

$$\sum_{g=1}^{G}\sum_{j=1}^{n} \lambda_{1g}^t p_{vjg}^t = \theta_{1g}^t p_{vpg}^t \;\forall v, \forall t. \tag{3}$$

The link of first and second stages

$$\sum_{g=1}^{G}\sum_{j=1}^{n} \lambda_{jg}^t Z_{djg}^t = \sum\sum_{j=1}^{n} \mu_{jg}^t Z_{djg}^t \;\forall d, \forall t.$$

The link of second and third stages

$$\sum_{j=1}^{n} \mu_{jg}^t u_{ejg}^t = \sum_{j=1}^{n} \rho_{jg}^t u_{ejg}^t \;\forall e, \forall t.$$

The link of two periods

$$\sum_{g=1}^{G}\sum_{j=1}^{n} \lambda_{jg}^{t-1} c_{hjg}^t = \sum_{g=1}^{G}\sum_{j=1}^{n} \lambda_{jg}^t c_{hjg}^t \;\forall h, \forall t. \tag{4}$$

w_1^t w_2^t and w_3^t are the weights assigned to the financing stage, R&D stage and operating stage respectively. Therefore, w_1^t w_2^t and w_3^t, ≥ 1 and $\sum_{g=1}^{G}\sum_{j=1}^{n} \gamma_{tg} = 1$.

From the above, the overall efficiency, period efficiency, division efficiency, and division period efficiency can be obtained using the meta-frontier model.

2.3. Group-frontier (GF)

As each DMU under the group frontier chooses the most favorable final weighted output, the DMU efficiencies under the group frontier are solved using the following equations:

(a) The objective function

The efficiency of the DMU is:

$$\max \text{GFE} = \sum_{t=1}^{T} \gamma_t \left(w_1^t \theta_1^t + w_2^t \theta_2^t + w_3^t \theta_3^t \right). \tag{5}$$

S.T.

Financing stage	R&D Stage	Operating Stage
$\sum_{j}^{n} \lambda_j^t X_{ij}^t \leq \theta_1^t X_{ip}^t \;\; \forall i, \forall t$	$\sum_{j}^{n} \mu_j^t Z_{dj}^t \leq \theta_2^t Z_{dp}^t \;\; \forall d, \forall t$	$\sum_{j}^{n} \rho_j^t u_{ej}^t \leq \theta_3^t u_{ep}^t \;\; \forall e, \forall t$
$\sum_{j}^{n} \lambda_j^t z_{dj}^t \leq \theta_1^t z_{dp}^t \;\; \forall d, \forall t$	$\sum_{j}^{n} \mu_j^t y_{sj}^t \geq \theta_2^t y_{sp}^t \;\; \forall s, \forall t$	$\sum_{j}^{n} \rho_j^t f_{bj}^t \leq \theta_3^t f_{bp}^t \;\; \forall b, \forall t$
$\sum_{j}^{n} \lambda_j^t q_{kj}^t \geq \theta_1^t q_{kp}^t \;\; \forall k, \forall t$	$\sum_{j}^{n} \mu_j^t w_{gj}^t \leq \theta_2^t w_{gp}^t \;\; \forall g, \forall t$	$\sum_{j}^{n} \rho_j^t n_{lj}^t \leq \theta_3^t n_{lp}^t \;\; \forall l, \forall t$

$$\sum_{j}^{n} \mu_j^t u_{ej}^t \leq \theta_2^t u_{ep}^t \;\; \forall e, \forall t$$

$$\sum_{j}^{n} \lambda_j^t \leq 1 \qquad \sum_{j}^{n} \mu_j^t = 1 \qquad \sum_{j}^{n} \rho_j^t = 1$$

$$\lambda_j^t \geq 0 \;\; \forall j, \; \forall t \;\;\; \mu_j^t \geq 0 \;\; \forall j, \forall t \;\;\; \rho_j^t \geq 0 \;\; \forall j, \forall t. \tag{6}$$

The link of first and second stages

$$\sum_{j=1}^{n} \lambda_j^t Z_{dj}^t = \sum_{j=1}^{n} \mu_j^t Z_{dj}^t \;\; \forall d, \forall t.$$

The link of second and third stages

$$\sum_{j=1}^{n} \mu_j^t u_{ej}^t = \sum_{j=1}^{n} \rho_j^t u_{ej}^t \;\; \forall e, \forall t.$$

The link of two periods

$$\sum_{j=1}^{n} \lambda_j^{t-1} c_{hj}^t = \sum_{j=1}^{n} \lambda_j^t c_{hj}^t \;\; \forall h, \forall t. \tag{7}$$

Among them, γ_t is the weight assigned to the period t, w_1^t w_2^t and w_3^t are the weights assigned to the Financing stage, R&D Stage and Operating Stage respectively. Therefore, w_1^t w_2^t and w_3^t, ≥ 1 and $\sum_{t=1}^{T} \gamma_{tg} = 1$.

From the above results, the overall efficiency, the period efficiency, the division efficiency and division period efficiency are obtained.

2.4. Technology Gap Ratio (TGR)

As the meta-frontier model contains g groups, the technical efficiency of the meta-frontier (MFE) is less than the technical efficiency of the group frontier (GFE). The ratio value, or the technology gap ratio (TGR), is:

$$\mathrm{TGR} = \frac{\rho^*}{\rho^{*g}} = \frac{\mathrm{MFE}}{\mathrm{GFE}}. \tag{8}$$

3. Empirical study

3.1. Data sources and description

This paper studied the efficiency of financing and R&D in the innovation process of technology-based SMEs listed on China's National Equities Exchange and Quotations (NEEQ) from 2015 to 2019. The administrative regions of China are divided into coastal areas and non-coastal areas based on whether they have coastlines according to the "China Marine Statistical Yearbook"[1]. The coastal areas of mainland China include Tianjin, Hebei, Liaoning,

[1] The website is https://data.cnki.net/yearbook/Single/N2021070174

Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi and Hainan. Coastal areas tend to be more economically developed and more attractive to talent due to easier access to sea transportation and a more convenient surrounding transportation system. Therefore, the technology-based SMEs in this study are divided into two groups: SMEs in coastal areas of China and SMEs in non-coastal areas of China. Enterprises listed on the NEEQ are classified into 19 categories according to the official guidelines for the Classification of Listed Companies' Management Industries. The technology-based SMEs studied in this article are those that belong to the scientific research and technical service industry. We exclude enterprises with severe data missing based on the data availability and finally obtained data for research from 60 SMEs in coastal areas of China and 50 SMEs in non-coastal areas of China.

The variables of each stage are shown in Table 1. According to Mintz (2004), Yi et al. (2021) and Liu et al. (2022), corporate financing mainly includes two forms: direct financing, which does not require the intervention of financial intermediaries, and indirect financing, which require the intervention of financial intermediaries. Therefore, direct and indirect financing are chosen as input variables for the financing stage in this study. From the standpoint of the production process, Schumpeter (1934) described innovation as a "new combination" of components. The combination of these production parameters could have a direct impact on innovation efficiency. Some visible input indicators, mainly R&D expenditure and R&D personnel, are invested in the R&D process and are directly used to generate valuable knowledge which are usually measured by the number of patent applications and patent authorizations (Huang et al., 2020; Chen et al., 2021; Feng et al., 2021). Schumpeter also proposed that innovation is the process of creating new value. Only R&D knowledge that creates value and revenue can really play a role in the innovation process. This study refers to the researches of Malhotra et al. (2015), Houmes et al. (2018) and Zhu et al. (2020), and chooses operating revenue, total assets turnover and equity ratio as output variables to measure the operation performance of the innovation achievements.

Table 1. Input and output variables

Stage	Input Variables	Output Variables	Link	Carry-over
Stage 1	Direct Financing Indirect Financing		R&D Expenditure	Fixed Assets
Stage 2	R&D Personnel	Patent Applications		
Stage 3	Selling Expenses Sales Personnel	Operating Revenue Total Assets Turnover Equity Ratio	Patent Authorizations	

The first stage: Financing stage

Input Variables:

Direct Financing: Funds raised without the intervention of financial intermediaries, including funds raised by enterprises through the issuance of stocks and bonds. The data of this variable is taken from the sum value of "cash received from absorbing investment" and "cash received from issuing bonds" in the annual financial report of each enterprise[2]. Unit: Ten thousand yuan.

