Research Article

The Impact of Financing Constraints and Uncertainty on Manufacturing Innovation Efficiency: An Empirical Analysis from Chinese Listed Firms

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Chinese listed manufacturing companies face more serious financing constraints. Considering financing constraints and uncertainties, an accurate assessment of the innovation efficiency of China’s listed manufacturing industry can provide decision support for China to become an innovation nation. We construct a heterogeneous stochastic frontier model to analyze the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of the Chinese manufacturing industry, using Chinese A-share listed manufacturing companies as a research sample from 2011–2019. The research results show that (1) Financing constraints make enterprises deviate from innovation efficiency, and internal financing significantly reduces enterprise financing constraints and does not bring uncertainty to subsequent financing, commercial credit, and external financing; although it can alleviate enterprise financing constraints, it will increase the uncertainty of subsequent financing constraints and the enterprise size. (2) Internal financing, commercial credit financing, external financing, and firm size can effectively alleviate the financing constraint for firms to carry out quality innovation activities of invention patents and quantitative innovation activities of utility patents; internal financing, external financing, and firm size can effectively alleviate the financing constraint for quantitative innovation activities of design patents, while commercial credit financing has no significant effect. (3) The influence of factors such as financing constraints makes the real innovation efficiency of China’s listed manufacturing industry only about 20%, and enterprises face more serious financing constraints. (4) The heterogeneity results found that the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency in the eastern region are the highest, and the innovation efficiency level is higher than the national average, followed by the central and western regions. The overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of the central region are higher than the national average, but the innovation quantity efficiency of the western region are lower than the national average; the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of large-scale enterprises are the highest and even higher than the average value of the whole sample, while the innovation efficiency of medium and small-scale enterprises are lower than the average value of the whole sample.

1. Introduction

China’s economic development has shifted from rapid development to high-quality development, and high-quality economic development needs the support of innovation, and the role of innovation in high-quality economic development has become more and more obvious. At the same time, many Chinese companies face high-tech blockades from other countries, do not have a competitive advantage in business activities, and often appear to passively accept unequal business rules [1]. For example, China’s semiconductor technology is largely restricted and blocked by other countries’ technologies and cannot rely on high-precision lithography to produce chips, thus appearing passive at
times in the commercial arena. Although relying on previous technology accumulation in other countries can lay the foundation for Chinese innovation, it is difficult to have a voice in the event of "uncertainties," so Chinese innovation is imperative [1].

From the current situation of manufacturing development, the manufacturing industry is the cornerstone of China’s high-quality economic development; especially in the global trade protectionism and economic policy environment uncertainty, the manufacturing industry has played an important role in supporting the orderly and healthy development of China’s economy [2]. However, in recent years, the transformation of China’s manufacturing industry has faced the development dilemma of “squeezing at both ends” [3]: firstly, China’s labor costs have risen, facing low labor cost competition from countries such as Vietnam and the Philippines, making the original low-end manufacturing industry in China gradually shift to these countries; secondly, China’s science and technology innovation-driven high-end manufacturing has been blocked and besieged by the technology of developed countries, and the high-end manufacturing industry is still in the development stage of breeding [4]. The above-mentioned issues are particularly important for China’s manufacturing innovation system under the warning of trade friction between China and the U.S., and listed manufacturing companies are facing more serious financing constraints. Under the condition of unchangeable external uncertainty, Chinese listed manufacturing companies can only improve their innovation capacity, especially their independent innovation capacity, to stand firmly in the international arena under the current level of financing [5].

