Research Paper

Research on pricing strategy of Cloud manufacturing service platform based on resource scarcity

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ABSTRACT

This study was done based on the increasing perfection of architecture and key technologies of cloud manufacturing (CMfg). It is of great significance for the development and application of CMfg to study the resource pricing under the specific transaction environment of cloud manufacturing service platform (CMSP). Hence, an optimal pricing strategy model adapted to the CMSP environment was proposed in this study. First, the transaction process of CMSP is analyzed, and the similarities and differences between the transaction process of CMSP and product auction are further discussed. Then the static Bayesian model is selected and improved from three aspects: the distribution function of competitor valuation, the existence of multiple winners and the platform resources information scarcity. Finally, through the solution of the model and parameter analysis, the advantages of the model are proved, and the pricing strategy is provided for the platform resource providers.

Keywords: Cloud manufacturing service platform (CMSP), Pricing strategy, Static Bayesian game, Scarcity.

INTRODUCTION

As a key research field of intelligent manufacturing, cloud manufacturing (CMfg) has attracted wide attention from academia and industry at home and abroad since it was proposed. Cloud manufacturing is a manufacturing mode of sharing, collaboration and interconnection based on cloud manufacturing service platform (CMSP) and the concept of "manufacturing as a service" by using network and cloud computing technology (Li et al., 2010). The research in the field of CMfg can be divided into two parts, CMfg architecture and key technologies in CMfg, both of which have had rich research results. In terms of CMfg architecture, Xu (2012) put forward the key technology and structure framework from cloud computing to cloud manufacturing, and elaborated the centralized management process of resources and the role of CMSP in the whole manufacturing life cycle. From the application level, Ren et al. (2011) proposed a public cloud manufacturing platform for small and medium-sized enterprises, summarizing the concept, architecture, key technologies and implementation process of the cloud manufacturing platform. The key technologies of cloud manufacturing are divided into: resource awareness and access, resource description, resource encapsulation, service search and matching, service composition and optimization, and service evaluation. Based on the investigation and analysis of research results related to cloud manufacturing services at home and abroad, Yi et al. (2016) summarized the research process and achievements of the above six key technologies of cloud manufacturing services, and revealed possible future research trends and development directions...
of cloud manufacturing services.

However, we have noticed that most of the existing studies are keen on the construction of cloud manufacturing architecture model and the design of various algorithms. In order to promote the implementation and application of CMSP, we realized that the operation mode and economic characteristics of cloud manufacturing platform deserves more attention. CMSP provides technical support and trading place for the integration, sharing and collaborative allocation of manufacturing resources, realizes the deep visibility and convenience of manufacturing resources, and provides methods and ways for the transformation of manufacturing enterprises into production services. From the perspective of economy and market, CMSP is the form of transformation and upgrading of traditional market with the help of information technology development.

In the operation of CMSP, the main types of tasks received by the platform are transaction, design and manufacturing. The available manufacturing capabilities on the CMSP can be divided into multiple types, and the same manufacturing capability is considered to be indistinguishable between enterprises. Enterprises may have a state of excess or shortage of manufacturing capacity, and the CMSP can grasp the state of the available manufacturing capabilities of the access enterprise in real time (Yi et al., 2015). Therefore, this study regards the CMSP as the market, various resource services as products, taking manufacturing tasks in CMSP as an example, researching the optimal pricing problem under the specific transaction environment of CMSP from the perspective of resource providers. The rest of the study is structured as follows. In Section 2, we review some related works on the pricing model of cloud platform. Section 3 introduces the transaction process of CMSP and completes the game characteristics analysis and basic model selection by comparing with product pricing. Then in Section 4, we expand the improvement and innovation of the basic Bayesian model in three aspects under the background of CMSP. Next, the pricing strategy model of CMSP is completed and solved, and the optimal pricing strategy for resource providers is analyzed in section 5. Subsequently, we analyze the influence of model parameters on the optimal pricing strategy through simulation experiments, and verify the advantages of using the truncated normal distribution in section 6. Finally, we summarize our work and plan for future work in Section 7.