Indirect Financing: Funds raised through the intervention of financial intermediaries between enterprises that lack funds and enterprises or individuals with idle funds, mainly referring to funds raised through bank credit. The data of this variable is taken from the value of "cash received from loans" in the annual financial report of each enterprise. Unit: Ten thousand yuan.

The second stage: R&D stage

Input Variables:

R&D Personnel: The number of employees engaged in scientific research and technological development in each enterprise at the end of each year. The data of this variable is taken from the value of "number of R&D (people)" in the annual financial report of each enterprise. Unit: person.

Output Variables:

Patent Applications: The number of patent applications submitted by each enterprise to China's national patent department in the current year. The data of this variable is taken from the Patent Star Searching System[3]. Unit: item.

The third stage: Operating stage

Input Variables:

Selling Expenses: Refers to various expenses incurred in the process of selling goods and materials as well as providing labor services in the current year. The data of this variable is taken from the value of "selling expenses" in the annual financial report of each enterprise. Unit: Ten thousand yuan.

Sales personnel: Refers to the number of employees directly engaged in sales at the end of each year. The data of this variable is taken from the value of "number of sales personnel" in the annual financial report of each enterprise. Unit: person.

Output Variables:

Operating Revenue: Refers to the income obtained by an enterprise from its main business or other business in the current year. The data of this variable is obtained from the website of Askci Consulting Co., Ltd[4]. Unit: Ten thousand yuan.

Total Assets Turnover: Refers to the ratio of the enterprise's net operating revenue divided by its average total assets over a certain period of time. It is used to evaluate the efficiency of a company's use of its assets to generate sales income. The data of this variable is obtained from the website of Askci Consulting Co., Ltd. Unit: time.

Equity Ratio: Refers to the ratio of shareholders' equity divided by the total assets. This ratio reflects how much of the enterprise's assets are invested by the owner. The data of this variable is obtained from the website of Askci Consulting Co., Ltd. Unit: percent.

[2] The annual financial report of each enterprise can be obtained from the website http://www.neeq.com.cn/disclosure/announcement.html

[3] The website is https://www.patentstar.com.cn/My/SmartQuery.aspx

[4] The website is https://s.askci.com/stock/1/

Link Variables between Financing Stage and R&D Stage

R&D Expenditure: Refers to the current expenditure and capital expenditure of the enterprise for systematic R&D work. The data of this variable is taken from the value of "R&D expenses" in the annual financial report of each enterprise. Unit: Ten thousand yuan.

Link Variables between R&D Stage and Operating Stage

Patent Authorizations: The number of patents authorized by China's national patent departments in each enterprise in the current year. The data for this variable is taken from the Patent Star Searching System[5]. Unit: item.

Carry-over Variable

Fixed Assets: Refers to the number of non-current assets held by an enterprise for the purpose of producing products, providing labor services, renting, or management. These assets are not directly sold to consumers and cannot be easily converted to cash. These are items of value that the company has bought and will use for more than one year. The data of this variable is taken from the value of "fixed assets" in the annual financial report of each enterprise. Unit: Ten thousand yuan.

Exogenous Variable (Non-discretionary variables)

The Intensity of Financial Regulation: Refers to the strength of the financial authorities to lead, organize, coordinate and control economic entities and their financial activities in accordance with the law. It will be introduced in detail in Section 3.7.

3.2. Input and output variables' statistical analysis

Table 2 reports the statistical features of all input variables for technology-based SMEs in coastal and non-coastal areas of China. We can see that the inputs of SMEs in coastal areas were generally higher than those in non-coastal areas. The average values of indirect financing, R&D expenditure, R&D personnel, selling expenses and sales personnel were all higher in SMEs in coastal areas of China. While the average values of direct financing and fixed assets were higher in non-coastal areas of China. The maximum values of direct financing, indirect financing, fixed assets, R&D personnel and selling expenses were higher in SMEs in coastal areas of China. While the maximum values of R&D expenditures and sales personnel were higher in non-coastal areas. The minimum values of most variables were nearly 0, however the minimum values of fixed assets and R&D personnel were larger in SMEs in non-coastal areas than in coastal areas.

Table 3 shows the statistical properties of all output variables for technology-based SMEs in coastal and non-coastal areas of China. We could find that the outputs of SMEs in coastal areas were generally higher than those in non-coastal areas in the R&D stage. In the operating stage, however, the outputs of SMEs in non-coastal areas were generally higher. The average values of patent applications and patent authorizations were higher in SMEs in coastal

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[5] The website is https://www.patentstar.com.cn/My/SmartQuery.aspx

Table 2. Statistics of input variables of technology-based SMEs

Item	SMEs	Direct Fin①	Indirect Fin②	Fixed Assets	R&D Exp③	R&D Person④	Selling Exp⑤	Sales Person⑥
Mean	SMEs in coastal areas of China	819.73	1444.46	2734.89	545.67	72.26	544.31	21.62
	SMEs in non-coastal areas of China	969.86	1224.63	2915.57	474.70	68.20	311.64	15.08
Std.Dev⑦	SMEs in coastal areas of China	2198.88	3148.62	6512.35	524.57	134.78	760.25	25.62
	SMEs in non-coastal areas of China	2475.76	3021.52	5877.98	410.16	99.75	371.15	24.19
Min	SMEs in coastal areas of China	0.00	0.00	1.15	0.00	1.00	0.00	0.00
	SMEs in non-coastal areas of China	0.00	0.00	5.05	0.00	2.00	0.00	0.00
Max	SMEs in coastal areas of China	17100.00	32138.87	49188.10	3154.51	1314.00	4069.72	141.00
	SMEs in non-coastal areas of China	16860.00	23580.00	41224.53	3302.37	550.00	2245.90	282.00

Notes: ①~⑦ are the abbreviations for Direct Financing, Indirect Financing, R&D Expenditure, R&D Personnel, Selling Expenses, Sales Personnel, and Standard Deviation.

Table 3. Statistics of output variables of technology-based SMEs

Item	SMEs	Patent App①	Patent Auth②	Revenue③	Ass Turn④	Equity Ratio
Mean	SMEs in coastal areas of China	6.92	4.75	8083.30	0.78	63.53%
	SMEs in non-coastal areas of China	5.06	3.60	8609.25	0.54	69.42%
Std.Dev⑤	SMEs in coastal areas of China	11.80	10.27	7779.78	0.63	18.68%
	SMEs in non-coastal areas of China	7.70	5.75	10374.02	0.38	19.07%
Min	SMEs in coastal areas of China	0.00	0.00	156.36	0.05	10.18%
	SMEs in non-coastal areas of China	0.00	0.00	0.00	0.00	17.91%
Max	SMEs in coastal areas of China	132.00	122.00	47200.00	8.18	97.81%
	SMEs in non-coastal areas of China	67.00	44.00	73300.00	3.17	99.21%

Notes: ①~⑤ are the abbreviations for Patent Applications, Patent Authorizations, Operating Revenue, Total Assets Turnover and Standard Deviation.

areas of China. While the average values of operating revenue and equity ratio were higher in non-coastal areas. The maximum values of patent applications and patent authorizations were higher in SMEs in coastal areas of China. While the maximum values of operating revenue and equity ratio were higher in non-coastal areas of China. Similar to the input variables, the minimum values of most output variables were nearly 0. However, the minimum values of operating revenue and total assets turnover were higher in SMEs in coastal areas of China, and the minimum values of equity ratio was higher in SMEs in non-coastal.

3.3. Overall annual efficiency scores

The annual efficiency scores and the five-year overall efficiency score of innovation for each SME in coastal areas of China are shown in Table 4. The efficiency scores of SMEs in coastal areas of China were not high in general. The average overall efficiency score was only 0.3953 and the average efficiency score of each year was between 0.4 and 0.5. Among the 60 technology-based SMEs in China's coastal areas studied in this paper, there were two enterprises whose overall efficiency scores were 1 in two of the five years. There were also four SMEs whose overall efficiency score was 1 in one of these years. All these enterprises are located in the economically developed regions in coastal areas of China, such as Shanghai, Guangdong, and Tianjin. There were two enterprises whose overall efficiency scores were all below 0.3 from 2015 to 2019. There were also four enterprises whose overall efficiency scores were below 0.3 in four of the five years. These enterprises are also located in economically developed areas such as Shanghai, Guangdong and Zhejiang.