When enterprises innovate, their R&D investments face greater information asymmetry and higher adjustment costs, and financing is more difficult [6], thus reducing the problem of insufficient R&D investment and reduced efficiency of enterprise innovation. The higher the uncertainty of the firm is, the more the firm’s investment will be subject to the degree of financing constraints, and the R&D investment decision tends to be more conservative and cautious, which is not conducive to innovation efficiency [7], thus leading to the reduction of firm innovation efficiency. In the existing literature, the impact of financing constraints on R&D [8] and on firm innovation [9], as well as the relationship between financing constraints, R&D investment, and innovation performance have been studied [10]. Scholars have also studied the impact of financing constraints on innovation activities of Chinese firms using regressions [11]. These studies improve the rich theoretical support for this paper, but they do not measure the specific values of firm innovation efficiency under the conditions of financing constraints and financing constraint uncertainty.

Is there an efficiency loss in the innovation efficiency of China’s listed manufacturing industry due to financing constraints and uncertainty? If there is an efficiency loss of Chinese listed manufacturing firms due to financing constraints and uncertainty, what is the specific value of innovation efficiency of Chinese listed manufacturing firms? Does this efficiency loss vary across regions and firm sizes? However, the existing literature has not paid much attention to this issue. In summary, considering the financing constraint and financing constraint uncertainty, it is of strong research significance to accurately assess the innovation efficiency of China’s listed manufacturing industry so that China can become a great technology and innovation country.

2. Methodology

The firm’s decision to carry out innovation efficiency activities without financing constraints and under a perfect market is also optimal, and the maximum innovation efficiency of the firm can be expressed as

$$\text{efficiency}_{i,t} = f(A_{i,t}) + v_{i,t},$$  \hspace{1cm} (1)

where efficiency$_{i,t}$ is the optimal innovation efficiency, $A_{i,t}$ is a vector of variables affecting the innovation efficiency of the firm, and $f(·)$ is a function affecting the innovation efficiency of the firm. Of course, the most effective innovation efficiency of a firm does not depend entirely on a set of variables that can affect the firm’s innovation efficiency but may also be randomly influenced by macroeconomic and policy factors that make the firm’s optimal innovation efficiency deviate randomly from the theoretical optimal innovation efficiency $f(A_{i,t})$. For this reason, $v_{i,t}$ is set to reflect the effect of these stochastic factors and efficiency$_{i,t}$ is the firm’s stochastic frontier investment efficiency. However, the presence of financing constraints and other effects make firms less efficient in innovation [12]. The reduction of the firm’s innovation efficiency can be seen as the deviation between the firm’s actual innovation efficiency and the stochastic frontier innovation efficiency. Based on this, in the case of considering the financing constraint, the actual innovation efficiency of the firm can then be expressed as

$$\text{efficiency}_{i,t} = f(A_{i,t}) - F(Z_{i,t}) + v_{i,t},$$  \hspace{1cm} (2)

where $F(Z_{i,t})$ indicates the loss of innovation efficiency of the firm due to the impact of financing constraints.

By combining (1) and (2), it can be seen that the relationship between the innovation efficiency of a firm without financing constraints and in the presence of financing constraints can be expressed as

$$E[\text{efficiency}_{i,t}|f(A_{i,t}), F(Z_{i,t}) = 0] > E[\text{efficiency}_{i,t}| f(A_{i,t}), F(Z_{i,t})].$$  \hspace{1cm} (3)

Thus, financing constraints can make firms less efficient in innovation and exhibit a unilateral distribution. If we set $F(Z_{i,t}) = \mu_{i,t}$, then the actual innovation efficiency efficiency$_{i,t}$ of the firm is related to the maximum innovation efficiency efficiency$^*_i$ as follows:

$$\text{efficiency}_{i,t} = \text{efficiency}^*_i - \mu_{i,t} = f(A_{i,t}) + v_{i,t} - \mu_{i,t}. \hspace{1cm} (4)$$

Model (4) is a qualitative stochastic frontier model. However, the specific form of $f(A_{i,t})$ needs to be given in the analytical model (4), i.e., set as $f(A_{i,t}) = X^t(\beta l)^i$, where $X_{i,t} = (1, A_{i,t})^t$, $A_{i,t}$ is a vector consisting of a series of
column variables affecting the efficiency of the firm’s frontier innovation, and $\beta$ is the corresponding vector coefficient.