RELATED WORKS

The related issues of cloud platform pricing are a fairly wide range due to the different angles and points. For the platform type, there are usually cloud computing platform, cloud manufacturing platform, e-commerce platform, logistics cloud platform and so on. For the research roles, there are usually providers, demanders and platform operators. Different researchers will conduct pricing analysis from different perspectives. For example, from the perspective of platform operators, platform charging criteria and policies competition between platforms may be considered to maximize platform revenue. In this section, we will review some of the existing literature on cloud platform pricing from the perspective of basic model. Through the analysis and summary of a large number of literature, we divide the pricing research of cloud platform into three categories from the perspective of the prototype of the model. Fixed pricing mechanism represented by cloud computing service charges. Weinhardt et al. (2009) proposed two basic pricing models for cloud computing: a pay-per-use pricing model and an on-demand pre-paid pricing model. Youseff et al. (2008) pointed out that any pricing model must combine one or more of per unit pricing, tiered pricing, and predetermined pricing. Presently, the fixed pricing mechanisms adopted by major cloud platforms such as Google, Microsoft, and Amazon are based on the above three forms. Pay-per-use is the user’s payment based on the unit cloud computing service they use. First, the cloud platform will inform about the pricing of each unit of service, and then the user can choose whether to purchase the relevant cloud service. The cloud platform also divides computing resources into multiple instances, each combination containing a fixed combination of computing resources (such as CPU frequency, memory size, etc.) and service level agreements, and specifying the price per unit time used. Weinhardt et al. (2009), Samimi and Patel (2011) and Al-Roomi et al. (2013) introduced the mainstream pricing mechanism used by major cloud computing platforms, and analyzed various practical factors affecting these pricing strategies, such as return on investment, market supply-demand relationship, etc., to lay the foundation for building a more adaptable pricing model for cloud computing market. Yeo et al. (2010) analyzed and compared the advantages and disadvantages of the fixed pricing mechanism adopted by cloud computing platforms.
from the aspects of demand, efficiency and service, and discussed the dynamic pricing algorithm. They believed that dynamic pricing could meet the computing or storage needs of users and improve their profits for cloud computing platforms. Joe-Wong and Sen (2012) evaluated the benefits of cloud platforms using different pricing strategies through a mathematical framework, and analyzed the fairness based on the real data of Google App Engine, giving a more reasonable method. However, this kind of pricing method is tailored for cloud computing resources and is not suitable for a broader cloud platform.

**Dynamic pricing model based on bilateral market.**

Friedma et al. (1993) proposed a dynamic resource pricing model based on double action. In bilateral auctions, multiple cloud users and cloud platforms can be freely quoted by bilateral auctions. Samimi et al. (2016), Shang et al. (2010) and Zhang et al. (2016) also studied the cloud platform and cloud user quotation algorithms in bilateral auctions, and Shi et al. (2016) analyzed the pricing strategy based on the bilateral auction mechanism. In addition, Garg et al. (2013) proposed a cloud platform framework "Mandi", which allows cloud users and cloud platforms to trade computing resources according to their requirements, allowing cloud platforms and cloud users to conduct multiple negotiations at the same time to determine the transaction price. The model of the bilateral market is very suitable for the pricing of the cloud platform, and the dynamic pricing scheme is more reasonable, but some competition factors between the platforms are ignored.

**Game model considering competition.**

Some researchers use the game theory of economics to analyze platform pricing by focusing on competitive factors. Truong-Huu et al. (2013) analyzed how the cloud platform is priced in a competitive environment in a simplified game model, and Qin et al. (2015) assumed that in the cloudy platform competition environment, most cloud platform pricing will follow an active cloud platform, and then based on the reinforcement learning algorithm to analyze the pricing strategy of the active cloud platform. This study assumes that only one cloud platform adopts a strategy of actively adjusting prices, while other competitors adopt a follow-up strategy. Shi Yuliang et al. (2016) proposed a service pricing model based on Pareto optimum idea, considering the benefits of multi-user and cloud platform, and multi-objective particle swarm optimization algorithm was used to obtain the global optimal resource allocation and pricing scheme. Yuan Ying et al. (2016) proposed a cloud resource allocation model based on incomplete information game, also predicted current bids according to the historical resource demand of cloud platforms based on hidden Markov theory, and urged cloud platforms to choose the most self-interested pricing according to the goal of maximizing revenue.

**Pricing analysis of cloud manufacturing service platform**

This section introduces the transaction process of CMSP and completes the game characteristics analysis and basic model selection by comparing with product pricing.