It could be seen that some of the technology-based SMEs in coastal areas off China's East Coast, such as Guangdong and Shanghai, have a greater level of innovation. The reason is that most of the well-known financial institutions at home and abroad are located there. The various resources required for production and operation are also relatively abundant in these areas. Meanwhile, supporting policies issued by the government are easier to carry out in these regions, so that the government can better play its role in supporting technological innovation. Although some SMEs in these regions achieved high levels of innovation efficiency, there were also some SMEs that achieved low levels of innovation efficiency. This indicates that there still exists the problem of insufficient supply of financial services for technology-based SMEs even in areas with the developed financial industry in China.

The annual efficiency scores and the five-year overall efficiency score of innovation for each SME in non-coastal areas of China are shown in Table 5. The average efficiency score of technology-based SMEs in China's non-coastal areas was slightly lower than that of coastal areas in 2015. However, the efficiency scores of SMEs in China's non-coastal areas have been higher than coastal areas since 2016. The five-year overall efficiency score of SMEs in non-coastal areas was also higher. Among the 50 SMEs in China's non-coastal areas studied in this paper, there was only one enterprise that achieved an overall efficiency score of 1 in one of these five years. Meanwhile, none of the SMEs achieved an overall efficiency score of less than 0.3 for each year. However, there were three enterprises whose overall efficiency scores were below 0.3 in four of these five years. It could be seen that the gap between different technology-based SMEs is smaller and the number of enterprises with extremely high or extremely low innovation efficiency is also smaller in non-coastal areas compared to coastal areas.

Table 4. Overall efficiency scores of technology-based SMEs in coastal areas of China from 2015 to 2019

DMU①	2015	2016	2017	2018	2019	Overall-Score	DMU	2015	2016	2017	2018	2019	Overall-Score
430319	0.0894	0.1112	0.2329	0.3368	0.1927	0.1358	832652	0.3928	0.1857	0.4569	0.4174	0.4393	0.3463
430385	0.1929	0.4358	0.3621	0.1351	0.2346	0.2157	832711	0.5299	0.2542	0.2467	0.2168	0.4114	0.3059
430420	0.2821	0.2288	0.1914	0.0219	0.0064	0.1162	832721	0.6908	0.5504	0.9260	0.7407	0.4180	0.6216
430437	0.4944	0.4302	0.3193	0.4943	0.6886	0.3475	832739	0.3352	0.3510	0.5250	0.4349	0.5198	0.3731
430601	0.0162	0.5426	0.2598	0.3014	0.3792	0.2249	832790	0.1016	0.0363	0.1852	0.2386	0.2349	0.1261
430620	0.9076	0.5852	0.7076	0.4774	0.4840	0.5618	832954	0.4778	0.2455	0.6667	1.0000	1.0000	0.6147
430640	0.2978	0.3155	0.3759	0.3392	0.3459	0.2951	833105	0.4063	0.3806	0.2663	0.6233	0.5876	0.4106
430742	0.4623	0.5207	0.5846	0.5551	0.5068	0.4304	833112	0.6765	0.7079	0.7315	0.5079	0.6487	0.5562
430764	0.4394	0.5653	0.3909	0.4434	0.2852	0.3146	833333	0.6933	0.5088	0.7232	0.4779	0.6845	0.5981
830846	0.6115	0.6218	0.5002	0.2261	0.9185	0.4956	833617	0.2101	0.2035	0.5037	0.1981	0.2839	0.2633
831039	0.6719	1.0000	0.5904	0.5268	0.7574	0.6335	833654	0.5327	0.3219	0.3443	0.2962	0.3770	0.2956
831216	0.7117	0.6816	0.6392	0.5316	0.6951	0.5208	833686	0.3582	0.4181	0.5564	0.6274	0.7347	0.4175
831242	0.2685	0.2391	0.2009	0.3359	0.5746	0.2759	833778	0.2237	0.1586	0.2507	0.3853	0.5042	0.2613
831248	0.2054	0.5771	0.5320	0.4414	0.9505	0.4510	833835	0.4133	0.3978	0.5172	0.0878	0.0831	0.2338
831415	0.5057	0.4898	0.5387	0.5060	0.6546	0.4125	833846	0.4726	0.2983	0.5154	0.7016	0.2276	0.3473
831502	0.4777	0.6299	0.6329	0.2828	0.2567	0.4317	833863	0.6164	0.7953	0.5357	0.2895	0.2658	0.4196
831538	0.5556	0.8823	0.5494	0.5174	0.6608	0.5077	833938	0.4884	0.7598	0.8076	0.4798	0.4719	0.4800
831590	0.8842	0.5188	0.5555	0.5732	0.6806	0.5915	833981	0.5130	0.5608	0.7687	0.8733	0.5917	0.6485
831640	0.2097	0.4069	0.2450	0.2845	0.3111	0.2513	834060	0.7777	0.6980	0.6644	0.6488	0.6714	0.5326
831708	0.3079	0.6230	0.3241	0.4085	0.3753	0.3078	834359	0.3034	0.3198	0.4877	0.4383	0.3081	0.2774
831747	0.5002	0.5083	0.5162	0.5161	1.0000	0.6082	834399	0.5459	0.7905	0.3237	0.1872	0.5355	0.4120
831843	0.2121	0.4624	0.5974	0.6981	0.3118	0.3430	834445	0.5887	0.3713	0.3914	0.2564	0.1866	0.2945
831869	0.6302	0.3113	0.4045	0.4192	0.6852	0.4069	834521	0.9543	1.0000	1.0000	0.9076	0.9402	0.9463
832172	0.1417	0.4017	0.2440	0.0324	0.1290	0.1682	834646	1.0000	0.8297	0.7003	0.5916	0.0732	0.5347
832255	0.1563	0.3239	0.3761	0.3182	0.4299	0.2495	834715	0.3555	0.4095	0.5883	0.3573	0.6014	0.4270
832471	0.3678	0.5039	0.5403	0.1762	0.6061	0.3632	834757	0.0928	0.3767	0.6609	0.2433	0.4797	0.2743
832510	0.2722	0.0924	0.4162	0.1476	0.5075	0.2670	835052	0.0373	0.1472	0.3891	0.2915	0.1202	0.1693
832547	0.4580	0.3022	0.4464	0.3303	0.5812	0.3253	835128	0.1674	0.4571	0.5283	0.1981	0.8067	0.4263
832567	0.5613	0.5322	0.4402	0.3236	0.4526	0.4075	835171	0.7302	0.8488	0.7093	0.8413	1.0000	0.7631
832597	0.0867	0.3335	0.3920	0.3198	0.2537	0.2103	Average	0.4360	0.4689	0.4952	0.4170	0.4938	0.3953
832643	0.4987	0.5762	0.6370	0.4401	0.5041	0.4692							

Notes: ① Decision Making Unit. We use stock codes to represent different SMEs in this table.

Table 5. Overall efficiency scores of technology-based SMEs in non-coastal areas of China from 2015 to 2019