The dummy variables of individual effects and time effects are included in the $X_{it}$ setting to reflect the characteristics of the panel data and the heterogeneity that exists across firms, so model (4) is further set as follows:

$$\text{efficiency}_{it} = X_{it}' \beta + \epsilon_{it}, \quad \epsilon_{it} = \nu_{it} - \mu_{it},$$

where $\epsilon_{it}$ is composed of $\nu_{it}$ and $\mu_{it}$. $\nu_{it}$ is the regular random disturbance term in the empirical evidence, which is assumed to be independent of each other and to obey a normal distribution. $\nu_{it} \sim \mathcal{N}(0, \sigma^2_{\nu})$ is the financing constraint efficiency, which indicates that the firm is affected by the financing constraint, i.e., the loss of the firm’s innovation efficiency, showing a unilateral distribution, which is set to obey a non-negative truncated seminormal distribution, set to $\mu_{it} \sim N^+(\omega_{it}, \sigma^2_{it})$. In the heterogeneous stochastic frontier model, the non-efficiency is set as a disturbance part, while the setting of the distribution function of the non-efficiency term will affect the estimates of efficiency to some extent, and it is still the setting of the main part of the model, i.e., the setting of the output function that plays a decisive role. This requires the relevant pretheoretical literature to choose the form of the model and the measurement of the core variables [21]. $\omega_{it}$ reflects the degree of deviation of the actual innovation efficiency from the frontier innovation efficiency by firms affected by financing constraints, and $\sigma^2_{it}$ expresses the uncertainty of the degree of deviation. Referring to the setting method in literature [14], the heterogeneity of $\mu_{it}$ is set as

$$\omega_{it} = \exp\left(b_0 + Z_{it}' \delta \right), \quad \sigma^2_{it} = \exp\left(b_1 + Z_{it}' \gamma \right),$$

where $b_0$ and $b_1$ are constants and $\delta$ and $\gamma$ are vectors of coefficients of the corresponding variables.

In literature [15], $\sigma^2_{it}$ is assumed to be a constant, while this paper differs from this strict assumption, which is relaxed in the heterogeneous setting, allowing the analysis of the impact of different types of financing on the financing constraint effect itself ($\omega_{it}$) and the uncertainty of the financing constraint ($\sigma^2_{it}$), which allows further quantitative analysis of the loss of innovation efficiency of firms.

The heterogeneous stochastic frontier model consisting of (5) and (6) can be estimated using the maximum likelihood method, and the corresponding likelihood function can be written as

$$\ln \text{efficiency}_{it} = -0.5 \ln (\sigma^2_{\nu} + \sigma^2_{it}) + \ln \left[ \frac{\phi(\epsilon_{it} + \sigma_{it})}{\sqrt{\sigma^2_{\nu} + \sigma^2_{it}}} \right]$$

$$- \ln \left[ \Phi\left( \frac{\omega_{it}}{\sigma_{it}} \right) \right] + \ln \left[ \Phi\left( \frac{\bar{\omega}_{it}}{\bar{\sigma}_{it}} \right) \right],$$

where

$$\bar{\omega}_{it} = \frac{\sigma^2_{\omega_{it}} - \sigma^2_{\epsilon_{it}}}{\sigma^2_{\nu} + \sigma^2_{it}}$$

$$\bar{\sigma}_{it}^2 = \frac{\sigma^2_{\omega_{it}} - \sigma^2_{\epsilon_{it}}}{\sigma^2_{\nu} + \sigma^2_{it}}$$

$\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal distribution density function and the cumulative distribution function, respectively.