**Cloud manufacturing service platform architecture and transaction process analysis**

The participants in the CMSP are as follows: cloud manufacturing service resource providers, CMSP provider, and cloud manufacturing service demanders. The CMSP provider creates an open service platform for providers and demanders to facilitate their transactions. This business model, which is built by the CMSP provider to connect the provider to the demand side, has the characteristics of bilateral market. As a powerful tool to guide and optimize the combination of user needs, cloud manufacturing service price has become a competitive means for CMSP provider to attract users.

Figure 1 shows the architecture and transaction process of the CMSP. Firstly, the requirement information of manufacturing task is submitted to the CMSP. The platform decomposes tasks into sub-tasks, and each sub-task can correspond to a specific manufacturing capability on the platform. Each sub-task generates an order separately, and the platform matches the resource of the resource pool according to the specific demand information of the order, and finally selects the candidate supplier set. Secondly, the candidate providers and the demander enter the trading platform together. At this time, candidate resource providers make their own bids based on various factors, such as resource valuation based on cost accounting, historical transaction price information, competitive environment and platform resource information, etc. After the resource provider bids, the platform finally determines the transaction and generates an order with the complete transaction information. At this point, the entire transaction process is over. And in this process, there is no negotiation process between the demander and the resource provider.

**Compared with product auction pricing**

For resource providers, the type of services and the number of resources they can provide are difficult to change
quickly, so in the trading environment of CMSP, price competition is the key factor for providers to win orders. Compared with the traditional trading mode, the automatic matching mechanism of the platform brings about the improvement of transaction efficiency and more reasonable resource allocation. But at the same time, CMSP is a relatively closed platform. When resource providers submit resource information, they cannot know the situation of other competing providers. The combination of these two characteristics makes the transaction process under CMSP similar to the product auction bidding process. Therefore, this section compares the transaction process under CMSP with the product auction process, and explores the pricing characteristics and method selection under cloud platform environment.

Reverse auction can be briefly introduced as follows. First, the purchaser provides the information of the desired product, the requirements for the service and the price positioning that can be afforded. Secondly, the final product provider are determined by the seller in a competitive manner. Ultimately, the purchaser can achieve the purchase with the optimal performance-to-price ratio. Based on the analysis of the transaction process under CMSP in section 3.1, the similarities between the transaction process under CMSP and the reverse auction process are summarized as follows, the demand side of the CMSP transaction process is similar to the purchaser in the reverse auction. The “product” that it purchases is the manufacturing resource that meets the needs of its manufacturing tasks. The demander, as the publisher of demand information, enjoys greater initiative. On one hand, specific requirements are issued by the demander, including resource categories, timeliness, security technology standards and target price range, etc. On the other hand, according to the specific demand information, cloud platform screens out the candidate resource suppliers from the current resource pool to meet the requirements.

The resource provider is similar to the bidder in a reverse auction. In the cloud platform environment, when a manufacturing task occurs, the system first filters out resource providers that meet other conditions besides price, and finally compares the price to give the final result. Therefore, for the resource provider, its hardware conditions (such as service type, resource number, etc.) are difficult to change easily, so the key to the target is the price. The CMSP is divided into three large areas, two resource pools are used to temporarily store user-submitted demand information and resource information. A system matching area can be regarded as a large bidding area, in which each manufacturing resource demand order forms a separate bidding area. In addition to the similarities mentioned above, there are also some differences in specific operation details between the CMSP transaction process and reverse auction process. In the CMSP, it is no longer for purchasers to select and compare bidding schemes. This process is automatically completed by the matching system of the platform. On the one hand, it improves the efficiency of transaction. On the other hand, it helps the demander to get a better performance-price ratio, at the same time, it also brings a higher challenge to the pricing of resource providers. Demanders and providers only submit the current demand

Figure 1: CMSP architecture and transaction process.
or supply information, and do not participate in the selection process of bidding schemes. And after the transaction is concluded, there is also no further negotiation. This feature ensures the authenticity of the basic information submitted by the demander and the provider. However, the providers do not know the budgetary quotation of demanders in advance, their quotation mainly depends on accurate accounting of the value of resources and analysis of competitors' quotations. In the auction process, whether it is a specific product or an engineering project, it is a whole when trading, and cannot be split. That is, in the product auction, the final auction product can only be obtained by a bidder. However, considering the CMSP, in order matching process of the system, the qualified resource providers with the lowest quotation may not have the ability to fully meet the current order requirements. We need to consider splitting the order and completing the manufacturing task by a number of different resource providers. Compared with a bidder in a product auction, that is, only the lowest bidder has a profit, and the other bidders have zero returns. In the CMSP transaction process, for a manufacturing task demand order, there may be multiple bidders winning the bid.