DMU	2015	2016	2017	2018	2019	Overall-Score	DMU	2015	2016	2017	2018	2019	Overall-Score
430047	0.5372	0.3202	0.2685	0.1014	0.3635	0.2357	832505	0.2686	0.4154	0.4547	0.4835	0.6064	0.4296
430119	0.2758	0.3357	0.6712	0.3139	0.5119	0.4089	832616	0.6017	0.5096	0.6805	0.6360	0.6603	0.5177
430135	0.0597	0.0601	0.1054	0.0997	0.3352	0.1103	832676	0.6810	0.3988	0.6476	0.3801	0.5251	0.4721
430186	0.5657	0.3847	0.4526	0.4235	0.4091	0.3084	832710	0.3149	0.3591	0.2340	0.2337	0.5128	0.2535
430211	0.2208	0.3119	0.2345	0.2694	0.5962	0.2562	832813	0.3320	0.7711	0.7179	0.4706	0.2143	0.3808
430242	0.2977	0.4524	0.4144	0.5378	0.4843	0.3785	832859	0.3344	0.7962	0.5398	0.4665	0.7235	0.5260
430266	0.2340	0.4275	0.4565	0.4486	0.4145	0.3784	832917	0.2802	0.4878	0.3992	0.4632	0.4517	0.3400
430283	0.1486	0.3143	0.3889	0.3848	0.4769	0.2684	833041	0.4377	0.1453	0.2854	0.1452	0.3023	0.2032
430380	0.2826	0.6872	0.5433	0.5082	0.4218	0.4177	833207	0.6463	0.9547	0.8401	0.7572	0.3729	0.6985
430731	0.5703	0.7024	0.7670	0.7466	0.6944	0.6495	833338	0.4846	0.3640	0.9241	0.7451	0.5920	0.5567
830873	0.3169	0.4104	0.2793	0.3903	0.3985	0.3364	833341	0.5161	0.3913	0.9611	0.5502	0.5044	0.5019
831124	0.3557	0.3764	0.5792	0.3582	0.5764	0.3570	833351	0.7274	0.5498	0.9037	0.7269	0.5870	0.6896
831183	0.6259	0.6936	0.4412	0.4837	0.3911	0.4413	833427	0.5382	0.6646	0.5557	0.3280	0.4709	0.3962
831209	0.4553	0.2306	0.6668	0.2373	0.7833	0.4360	833433	0.5277	0.3245	0.5293	0.2640	0.2436	0.2787
831541	0.4045	0.5547	0.2513	0.6050	0.9630	0.4579	833687	0.2806	0.4711	0.0961	0.2588	0.1991	0.2008
831709	0.2775	0.4145	0.3218	0.2788	0.3566	0.2501	833712	0.6672	0.3378	0.3440	0.5099	0.5075	0.3993
831917	0.2502	0.3440	0.2863	0.2584	0.1842	0.2052	833816	0.4016	0.5397	0.6791	0.6723	0.4536	0.4670
831988	0.3390	0.5085	0.3450	0.5301	0.6791	0.3429	833873	0.3119	0.1804	0.4018	0.3333	0.4418	0.2563
831999	0.2131	0.4222	0.7180	0.7709	0.4427	0.4541	833966	0.6680	0.8334	0.2953	0.3358	0.3740	0.4236
832002	0.3800	0.6273	0.3586	0.5347	0.4551	0.3485	834010	0.6911	0.9846	0.6926	0.5324	0.7878	0.6660
832007	0.2155	0.2603	0.4868	0.2229	0.6266	0.2941	834147	0.6907	0.5918	0.7750	0.7314	0.8280	0.6292
832033	0.3142	0.6135	0.5869	0.4512	0.1814	0.3862	834256	0.6732	0.6724	0.5710	0.5269	0.7146	0.4801
832035	0.8886	0.4645	0.5354	0.6408	0.7550	0.5877	834621	0.3732	0.5421	0.5400	0.5370	0.6370	0.4224
832036	0.5206	0.7583	0.6250	0.4202	0.5740	0.4347	834857	0.5791	0.3835	0.6930	0.5235	0.5779	0.4422
832317	0.3549	1.0000	0.6758	0.5490	0.7059	0.5617	Average	0.4325	0.4969	0.5130	0.4546	0.5066	0.4062
832326	0.4921	0.5017	0.4309	0.5547	0.2599	0.3742							

3.4. Average efficiency scores analysis in each stage

There are different performance for innovation efficiencies of technology-based SMEs in coastal and non-coastal areas of China in each stage and the results are shown in Table 6. Since each category contains too many enterprises, we use the average value of the efficiency scores of SMEs to compare the differences between SMEs in coastal and non-coastal areas of China. The average efficiency scores of SMEs were higher in coastal areas of China than in non-coastal areas in 2015 and 2016 in the first stage (financing stage). However, the average efficiency scores of SMEs in non-coastal areas of China have been higher since 2017. The five-year average efficiency score of SMEs in coastal areas of China was 0.4878 in the first stage, while the score of SMEs in non-coastal areas of China was 0.5226. The average efficiency scores of SMEs were higher in coastal areas of China than in non-coastal areas in the second stage (R&D stage) except for 2016. The average scores of SMEs in coastal areas of China were between 0.21 and 0.41, while the average scores of SMEs in non-coastal areas were below 0.37. The average efficiency scores of SMEs were higher in China's non-coastal areas than coastal areas in the third stage (operating stage) except for 2017. The average scores of SMEs in coastal areas of China were between 0.50 and 0.69, while the average scores of SMEs in non-coastal areas were between 0.58 and 0.75.

The different performances of technology-based SMEs in coastal and non-coastal areas at different stages may be mainly due to the following reasons. Firstly, the capital market is relatively lagging behind and the financing costs of SMEs are relatively high in the non-coastal areas of China. As a result, the financing efficiency was lower in Chinas' non-coastal areas than coastal areas in 2015 and 2016. However, financial technology (fintech) companies has been growing rapidly in China since 2016 and gradually expanded their business from payments and settlements to personal and corporate loans. Their collaboration with commercial banks is also becoming increasingly closer. Artificial intelligence, big data, blockchain, and other financial technologies have drastically lower the costs of financing for technology-based SMEs (Assarzadeh & Aberoumand, 2018; Lai & Samers, 2021). This effect is especially obvi-

Table 6. Average efficiency scores of technology-based SMEs in each stage from 2015 to 2019

SMEs	2015 Stage-1	2016 Stage-1	2017 Satge-1	2018 Stage-1	2019 Stage-1	Average Stage-1
SMEs in coastal areas of China	0.4568	0.5091	0.4402	0.4833	0.5496	0.4878
SMEs in non-coastal areas of China	0.4430	0.4788	0.5117	0.5187	0.6608	0.5226
SMEs	2015 Stage-2	2016 Stage-2	2017 Stage-2	2018 Stage-2	2019 Stage-2	Average Stage-2
SMEs in coastal areas of China	0.2170	0.2099	0.3767	0.2637	0.4013	0.2937
SMEs in non-coastal areas of China	0.1693	0.2669	0.3684	0.2508	0.2743	0.2659
SMEs	2015 Stage-3	2016 Stage-3	2017 Stage-3	2018 Stage-3	2019 Stage-3	Average Stage-3
SMEs in coastal areas of China	0.6343	0.6878	0.6687	0.5039	0.5305	0.6050
SMEs in non-coastal areas of China	0.6851	0.7451	0.6590	0.5944	0.5846	0.6536

ous in non-coastal areas whose financial industries is undeveloped (Lagna & Ravishankar, 2022; Demir et al., 2022). Secondly, the coastal areas of China have a large number of leading technology-based enterprises and scientific research institutions. They are the regions with the greatest scientific and technological innovation potential. Therefore, SMEs in coastal areas of China achieved higher R&D efficiency than those in non-coastal areas. Thirdly, enterprises in coastal areas have higher operating costs compared to the enterprises in non-coastal areas. Although coastal areas are more economically developed and have more facilities than the non-coastal areas, the costs of human and material resources are also higher (Zhang et al., 2019). Therefore, the high investment in funds and human resources in SMEs in coastal areas did not bring the high efficiency of operating outputs.

3.5. The technical efficiency of the group frontier for SMEs in Coastal and non-Coastal areas of China

We could learn the technical efficiency of the group frontier for SMEs in coastal and non-coastal areas of China from the technology gap ratio (TGR). TGR indicates the distance between the meta frontier and the group frontier. This indicator is used to evaluate whether the production technology level used by the group samples is close to the potential production technology level of the meta frontier (Battese et al., 2004). The value of this ratio is between 0 and 1. The closer the value of TGR getting to 1, the closer the production efficiency of the evaluated unit getting to the potential production efficiency level. Among the 60 SMEs in coastal areas studied in this paper, there were four enterprises whose overall TGRs were 1 in two of the five years, and there were six enterprises whose overall TGR was 1 in one of the five years. However, among the 50 SMEs in non-coastal areas, there was only one enterprise whose overall TGRs were 1 in two of the five years, and there were two enterprises whose overall TGR was 1 in one of the five years.

The average TGRs of technology-based SMEs in coastal and non-coastal areas of China are shown in Table 7. It could be seen that the overall TGRs of SMEs were higher in coastal areas of China than in non-coastal areas in 2015 and 2019. The average overall TGR of SMEs in coastal areas of China was also higher. The reason for this phenomenon is that the TGRs were higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years in the first stage (financing stage) and second stage (R&D stage). In the first stage, the TGRs of SMEs in coastal areas of China exceeded 0.9 in three of the five years, but the TGRs of SMEs in non-coastal areas were above 0.9 only in 2018 and 2019. In the second stage, the TGRs of SMEs in China's coastal areas were significantly greater than in non-coastal areas. The TGRs of SMEs in coastal areas of China were all above 0.79, but the TGRs of SMEs in non-coastal areas were below 0.78. In the third stage (operating stage), the TGRs of SMEs were lower in coastal areas of China than in non-coastal areas, but the gap between them is small. The TGRs of SMEs in coastal areas of China ranged between 0.75 and 0.87, while the TGRs of SMEs in non-coastal areas were over 0.9 in three of the five years.