After the maximum likelihood method is estimated, the likelihood ratio can be further used to test the effect of financing constraints on the innovation efficiency of firms. On one hand, it is possible to qualitatively analyze whether the set heterogeneous stochastic frontier model is correct. The original hypothesis $H_0$: $\mu_{it} = 0$ is that there is no financing constraint, and the firm’s innovation efficiency is maximum at this time, corresponding to the alternative hypothesis $H_1$: $\mu_{it} \neq 0$. The likelihood ratio statistics are $LR = -2 \ln(L(H_0) - L(H_1))$, $L(H_0)$, and $L(H_1)$, corresponding to the values of the likelihood functions under the original and alternative hypotheses, respectively, and the likelihood ratio statistics asymptotically follow a chi-square distribution. On the other hand, an enterprise innovation efficiency index ($\text{Effi}_{it}$) can be constructed for quantitative analysis, which indicates the deviation of the actual innovation efficiency of the enterprise from the optimal innovation efficiency, calculated as follows:

$$\text{Effi}_{it}^2 = \frac{\exp(X_{it}' \beta - \mu_{it})}{\exp(X_{it}' \beta)} = \exp(-\mu_{it}),$$

where $\text{Effi}_{it}$ is between 0 and 1. When $\mu_{it} \rightarrow -\infty$, Effi$_{it} = 0$, indicating that the enterprise faces the most serious financing constraint and that the enterprise innovation efficiency level is close to 0. When $\mu_{it} \rightarrow 0$, Effi$_{it} = 1$, indicating that there is no financing constraint and that the enterprise innovation efficiency level is the highest. After using the maximum likelihood estimation method to obtain the relevant parameter values, the following estimation equation for Effi$_{it}$ can be obtained according to the way it was set up in literature [16].

$$\text{Effi}_{it} = E\left[ \exp\left( -\mu_{it} \mid \epsilon_{it}, \bar{\epsilon}_{it} \right) \right]$$

$$= \exp\left( -\bar{\omega}_{it} + 0.5 \bar{\sigma}_{it} \right) \frac{\Phi\left( \bar{\omega}_{it}/\bar{\sigma}_{it} - \bar{\sigma}_{it} \right)}{\bar{\omega}_{it}/\bar{\sigma}_{it}},$$

where $\bar{\omega}_{it}$ and $\bar{\sigma}_{it}$ are defined as described previously, except that the parameters are replaced with estimates. Following the literature, the explanatory variables need to be treated logarithmically [17].

3. Model and Data

3.1. Model. In order to measure the value of manufacturing innovation efficiency and to construct efficiency$_{it}$ at the optimal level of innovation efficiency, it is first necessary to set the innovation efficiency of the firm as follows:
where efficiency\(_{i,t}\) is the natural logarithm of the number of patents granted by the enterprise, \(\eta_i\) is a time dummy variable, and \(\text{ind}_{i,t}\) is an industry dummy variable. \(\text{rdspend}\) is R&D investment, measured by using the proportion of R&D investment to business revenue; the greater the enterprise R&D investment, the greater the incentive for enterprises to engage in R&D, which is conducive to enterprise innovation output. \(\text{rdperson}\) is the number of R&D personnel as a percentage; the higher the percentage of enterprise R&D personnel is, the more inclined enterprises are to R&D activities, which is conducive to enhancing enterprise innovation.

Due to the existence of financing constraints, which lead to a decrease in the efficiency of enterprise innovation, according to financing theory, enterprises generally consider internal financing, commercial credit financing, and external financing in that order. To this end, this paper selects several indicators commonly used in the literature based on the availability of data and chooses relevant indicators from three channels of financing to portray the financing constraints faced by enterprises. Among them, internal financing (\(cf\)) is measured using cash flow, drawing on literature [17], and cash flow is calculated using the ratio of the firm’s free cash flow to its net fixed capital at the beginning of the period. Business credit financing (\(business\)) is measured using net accounts receivable as a percentage of total assets [18]. External financing (\(onpm\)) is measured using the increase in the sum of equity and capital stock as a percentage of total assets [17]. In addition, the size of the enterprise (\(size\)) measured using the logarithm of total assets will serve as an important reference basis for the enterprise to conduct commercial credit financing. Generally, the larger the size of the enterprise is, the more information asymmetry can be reduced, the higher the value of loan collateral can be obtained, and the more bank loans can be obtained, thus alleviating financing constraints. Therefore, we set it in (6) as follows:

\[
\ln w_{i,t} = b_{i} + Z_{i,t}\delta \\
= b_{i} + \delta_{1}cf_{i,t} + \delta_{2}business_{i,t} + \delta_{3}onpm_{i,t} + \delta_{4}size_{i,t}.\tag{12}
\]

A major advantage of the heterogeneous stochastic frontier model is that it takes into account the fact that financing constraint uncertainty may be influenced from the financing constraint mechanism and can further analyze the mechanism of action of the uncertainty of corporate financing constraints. The variance of the deviation of the firm’s efficiency in (6) is used as an estimate of the uncertainty of the financing constraint and is set as follows:

\[
\ln \sigma^2_{i,t} = b_{i} + Z'_{i,t}\gamma \\
= b_{i} + \gamma_{1}cf_{i,t} + \gamma_{2}business_{i,t} + \gamma_{3}onpm_{i,t} + \gamma_{4}size_{i,t}.\tag{13}
\]

The explanatory variables of financing constraint and financing constraint uncertainty can be set differently, and the reason why they are set to be the same is mainly because it is impossible to define whether the variables affecting financing constraint affect financing constraint uncertainty and whether the variables affecting financing constraint uncertainty affect financing constraints. For this reason, we set the explanatory variables of the two to be the same by referring to literature [14, 17] and [18]. In (13), if the estimated coefficient of the variable is positive, it indicates that as the variable increases it will intensify the uncertainty of the firm’s financing constraint, and conversely, it can reduce the uncertainty of the firm’s subsequent financing constraint.

3.2. Data. In this paper, we use R&D input (\(\text{rdspend}\)) and the share of the number of R&D personnel (\(\text{rdperson}\)) as input indicators and use the logarithm of total patents granted (\(\ln\text{patent}\)) as output indicators to measure the innovation efficiency of manufacturing industries. Further, the overall innovation efficiency of enterprises (\(\text{efficiency}\)) is measured using the total number of patents granted (\(\ln\text{ipatent}\)); the innovation quality efficiency of manufacturing enterprises (\(\text{efficiency} 1\)) is measured using the number of invention patents granted (\(\ln\text{inpatent}\)); and design patents granted (\(\ln\text{indpatent}\)) to measure the innovation quantity efficiency of manufacturing enterprises (\(\text{efficiency} 2\)) is measured using the number of utility patents granted (\(\ln\text{inpatent}\)) and design patents granted (\(\ln\text{indpatent}\)). The above indicators were obtained from the CSMAR database and the Wind database. The basic statistics for constructing heterogeneous stochastic frontier model variables are shown in Table 1.

4. Results and Discussion

4.1. Estimation Results of the Overall Innovation Efficiency Heterogeneity Stochastic Frontier Model. We estimated a variety of stochastic frontier models to verify whether the set models are correct. Table 2 shows the estimation results under various assumption settings when total patent grants (\(\ln\text{patent}\)) are the explanatory variable. Among them, Model 1 in column (1) is the estimation result without any constraint for the heterogeneous stochastic frontier model
estimated in this paper. Model 2 in column (2) is the estimation result of the way proposed by Battese and Coelli [13], which assumes that internal financing, commercial credit financing, external financing, and firm size have no effect on uncertainty. Model 3 in column (3) assumes that these variables have no effect on the financing constraint effect and that firm innovation efficiency bias does not exist. Model 4 in column (4) assumes that the financing constraint effect obeys a heterogenous half-normal distribution truncated at zero, corresponding to the model proposed by Caudill et al. [19]. Model 5 in column (5) is estimated for frictionless capital markets. From the likelihood ratio test results in the last four rows of Table 2, it is clear that the test results reject the original hypothesis regardless of whether the original hypothesis is set to "no innovation efficiency deviation" (LR1) or "heterogeneous innovation efficiency deviation" (LR2), indicating that the heterogeneous stochastic frontier model (Model 1) is better.