**Game characteristics and static Bayesian model**

Based on the analysis of section 3.1 and 3.2, The bidding process of resource providers under cloud platform environment has the following four game characteristics:

There are three major areas in the CMSP. Two resource pools are used to store demand information and resource information. The matching in the transaction process can be regarded as a large bidding area. Under the screening condition of automatic matching of CMSP, price competition is the key factor for a single resource provider to win the bid. CMSP is a relatively closed platform. Resource providers cannot know the situation of other competitors when they submit the supply information. The resource provider submits the supply quotation information in a sequential order, but since the quotation information submitted before cannot be observed, the resource provider who owns the resource can be considered to take action at the same time.

Based on the above-mentioned characteristics of the game between the competitors of resource providers, the participants of the game make a decision at the same time, but one or more of the players don't know all the information of the game, which accords with the characteristics of the incomplete information static game theory (also known as Bayesian game). Therefore, this study selects the relevant theory of incomplete information static game to describe the bidding process of resource providers under the CMSP, and analyzes the corresponding pricing strategy. The basic model of the static Bayesian game is thus explained hereafter.

**The basic assumptions of the model**

Suppose there are \( n \) bidders, and each bidder is rational. Assuming that the valuation of auction items is \( v \), \( v \) is a random variable, and \( v \in [\underline{v}, \overline{v}] \), \( \underline{v} \) and \( \overline{v} \) are the lowest and highest possible values respectively, and the distribution function \( F(v) \) is the consensus among bidders. Assume that each bidder has his own valuation \( V_i \), \( V_i \in [\underline{v}, \overline{v}] \), \( i = 1, 2, ..., n \), is private information, and only the i-th bidder knows that other bidders do not know when they are quoting. The bidder's optimal strategy function \( b(v) \) is a strictly increasing function of its valuation \( v \). For each bidder, the optimal strategy function is the same, except that they have different valuation \( v \), so the i-th bidder's strategy function is \( b_i = b_i(v_i) \), and there is \( b_i \in [\underline{v}, v_i] \), that is, the bidder's actual bid cannot be higher than his own valuation of the manufacturing service, otherwise it would be unprofitable.

**Payoff function hypothesis**

If the i-th bidder wins the bid, its net utility is expressed as \( b_i - v_i \), and other bidders have a utility of 0 because they failed to win the bid. The winning bidder's quote is the lowest of all quotes, \( b_i = \min\{b_1, ..., b_n\} \), so the bidder's payoff function can be expressed as:

\[
\begin{align*}
&u_i(b_j, b_j, v_i) = \\
&b_i - v_i, \quad \text{if } b_i < b_j, j = 1, ..., i - 1, i + 1, ..., n \\
&\frac{1}{n}(b_i - v_i), \quad \text{if } b_i = b_j, j = 1, ..., i - 1, i + 1, ..., n(1) \\
&0, \quad \text{if } \exists j, b_i > b_j
\end{align*}
\]

When \( n \) bidders offer the same price, the order is randomly distributed among \( n \) bidders. And the subjective probability that the i-th bidder evaluates other bidders is:

\[
p(v_1, v_2, ..., v_{i-1}, v_{i+1}, ..., v_n | v_i) = \frac{p(v_1,...,v_{i-1},v_{i+1},...,v_n)}{p(v_1)} (2)
\]

The process of analyzing the Bayesian game is to solve the Bayesian Nash equilibrium in consideration of the maximum benefit of the bidder.