The different performances of the TGRs for SMEs in coastal and non-coastal areas may be mainly due to the following reasons. Firstly, from the perspective of the entire innovation process, the production efficiency of the SMEs in coastal areas of China is closer to the potential production efficiency level compare with the SMEs in non-coastal areas. There is

Table 7. Average TGRs of technology-based SMEs from 2015 to 2019

SMEs	2015 Overall	2016 Overall	2017 Overall	2018 Overall	2019 Overall	Average Overall
SMEs in coastal areas of China	0.8651	0.8699	0.8643	0.7930	0.8955	0.8492
SMEs in non-coastal areas of China	0.8545	0.8770	0.8703	0.8199	0.8546	0.8222
SMEs	2015 Stage-1	2016 Stage-1	2017 Stage-1	2018 Stage-1	2019 Stage-1	Average Stage-1
SMEs in coastal areas of China	0.9598	0.9054	0.8009	0.7633	0.9692	0.9278
SMEs in non-coastal areas of China	0.8512	0.8818	0.8402	0.9212	0.9652	0.9001
SMEs	2015 Stage-2	2016 Stage-2	2017 Stage-2	2018 Stage-2	2019 Stage-2	Average Stage-2
SMEs in coastal areas of China	0.8400	0.7974	0.8399	0.9784	0.8584	0.8395
SMEs in non-coastal areas of China	0.4549	0.6244	0.7725	0.5774	0.7431	0.6261
SMEs	2015 Stage-3	2016 Stage-3	2017 Stage-3	2018 Stage-3	2019 Stage-3	Average Stage-3
SMEs in coastal areas of China	0.8235	0.8641	0.8477	0.7530	0.8325	0.8280
SMEs in non-coastal areas of China	0.9474	0.9599	0.9600	0.8907	0.7505	0.9011

more room for improvement in the innovation efficiency of SMEs in non-coastal areas. Secondly, from the perspective of each stage. The TGRs of SMEs are higher in coastal areas of China than in non-coastal areas in the financing stage and R&D stage. The gap between the TGRs of SMEs in coastal and non-coastal areas is small in the financing stage, in the R&D stage, however, the gap between them is large. This means that SMEs in non-coastal areas of China have a larger gap between group frontier (GF) and meta-frontier (MF) especially in the R&D stage. The R&D efficiency of SMEs in non-coastal areas still has a lot of potential for improvement. The TGRs of SMEs are slightly higher in non-coastal areas of China than in coastal areas in the operating stage. This means that SMEs in coastal areas of China have a slightly larger gap between group frontier (GF) and meta-frontier (MF) in the operating stage. Coastal areas should strive to improve the operating efficiency of local enterprises by reducing their operating costs.

3.6. The Efficiency of the input and output variables

We could learn the efficiencies of input and output variables from the financing, R&D, and operating stages of technology-based SMEs in coastal and non-coastal areas of China, as shown in Table 8. In the financing stage, the average efficiency scores of direct financing, indirect financing, and R&D expenditure were higher in SMEs in non-coastal areas of China than in coastal areas in most of these years. The average efficiency scores of direct financing and indirect financing were between 0.18 and 0.4 in SMEs in non-coastal areas of China, while in SMEs in coastal areas, the average scores of these two variables were between 0.06 and 0.30. Furthermore, the efficiency scores of indirect financing were generally higher than those of direct financing in SMEs in both coastal and non-coastal areas of China. For the output variables in the financing stage, the average efficiency scores of R&D expenditure were between 0.30 and 0.78 in SMEs in non-coastal areas of China, while in coastal areas, the average scores of this variable were between 0.43 and 0.74.

In the R&D stage, the average efficiency scores of R&D personnel and patent applications were higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years. The average efficiency scores of R&D personnel ranged from 0.24 and 0.44 in SMEs in coastal areas of China, while the average scores of these variables ranged between 0.20 and 0.42 in SMEs in non-coastal areas. The average efficiency scores of patent applications were between 0.35 and 0.61 in SMEs in coastal areas of China, while the average scores of these variables ranged between 0.37 and 0.59 in SMEs in non-coastal areas. However, the average efficiency scores of patent authorizations were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years. The average efficiency scores of patent authorizations were between 0.37 and 0.81 in SMEs in coastal areas of China, while the average scores of this variable were between 0.47 and 0.89 in SMEs in non-coastal areas.

In the operating stage, the average efficiency scores of selling expenses, sales personnel, and equity ratio were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years. The average efficiency scores of selling expenses and sales personnel were generally between 0.4 and 0.7 in SMEs in non-coastal areas of China, while the average scores of these two variables were generally between 0.35 and 0.65 in SMEs in coastal areas. The average efficiency scores of operating revenue, total assets turnover, and equity ratio were generally between 0.60 and 0.85 in SMEs in both coastal and non-coastal areas of China.

The average efficiency scores of all variables were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years in the financing stage. And the average efficiency scores of most variables were higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years in the R&D stage. However, the majority of them were less than 0.5. Therefore, SMEs in both coastal and non-coastal areas of China have more potential to improve in the financing stage and R&D stage and they have relatively limited space for improvement in the operating stage.

3.7. The influence of financial regulation on the efficiency scores of overall and each stage

The efficiency of financing and R&D in the innovation process in technology-based SMEs is affected by the intensity of local financial regulation. Such external influencing factors could be used as non-discretionary variables in the DEA model to investigate their impact on input-output efficiency.

Researchers mainly used the following two methods to measure the intensity of financial regulation within a country in previous studies. The first method is to use costs related to regional financial regulation to measure the intensity of local financial regulation, such as the number of supervisors in financial regulatory agencies (Ma & Peng, 2019) and the number of regulatory expenditures (Wang et al., 2019; Tang et al., 2020; Duan & Zhuang, 2020).

Table 8. Average efficiency scores of input and output variables in technology-based SMEs from 2015 to 2019

Year	SMEs	Direct Fin	Indirect Fin	R&D Exp	R&D Person	Patent App	Patent Auth	Selling exp	Sales Person	Revenue	Ass Turn	Equity Ratio
2015	SMEs in coastal areas of China	0.2345	0.1945	0.4379	0.2531	0.4825	0.3745	0.5461	0.4894	0.7745	0.6940	0.8014
	SMEs in non-coastal areas of China	0.1923	0.2569	0.3099	0.2045	0.3752	0.4756	0.5755	0.5939	0.8184	0.7463	0.8218
2016	SMEs in coastal areas of China	0.1775	0.3015	0.3983	0.2462	0.3503	0.8106	0.6483	0.5828	0.7612	0.7972	0.8317
	SMEs in non-coastal areas of China	0.1861	0.2435	0.4893	0.3105	0.4880	0.8922	0.6897	0.6671	0.7320	0.7309	0.8536
2017	SMEs in coastal areas of China	0.0698	0.1479	0.7339	0.4377	0.5628	0.7659	0.5525	0.5427	0.7848	0.7596	0.8163
	SMEs in non-coastal areas of China	0.2510	0.2633	0.7807	0.4187	0.5306	0.8092	0.5646	0.5252	0.7578	0.6920	0.8237
2018	SMEs in coastal areas of China	0.1207	0.1744	0.5386	0.3242	0.6121	0.5841	0.4768	0.3445	0.6526	0.5940	0.7264
	SMEs in non-coastal areas of China	0.2518	0.1999	0.5755	0.2978	0.5950	0.5869	0.5943	0.3912	0.7143	0.6053	0.7815
2019	SMEs in coastal areas of China	0.1681	0.2707	0.4857	0.4414	0.5627	0.5537	0.3576	0.4538	0.7219	0.7092	0.7407
	SMEs in non-coastal areas of China	0.2931	0.3965	0.4372	0.3202	0.4862	0.5135	0.4620	0.4876	0.6738	0.6465	0.7820

The second method is to use information related to the implementation of financial regulatory policies, such as the number of financial regulatory policies issued by local governments and the number of on-site inspections conducted by financial regulatory agencies (Zeng et al., 2016; Ma & Peng, 2019).