In the estimated results in column (1), the estimated coefficient of enterprise R&D input (rds pend) in the frontier innovation efficiency equation is significantly positive at the 1% level, indicating that the frontier innovation efficiency of manufacturing enterprises will increase with the increase in R&D input, and the more the enterprise R&D input, the higher the enterprise innovation output. In addition, the estimated coefficient of the R&D personnel ratio (rdperson) is positive but insignificant, indicating that the ratio of R&D personnel in enterprises has not reached a certain proportion, and their innovation effect has not been revealed. In the financing constraint equation, the estimated coefficients of internal financing (cf), business credit financing (business), external financing (onpm), and firm size

<table>
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<th>Variable</th>
<th>(1) Frontier innovation efficiency</th>
<th>Model 1: Unconstrained</th>
<th>(2) Model 2: y = 0</th>
<th>(3) Model 3: δ = 0</th>
<th>(4) Model 4: wi,t = 0</th>
<th>(5) Model 5: μi,t = 0</th>
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<tr>
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Note: 1. LR1 and LR2 are the chi-square values obtained from the likelihood ratio tests performed for Model 5 and Model 1, respectively. 2Z statistics in parentheses; *, **, and *** p < 0.1, 0.05, and 0.01, respectively, the same as the following table.
but subsequent financing constraint uncertainty will also reduce information asymmetry, and large-scale enterprises can alleviate uncertainty of subsequent financing, while commercial credit and external financing do not bring uncertainty of subsequent financing constraints and does not significantly affect the quality efficiency of enterprise frontier innovation. Understanding the role of financing constraints in the innovation efficiency of enterprises, effective financing instruments or channels can be adopted to enhance the innovation efficiency of the manufacturing industry.

### 4.2. Estimation Results for Different Patent Types

Table 3 reports the estimation results of heterogeneous stochastic frontier models for different patent types. Among them, column (1) shows the estimation results of invention patent grant (lnipatent) as the explanatory variable, column (2) shows the estimation results of utility patent grant (lnupatent) as the explanatory variable, and column (3) shows the estimation results of design patent grant (lndpatent) as the explanatory variable.

From the estimated results in Table 3, it can be seen that R&D investment can significantly improve the quality efficiency and the innovation quantity efficiency of enterprise frontier innovation, while the R&D personnel ratio only acts on the quality efficiency of enterprise frontier innovation and does not have a significant effect on the quantity efficiency of frontier innovation. This result analyzed above indicates that the higher the proportion of R&D personnel in manufacturing companies, the more manufacturing companies pay attention and concern to quality innovation in
their companies. In the financing constraint equation, internal financing, commercial credit financing, external financing, and firm size can effectively alleviate the financing constraint for the quality innovation activities of invention patents and the quantity innovation activities of utility patents; internal financing, external financing, and firm size can effectively alleviate the financing constraint for the quantity innovation activities of design patents, and commercial credit financing has no significant effect. In the financing constraint uncertainty equation, commercial credit financing, external financing, and firm size can increase the uncertainty of subsequent financing for qualitative innovation activities of invention patents and quantitative innovation activities of utility patents, while internal financing cannot significantly affect the uncertainty of subsequent financing for firms. Internal financing, external financing, and firm size all increase the uncertainty of subsequent financing when firms perform quantitative innovation activities of design patents, while commercial credit financing reduces the uncertainty of subsequent financing.