However, the second method has some drawbacks in measuring the intensity of regional financial regulation. On one hand, policies differ greatly in the extent of their impacts. The intensity of local financial regulation cannot be judged simply based on the number of relevant policies. On the other hand, China's financial regulation pays more attention to formulating strict approval mechanisms and market-access standards, thereby prohibiting enterprises that do not meet these requirements from carrying out related financial activities. On-site inspections have less effect on the supervision of financial activities compared with those strict ex-ante standards. Merely using the number of on-site inspections can not accurately reflect the intensity of financial regulation.

There are also some controversies about the statistics on the number of supervisors in financial regulatory agencies. Most previous studies used the total number of employees or the number of recruits in local financial regulatory agencies to reflect the intensity of local financial regulation (Ma & Peng, 2019). However, financial regulatory agencies such as the China Banking and Insurance Regulatory Commission and the Central Bank are also in charge of policy research, financial coordination, and providing financial services. It is not accurate to use the total number of personnel in these institutions to represent the number of supervisors in financial regulatory agencies.

Therefore, this paper uses the financial regulatory expenditure of the province where the enterprise is located as the proxy variable for financial regulation and divides the data by the regional added value of the financial industry in the current year to eliminate the influence of the financial scale of different regions. The linear expression of the intensity of financial regulation is as follows:

$$\text{financial regulation} = \frac{\text{financial regulatory expenditure}}{\text{the added value of the financial industry}}.$$

The overall efficiency scores of innovation in technology-based SMEs in both coastal and non-coastal areas of China have increased significantly after adding the intensity of financial regulation as shown in Table 9. The increase was greater in SMEs in non-coastal areas of China than in coastal areas. The average overall efficiency score of SMEs in non-coastal areas of China increased from 0.4062 to 0.4333 after adding this exogenous variable, while the score of SMEs in coastal areas increased from 0.3953 to 0.4197.

The financing efficiency scores of SMEs in both coastal and non-coastal areas of China have increased after adding the intensity of financial regulation. In the financing stage, the five-year average efficiency score of SMEs in coastal areas of China increased from 0.4878 to 0.5712. The five-year average efficiency score of SMEs in non-coastal areas of China increased from 0.5226 to 0.6155. The R&D efficiency scores of SMEs in both coastal and non-coastal areas of China have also increased in most of the five years after adding the intensity of financial regulation, but the increase was relatively small. In the R&D stage, the five-year average efficiency score of SMEs in coastal areas of China increased from 0.2937 to 0.3039.

The five-year average efficiency score of SMEs in non-coastal areas of China increased from 0.2659 to 0.2741. The operating efficiency scores of SMEs in coastal areas of China decreased slightly in most of the five years after adding the intensity of financial regulation, while the scores of SMEs in non-coastal areas of China increased slightly in most of the five years. In the operating stage, the five-year average efficiency score of SMEs in coastal areas of China decreased from 0.6050 to 0.6048 after adding the intensity of financial regulation. The five-year average efficiency score of SMEs in non-coastal areas of China increased from 0.6536 to 0.6538.

The extent of improvement in the overall efficiency score of innovation and the efficiency score of the first stage (financing stage) was greater in SMEs in non-coastal areas of China than in coastal areas after adding the intensity of financial regulation as shown in Table 10. All SMEs in non-coastal areas of China improved their five-year overall efficiency scores and their five-year financing efficiency scores after adding the intensity of financial regulation. Among the 60 SMEs in China's coastal areas studied in this paper, there were 59 enterprises whose five-year overall efficiency scores and five-year financing efficiency scores increased. The ratio of SMEs whose annual overall efficiency scores increased was higher in non-coastal areas than in coastal areas in most of the five years after adding the variable of financial regulation. Although the ratio of SMEs with increased financing efficiency in coastal areas is slightly higher than that in non-coastal areas in each year, the ratio of SMEs with increased five-year financing efficiency score was higher in non-coastal areas.

Table 9. Average efficiency scores of technology-based SMEs after adding financial regulation

SMEs	2015 Overall	2016 Overall	2017 Overall	2018 Overall	2019 Overall	Average Overall
SMEs in coastal areas of China	0.4982	0.4934	0.5192	0.4442	0.5113	0.4197
SMEs in non-coastal areas of China	0.4699	0.5336	0.5630	0.4863	0.5196	0.4333
SMEs	2015 Stage-1	2016 Stage-1	2017 Stage-1	2018 Stage-1	2019 Stage-1	Average Stage-1
SMEs in coastal areas of China	0.6277	0.5644	0.5041	0.5656	0.5939	0.5712
SMEs in non-coastal areas of China	0.5389	0.5750	0.6532	0.6137	0.6969	0.6155
SMEs	2015 Stage-2	2016 Stage-2	2017 Stage-2	2018 Stage-2	2019 Stage-2	Average Stage-2
SMEs in coastal areas of China	0.2325	0.2281	0.3851	0.2635	0.4102	0.3039
SMEs in non-coastal areas of China	0.1849	0.2806	0.3769	0.2505	0.2775	0.2741
SMEs	2015 Stage-3	2016 Stage-3	2017 Stage-3	2018 Stage-3	2019 Stage-3	Average Stage-3
SMEs in coastal areas of China	0.6345	0.6876	0.6685	0.5034	0.5299	0.6048
SMEs in non-coastal areas of China	0.6858	0.7451	0.6590	0.5948	0.5845	0.6538

The intensity of financial regulation has a greater improvement effect on the R&D efficiency score in SMEs in non-coastal areas than in coastal areas. There were 40 SMEs in non-coastal areas of China whose average efficiency scores increased in the R&D stage, accounting for around 80% of the total. And among the 60 SMEs in coastal areas of China studied in this paper, there were 42 enterprises whose average efficiency scores increased in the R&D stage, accounting for 70% of the total.

The intensity of financial regulation has a slightly greater improvement effect on the operating efficiency score in SMEs in non-coastal areas than it does in coastal areas. The number of SMEs in coastal and non-coastal areas whose efficiency scores increased is similar to each other in the operating stage, but the ratio in non-coastal areas of China was substantially higher. There were 19 SMEs in non-coastal areas of China whose average operating efficiency scores increased, accounting for 38% of the total. While there were 13 SMEs in coastal areas of China whose five-year operating efficiency score increased, only accounted for 21.67% of the total.

Table 10. The number and ratio of technology-based SMEs whose efficiency scores increased after adding financial regulation

SMEs	2015 Overall	2016 Overall	2017 Overall	2018 Overall	2019 Overall	Average Overall
SMEs in coastal areas of China	46 (76.67%)	42 (70.00%)	51 (85.00%)	55 (91.67%)	23 (38.33%)	59 (98.33%)
SMEs in non-coastal areas of China	39 (78.00%)	40 (80.00%)	42 (84.00%)	40 (80.00%)	22 (44.00%)	50 (100.00%)
SMEs	2015 Stage-1	2016 Stage-1	2017 Stage-1	2018 Stage-1	2019 Stage-1	Average Stage-1
SMEs in coastal areas of China	42 (70.00%)	34 (56.67%)	50 (83.33%)	54 (90.00%)	17 (28.33%)	59 (98.33%)
SMEs in non-coastal areas of China	29 (58.00%)	28 (56.00%)	41 (82.00%)	39 (78.00%)	11 (22.00%)	50 (100.00%)
SMEs	2015 Stage-2	2016 Stage-2	2017 Stage-2	2018 Stage-2	2019 Stage-2	Average Stage-2
SMEs in coastal areas of China	33 (55.00%)	30 (50.00%)	14 (23.33%)	16 (26.67%)	18 (30.00%)	42 (70.00%)
SMEs in non-coastal areas of China	32 (64.00%)	29 (58.00%)	13 (26.00%)	12 (24.00%)	19 (38.00%)	40 (80.00%)
SMEs	2015 Stage-3	2016 Stage-3	2017 Stage-3	2018 Stage-3	2019 Stage-3	Average Stage-3
SMEs in coastal areas of China	18 (30.00%)	9 (15.00%)	11 (18.33%)	12 (20.00%)	15 (25.00%)	13 (21.67%)
SMEs in non-coastal areas of China	16 (32.00%)	7 (14.00%)	5 (10.00%)	9 (18.00%)	13 (26.00%)	19 (38.00%)

Note: The ratios of technology-based SMEs whose efficiency scores increased after adding financial regulation are shown in the brackets.