4.3. Innovation Efficiency Analysis. After the heterogeneous stochastic frontier model gets the estimation results, the innovation efficiency of each firm per year can be measured quantitatively, and the degree of financing constraints faced by the firm can also be judged based on the innovation efficiency value. The frequency distribution chart of innovation efficiency of manufacturing enterprises under the restriction of financing constraints is shown in Figure 1. The figure shows that both the overall innovation efficiency and the innovation quality and innovation quantity efficiencies show a left-skewed feature, indicating that the listed manufacturing enterprises in China are facing more serious financing constraints and the innovation efficiency of enterprises is not high. Specifically, the mean value of the overall innovation efficiency is 0.177, and the innovation efficiency of most enterprises is concentrated in 0.12~0.18, indicating that the overall innovation efficiency of listed manufacturing enterprises is only 12%~18%, which is reduced by 82%~88% compared to the optimal innovation efficiency. The average value of the innovation quality efficiency of manufacturing enterprises is 0.164, and the average value of the innovation quantity efficiency measured by the number of utility and design patents granted is 0.192 and 0.219, respectively. Compared with the optimal innovation efficiency, the actual innovation quality efficiency of enterprises is 85%~90% lower, and the innovation quantity efficiency is also reduced by 82%~85% and 80%~82%, respectively. It is also noted that enterprises are more willing to
carry out innovation quantity activities of utility and design patents and somewhat less willing to carry out innovation quality activities of invention patents in the case of financing constraints in manufacturing enterprises.

The above analysis shows that the real innovation efficiency of Chinese manufacturing enterprises is only about 20% due to the influence of financing constraints, and enterprises face more serious financing constraints. The efficiency of R&D investment in China’s nonlisted manufacturing industry is also only 59% due to the large R&D investment required from the beginning of the patent planning to licensing as well as the long waiting time [18]. The listed manufacturing companies will focus more on corporate performance when they face financing constraints and may just give up on independent innovation, and R&D investment to the final patent licensing will also lead to more innovation efficiency loss.

4.4. Heterogeneity Analysis

4.4.1. Regional Heterogeneity. The results of regional heterogeneity are reported in Table 4 (the eastern, middle, and western regions are divided mainly according to the degree of economic development. East: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; middle: Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan; west: Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, and Guangxi. It is important to note that the four Chinese municipalities have the same status as provinces. Hong Kong, Macau, and Taiwan are not included in the sample.). From the results in Table 4, we can see that the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency are the highest in the eastern
region, followed by the middle region and the western region. The innovation efficiency of the eastern region is higher than the national average, except for the middle region, where the overall innovation efficiency is higher than the national average, but the innovation quality efficiency and innovation quantity efficiency are lower than the national average, while the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of the western region are lower than the national average.

From the trend of change in Figure 2, before 2018, the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of the manufacturing industry in the east and the middle and western regions showed a growth trend, but after 2018, the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of utility patents in the east and middle regions all decreased slightly, by about 5%, and the gap in the middle and western regions narrowed, and the design of the innovation efficiency of patents declined more, amounting

<table>
<thead>
<tr>
<th>Enterprise size</th>
<th>Overall innovation efficiency (efficiency)</th>
<th>Innovation quality efficiency (efficiency1)</th>
<th>Innovation quality efficiency (efficiency2)</th>
<th>Innovation quantity efficiency (efficiency3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale</td>
<td>0.147</td>
<td>0.142</td>
<td>0.168</td>
<td>0.198</td>
</tr>
<tr>
<td>Medium scale</td>
<td>0.167</td>
<td>0.156</td>
<td>0.184</td>
<td>0.212</td>
</tr>
<tr>
<td>Large scale</td>
<td>0.219</td>
<td>0.193</td>
<td>0.224</td>
<td>0.248</td>
</tr>
<tr>
<td>Overall average</td>
<td>0.177</td>
<td>0.164</td>
<td>0.192</td>
<td>0.219</td>
</tr>
</tbody>
</table>

Table 5: Firm size heterogeneity in the innovation efficiency.