3.8. The Influence of financial regulation on the efficiency of input and output variables

The comparison of the efficiency scores of each input and output variable with and without adding the intensity of financial regulation is shown in Table 11. In the financing stage, the average efficiency scores of all variables in SMEs in both coastal and non-coastal areas of China have increased significantly after adding the intensity of financial regulation. The increase in the efficiency scores of variables was higher in SMEs in non-coastal areas of China than in coastal areas. The average efficiency scores of direct financing and indirect financing in SMEs in coastal areas of China were around 0.2 before adding the intensity of financial regulation and they improved to around 0.3 after adding this variable. The average efficiency scores of these two variables were over 0.2 in SMEs in non-coastal areas of China before adding the intensity of financial regulation and they improved to around 0.4 after adding this variable. In addition, the average efficiency score of indirect financing was higher than that of direct financing in SMEs in both coastal and non-coastal areas of China regardless of whether the intensity of financial regulation was added or not. This demonstrates that the financial system is still dominated by indirect financing in China at present. The average efficiency scores of R&D expenditure in SMEs in coastal and non-coastal areas of China were both about 0.52 before adding the intensity of financial regulation. However, the score in SMEs in coastal areas of China improved to 0.5964, and the score in SMEs in non-coastal areas of China improved to 0.6368 after adding this variable.

In the R&D stage, the average efficiency scores of R&D personnel, patent applications, and patent authorizations in SMEs in both coastal and non-coastal areas of China have increased after adding the intensity of financial regulation. However, the increase was relatively less compared with the financing stage. For example, regardless of whether the intensity of financial regulation was added or not, the average efficiency scores of R&D personnel in SMEs in coastal and non-coastal areas of China were all about 0.3, the average scores of patent applications were around 0.5, and the average scores of patent authorizations ranged between 0.60 and 0.70.

In the operating stage, the efficiency scores of most variables in SMEs in both coastal and non-coastal areas of China decreased slightly after adding the intensity of financial regulation. For example, the average efficiency scores of selling expenses in SMEs in coastal areas of China were around 0.5163 before adding the intensity of financial regulation and it decreased to about 0.5155 after adding this variable. The average efficiency score of selling expenses was 0.5772 in SMEs in non-coastal areas of China before adding the intensity of financial regulation and it reduced to 0.5766 after adding this variable. Although the efficiency scores of sales personnel in SMEs in coastal and non-coastal areas of China increased after adding the intensity of financial regulation, the increase was quite small.

The improvement in the efficiency scores of all input and output variables was greater in SMEs in non-coastal areas than in coastal areas after adding the intensity of financial regulation as shown in Table 12. In the financing stage, almost all SMEs in non-coastal areas have increased their efficiency scores of direct financing and indirect financing. However, only 39 SMEs in coastal areas increased their efficiency scores of direct financing, accounting for nearly 65% of the total. And there were 57 SMEs in coastal areas that increased their

Table 11. Comparison of average efficiency scores of input and output variables with and without adding financial regulation

	SMEs	Direct Fin	Indirect Fin	R&D Exp	R&D Person	Patent App	Patent Auth	Selling exp	Sales Person	Revenue	Ass Turn	Equity Ratio
Without adding the intensity of financial regulation	SMEs in coastal areas of China	0.1541	0.2178	0.5189	0.3405	0.5141	0.6178	0.5163	0.4827	0.7390	0.7108	0.7833
	SMEs in non-coastal areas of China	0.2349	0.2720	0.5185	0.3103	0.4950	0.6555	0.5772	0.5330	0.7393	0.6842	0.8125
With adding the intensity of financial regulation	SMEs in coastal areas of China	0.2607	0.3506	0.5964	0.3494	0.5166	0.6235	0.5155	0.4830	0.7391	0.7108	0.7832
	SMEs in non-coastal areas of China	0.3530	0.4148	0.6368	0.3193	0.5017	0.6749	0.5766	0.5349	0.7390	0.6841	0.8126

Table 12. The number and ratio of technology-based SMEs whose efficiency scores of input or output variables increased after adding financial regulation

SMEs	Direct Fin	Indirect Fin	R&D Exp	R&D Person	Patent App	Patent Auth	Selling exp	Sales Person	Revenue	Ass Turn	Equity Ratio
SMEs in coastal areas of China	39 (65.00%)	57 (95.00%)	42 (70.00%)	42 (70.00%)	26 (43.33%)	10 (16.67%)	11 (18.33%)	16 (26.67%)	12 (20.00%)	17 (28.33%)	10 (16.67%)
SMEs in non-coastal areas of China	43 (86.00%)	50 (100.00%)	44 (88.00%)	39 (78.00%)	34 (68.00%)	18 (36.00%)	16 (32.00%)	15 (30.00%)	17 (34.00%)	15 (30.00%)	15 (30.00%)

Note: The ratios of technology-based SMEs whose efficiency scores increased after adding financial regulation are shown in the brackets.

efficiency scores of indirect financing, accounting for nearly 95% of the total. Among the 60 SMEs in coastal areas studied in this paper, there were 42 enterprises whose efficiency scores of R&D expenditure increased, accounting for 70% of the total. Among the 50 SMEs in non-coastal areas studied in this paper, there were 44 enterprises whose efficiency scores of R&D expenditure increased, accounting for 88% of the total.

In the R&D stage, financial regulation has a higher effect on the efficiency of the input and output variables in SMEs in non-coastal areas than in coastal areas. For example, there were 39 SMEs in non-coastal areas whose efficiency scores of R&D personnel increased, accounting for 78% of the total. And there were 42 SMEs in coastal areas whose efficiency scores of R&D personnel increased, accounting for 70% of the total. For output variable, there were 34 SMEs in non-coastal areas whose efficiency scores of patent applications increased, accounting for 68% of the total, while there were 26 SMEs in coastal areas whose efficiency scores of patent applications increased, accounting for 43% of the total.

In the operating stage, financial regulation has a slightly higher positive effect on the efficiency of the input and output variables in SMEs in non-coastal areas than in coastal areas. The number of SMEs with increased efficiency scores of each input or output variable in coastal areas was similar to that in non-coastal areas. However, the ratio of SMEs with increased efficiency scores was much higher in non-coastal areas than in coastal areas. For example, there were 16 SMEs in non-coastal areas whose efficiency scores of selling expenses increased, accounting for 32% of the total. And there were 11 SMEs in coastal areas whose efficiency scores of selling expenses increased, accounting for 18.33% of the total. For output variable, there were 17 SMEs in non-coastal areas whose efficiency scores of operating revenue increased, accounting for 34% of the total, while there were 12 SMEs in coastal areas whose efficiency scores of operating revenue increased, accounting for 20% of the total.

The reasons why the efficiency scores of financing and R&D in SMEs in coastal and non-coastal areas of China increased after adding the intensity of financial regulation are as follows. Firstly, effective financial regulation could maintain financial stability (Rizwan et al., 2018; Jungo et al., 2022). By supervising the activities of financial institutions and enterprises, it is possible to prevent the financial system from being disordered and improve the efficiency of resource allocation (Badertscher et al., 2013; Shroff et al., 2017). Secondly, effective financial regulation could strengthen the guidance to credit businesses and ensure that the financing support provided by financial institutions could help technology-based SMEs with genuine financing needs. Therefore, the financing costs of technological innovation could be reduced and the efficiency of technological innovation could be improved (Zheng et al., 2017). Thirdly, financial regulation could also govern the trading behaviors in financial activities, prevent market risks and protect the legitimate rights and interests of all parties involved in the transactions (Hlaing & Kakinaka, 2018).

The efficiency scores of SMEs in coastal areas of China decreased, and the scores of SMEs in non-coastal areas of China increased slightly in the operating stage. The following are some possible explanations for this phenomenon. Although financial regulation could alleviate the funding difficulties faced by SMEs, it could also restrict the economic behaviors of these enterprises and require them to conduct transactions within a specific procedural framework, which may have an impact on the process of transformation from knowledge achievements to high-technology product achievements (Feng et al., 2021). Therefore, in the operating stage, financial regulation has an inhibiting effect on SMEs in coastal areas of China. However, the extent of such inhibiting effect is relatively low. After adding the obvious promoting effect in the financing and R&D stages, financial regulation still plays a role in improving the overall efficiency scores in SMEs in coastal areas of China. Compared with coastal areas, the ability of financial innovation is relatively weak and the capital market is relatively lagging behind in the non-coastal areas of China. Financial regulation could promote financial innovation of financial institutions in these areas (An et al., 2021), which has resulted in a positive effect of financial regulation on SMEs in non-coastal areas of China in the operating stage.