Figure 3: Trend of innovation efficiency of firm size.
to about 15%. The overall innovation efficiency of the western region in 2018 grew steadily with the innovation quantity efficiency of utility patents, and the innovation quality efficiency also showed an overall trend of growth, but the innovation quantity efficiency of design patents declined more. The possible reason is that trade frictions in 2018, the technological blockade against China, and China’s increased reliance on independent innovation led to a brief decline due to the innovation cycle but also more emphasis on quality innovation and no longer more reliance on the quantitative innovation in design patents.

4.4.2. Enterprise Size Heterogeneity. Firms are classified into small, medium, and large-scale firms according to their total assets in the current year, and Table 5 reports the results of firm size heterogeneity in innovation efficiency. From the results in Table 5, it can be seen that the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of large-scale enterprises are the highest and even higher than the average value of the whole sample, while in the small and medium-sized enterprises, both the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency are lower than the average value of the whole sample.

From the trend of Figure 3 before 2018, the overall innovation efficiency, innovation quality efficiency, and innovation quantity efficiency of both large-scale enterprises and small-scale and medium-scale enterprises showed an increasing trend and slightly decreased after 2018; the innovation efficiency of large-scale enterprises was much higher than that of small-scale and medium-scale enterprises, and this gap did not tend to narrow.
5. Conclusion and Policy Implications

Under the conditions of a perfect market and the absence of financing constraints, the innovation efficiency level of firms will be optimal, but under the influence of financing constraints, the innovation efficiency of firms will deviate significantly. To this end, considering the influence of financing constraints and uncertainty, a heterogeneous stochastic frontier model is used to study the innovation efficiency of China’s listed manufacturing industry, and the results show the following conclusions:

(1) Among the financing constraints affecting the innovation efficiency of enterprises, financing constraints make the innovation efficiency of enterprises deviate, internal financing significantly reduces the financing constraints of enterprises and does not bring uncertainty to the subsequent financing, commercial credit, and external financing, although it can alleviate the enterprise financing constraint, it will increase the uncertainty of the subsequent financing constraint, and the enterprise size can alleviate the financing constraint, but it also increases the uncertainty of the subsequent financing constraint.

(2) There are also differences in the financing constraints of different innovation efficiencies as follows: on one hand, internal financing, commercial credit financing, external financing, and firm size can effectively alleviate the financing constraints of firms’ quality innovation activities for invention patents and quantitative innovation activities for utility patents; internal financing, external financing, and firm size can effectively alleviate the financing constraints of quantitative innovation activities for design patents. Internal financing, external financing, and firm size in-crease the uncertainty of subsequent financing for qualitative innovation activities of design patents, while commercial credit financing has no significant effect. On the other hand, commercial credit financing, external financing, and firm size increase the uncertainty of subsequent financing for qualitative innovation activities of invention patents and quantitative innovation activities of utility patents, while internal financing does not significantly affect the uncertainty of subsequent financing. Internal financing, external financing, and firm size all increase the uncertainty of subsequent financing.
6 Limitations and Future Research

We do not consider the endogeneity issue when estimating the efficiency of manufacturing innovation in China using the stochastic frontier analysis (SFA) method, and the existing literature exploring the endogeneity issue is still in its initial stage. When estimating efficiency using the SFA method, we can refer to literature [20] when considering the endogeneity issue. Secondly, it is also a very interesting study for future research to consider the inclusion of cross-sectional and spatial correlation in the framework of the SFA due to the existence of correlation between production units.

Appendix

Considering that in China, it often takes more than one year for a patent to be granted, for this reason, the authors re-estimated the outcome variable lagged by one period using the SFA method, and the estimation results are shown in Table 6, and its estimation results have not changed essentially. In addition, the innovation efficiency distribution is redrawn (Figure 4, which results in a slight change in the innovation efficiency distribution but does not affect the conclusions obtained.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

All authors equally contributed to this work.

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