The reasons why efficiency improvements are greater in SMEs in non-coastal areas than in coastal areas during the financing stage, R&D stage, and operating stage are as follows. Compared with coastal areas of China, non-coastal areas of China have fewer financial institutions and fewer types of financial instruments. The development of the financial industry is relatively backward in China's non-coastal areas. Many technology-based SMEs in non-coastal areas experience difficulty in their R&D, production, and sales activities because they can not access sufficient funding on time. Therefore, financial regulation could be more beneficial to technology-based SMEs in China's non-coastal than in China's coastal areas in solving funding issues. Firstly, effective financial regulation could help financial institutions in non-coastal areas of China to achieve a large number of surplus funds in the capital market by providing a variety of financial instruments (Kodongo, 2018; Anarfo et al., 2020). This will encourage the conversion of household savings to investment and address the issue of insufficient supply of direct financing in non-coastal areas of China (Belo et al., 2019). Secondly, by supervising the behaviors of all parties in financial transactions, financial regulatory agencies could also encourage financial institutions to innovate in financial services and enhance the availability of indirect financing for technology-based SMEs in non-coastal areas (An et al., 2021). Thirdly, financial regulation also improves the efficiency of the distribution of funds in non-coastal areas of China. Financial institutions could evaluate various alternative projects by gathering information on enterprises' business management, ensuring that funds are invested in enterprises that can produce market-competitive products (Minnis & Shroff, 2017; Roychowdhury et al., 2019). As a result, financial regulation may be more helpful in solving the problem of insufficient supply of funds encountered by technology-based SMEs in non-coastal areas of China than in coastal areas of China.

Conclusions and suggestions

This study focuses on the innovation efficiency from the financing stage, R&D stage, and operating stage in technology-based SMEs in China over the period of 2015–2019 by using the three-stage meta under exogenous dynamic DDF-DEA model. We calculated the efficiency scores and the technology gap ratios of SMEs in coastal and non-coastal areas of China in the financing, R&D, and operating stages, as well as the efficiency scores of each input and output variable. We also investigate the impact of the intensity of financial regulation as an exogenous variable on the efficiency of the entire innovation process. The conclusions of this study are as follows:

1. The overall efficiency scores of innovation were higher in SMEs in non-coastal areas of China than in coastal areas, but neither of them were very high. The average annual efficiency scores and average overall efficiency scores of SMEs in non-coastal areas of China are basically between 0.40 and 0.52, while the scores of SMEs in coastal areas of China were all below 0.50.
2. Both coastal and non-coastal areas of China have the problem of insufficient supply of financial services for technology-based SMEs. Among the 60 SMEs in coastal areas of China studied in this paper, there were two enterprises whose overall efficiency scores were all below 0.3 from 2015 to 2019. Among the 50 SMEs in non-coastal areas of China studied in this paper, none of them achieved the overall efficiency score below 0.3 in all these five years. However, there were three enterprises whose overall efficiency scores were below 0.3 in four of the five years.
3. The efficiencies of SMEs in coastal and non-coastal areas have different performances at different stages. In the financing stage, the efficiency scores were higher in SMEs in coastal areas of China than in non-coastal areas in 2015 and 2016. However, the efficiency scores in SMEs in non-coastal areas of China have been higher since 2017. In the R&D stage, the efficiency scores of SMEs were higher in coastal areas of China than in non-coastal areas. In the operating stage, the average efficiency scores of SMEs were higher in non-coastal areas of China than in coastal areas.
4. The technical efficiency of the group frontier for SMEs is higher in SMEs in coastal areas than in non-coastal areas. The TGRs are higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years in the financing stage and R&D stage. In the operating stage, the TGRs of SMEs were lower in coastal areas of China than in non-coastal areas, but the gap between them is small.
5. In the financing stage, the average efficiency scores of direct financing, indirect financing, and R&D expenditure were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years. In the R&D stage, the average efficiency scores of R&D personnel and patent applications were higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years. The average efficiency scores of patent authorizations were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years. In the operating stage, the average efficiency scores of selling expenses, sales personnel, and equity ratio were higher in SMEs in non-coastal areas of China than in coastal areas in most of the five years. The average efficiency scores of operating revenue and total assets turnover were higher in SMEs in coastal areas of China than in non-coastal areas in most of the five years.
6. The overall efficiency scores in SMEs in both coastal and non-coastal areas of China increased significantly after adding the exogenous variable of the intensity of financial regulation. In the financing stage, the efficiency scores of SMEs in both coastal and non-coastal areas of China have increased after adding the intensity of financial regulation. In the R&D stage, the efficiency scores of SMEs in both coastal and non-coastal areas of China have also increased in most of the five years, but the increase was relatively small. In the operating stage, the efficiency scores of SMEs in coastal areas

of China decreased slightly and the efficiency scores of SMEs in non-coastal areas of China increased slightly in most of the five years.

7. The efficiency improvement in the overall efficiency score of innovation was greater in SMEs in non-coastal areas of China than in coastal areas after adding the intensity of financial regulation. In the financing stage, R&D stage, and operating stage, the intensity of financial regulation has a greater improvement effect on the efficiency score in SMEs in non-coastal areas than in coastal areas.
8. In the financing and R&D stages, the average efficiency scores of all variables have increased significantly in SMEs in both coastal and non-coastal areas of China after adding the intensity of financial regulation. In the operating stage, however, the efficiency scores of most variables have decreased slightly in SMEs in both coastal and non-coastal areas of China after adding the intensity of financial regulation. In the financing stage, R&D stage, and operating stage, the improvement in the efficiency scores of all input and output variables was much greater in SMEs in non-coastal areas than in coastal areas after adding the intensity of financial regulation.

Based on the preceding analysis and conclusions, we propose the following recommendations for how the financial system could improve its efficiency in supporting technological innovation.

1. More attention should be paid to the critical role of financial regulation in improving the efficiency of innovation in technology-based enterprises in China. Financial regulatory agencies in China should further strengthen financial regulation. They could construct diversified regulatory rules for technology-based enterprises at various phases of development, as well as investigate the establishment of a financial system that could cover the entire process of technological innovation in enterprises. The regulatory agencies should fully analyze the characteristics of different enterprises and encourage commercial banks to develop differentiated credit evaluation standards based on the current and expected development of the enterprise.
2. Financial institutions in China's coastal and non-coastal areas should strengthen the innovation of direct financing instruments. Indirect financing currently dominates the financial system in China. This situation is adapted to the characteristics of the industrial structure and the needs of economic development within a given time period in China. However, in the long run, it is still important to improve the innovation of direct financing instruments in order to stimulate technological innovation in technology-based enterprises. These financing instruments should be adapted to the actual needs of the enterprises, taking into account information about the enterprise's credit rating and business performance. Financial institutions could also customize financial products for enterprises at various stages of development rather than recommending a single product as they used to. By providing more direct financing channels for technology-based enterprises, the efficiency of financing and R&D in the innovation process could be improved.
3. In the coastal areas, financial institutions should streamline some of the administrative procedures and approval procedures, as well as optimize the identification methods

for property collateral to improve the efficiency of financing and R&D in the innovation process in technology-based enterprises. Strengthening information exchange across financial institutions is also vital for improving the convenience of financing for technology-based enterprises. The government could develop an information-sharing platform for technology-based firms by integrating enterprises' registration information, tax information, insurance information, bank account information, and patent information on the basis of the existing credit information system.

4. In the non-coastal areas, the application of digital technology in the financial sector should be further strengthened to address the issue of insufficient supply of financial resources and financial services. Financial institutions in China's non-coastal areas could employ big data technology to collect information on enterprises' technological innovation capabilities and business performance through numerous channels and gradually improve the construction of the corporate information system. Financial institutions could also seek cooperation with financial technology enterprises to jointly build a digital financial platform. Financial institutions in non-coastal regions could solve the problem of insufficient supply of financial resources and financial services by providing online financial services on this platform. Simultaneously, financial technology must be developed on the foundation of effective regulation. The division of responsibilities of different financial regulatory agencies should be further clarify to prevent inadequate supervision.

There are still some limitations in this study which could be further investigated. This study sets the same weights for all variables in each stage. It would be very meaningful if different weights could be set for different variables or stages based on relevant evidence in the future. Furthermore, this study only considers the behaviors of high-tech enterprises, and does not include other sectors such as financial institutions and the government. It is also beneficial to further consider the inclusion of more sectors in order to expand the study of the influence of interdependence among different sectors.

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