**IMPROVED STATIC BAYESIAN MODEL UNDER THE CLOUD MANUFACTURING SERVICE PLATFORM**

The improvement and innovation of the basic Bayesian model under the background of CMSP will be done in this section.
HYPOTHESIS AND BACKGROUND OF PRICING MODEL

Based on the transaction process analysis and the game characteristics under cloud platform environment, this section discusses the static Bayesian model hypothesis under the background of CMSP. Assume that a demand order for a certain manufacturing capability has n independent resource providers participating in the auction. The resource provider’s quotes are independent of each other. Without knowing the competitor’s quotation information, the quotation distribution function can only be determined through market research. And every resource provider is pursuing its own profit maximization. Since the manufacturing tasks in the CMSP are decomposed according to the platform mechanism, and are divided into several sub-tasks, this study only evaluates the price competition process for one sub-demand task, that is, the impact of service composition of the platform on the current round of quotation is not considered. Based on this, the pricing problem of manufacturing services under CMSP is expressed as a standard static Bayesian game process.

Behavior space: The actual quotation of resource providers should not be lower than their own cost estimates of manufacturing services, otherwise it would be unprofitable, but also not higher than a maximum limit, otherwise the probability of obtaining orders would be greatly reduced. That is, the quotation should be within a reasonable range.

\[ A_i \in [p_1, p_2], \quad (p_1, p_2) > 0 \]

Type space: The i-th manufacturing service provider’s unit service cost is \( c_i \). The provider only knows its own cost estimate, but does not know the quotation information of other competitors. Therefore, the quotation of other providers can only be estimated by the industry situation and historical quotation information. The pricing strategy is aimed at maximizing the profit of the manufacturing service provider, and the profit is composed of the difference between the total revenue and the total cost.

Analysis of valuation distribution function: Truncated normal distribution

Based on the hypothesis of section 3.1, the key factor in pricing strategy is to accurately estimate the distribution of competitors’ quotations, because it is impossible to understand the quotation situation of other suppliers with the same manufacturing capacity when the resource provider submits the quotation information.

This study summarizes the literature and finds that in similar studies, such as the application of static Bayesian model to solve the problem of product auction and engineering bidding pricing, many researchers usually choose to set the competitor’s bidding distribution function as a uniform distribution in a certain interval for the simplification of calculation and problem analysis. Although different distribution types do not affect the effectiveness of static Bayesian pricing model, the uniform distribution of quotation information deviates greatly from the actual situation, which may affect the practical significance of the final conclusion. The normal distribution has an extremely wide range of practical backgrounds, and the probability distributions of many random variables in production and scientific experiments can be approximately described by a normal distribution. In general, if a quantity is the result of many small independent random factors, then this quantity can be considered to have a normal distribution. In this study, the normal distribution is chosen as the quotation distribution function of the platform supplier. The mean value can be determined by the historical quotation information mean value, and the variance is more complicated, which should be closely related to the corresponding manufacturing capability attributes. Taking into account the range of quotations mentioned in section 4.1, the study finally chose the truncated normal distribution as the quotation distribution function.

\[ V_i \] represents the valuation of the i-th provider and \( V_i \) obeys truncated normal distribution \([v_{\min}, v_{\max}]\):

\[
 f(v; \mu, \sigma, v_{\min}, v_{\max}) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\sigma^2}} \Phi\left(\frac{\mu - v_{\min}}{\sigma}\right) - \Phi\left(\frac{v_{\max} - \mu}{\sigma}\right)
\]

(3)

\[ \varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}, \Phi(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2} dt \]

(4)

Static Bayesian model with multiple winners

In the CMSP, the resource provider and service demander information are automatically matched by the platform system. According to the cloud manufacturing platform matching allocation rules, when the manufacturing capability exceeds the current maximum supply capacity of the lowest price resource provider, it cannot be satisfied. The manufacturing capability will be completed by the sub-low-cost resource provider. Unlike the case where only the only successful bidder exists in the auction and bidding process, multiple bid winners are allowed in the bidding process on the CMSP. In the basic model of Bayesian game, if the price of a bidder is not the lowest, the income is zero, but according to the characteristics of the transaction bidding mentioned above, even if the price of a resource provider is not the lowest, it also has the possibility of gaining revenue on the CMSP. Therefore, the classical Bayesian game in CMSP can be improved and the bidder’s payoff function can be expressed as:
Creates value for table \( P < n \) \( b - \ldots 1 \) \( Q \ldots 1 \) \( j \in \ldots \), pricing strategy model of CMSP is completed and \( v \) \( \in \) \( \ldots \). To measure the price rise \( - \) \( v \) \( j \) \( 1 \) \( \infty \) or this arctan \( \in \) \( \ldots \) \( i \) \( n \) \( b \) \( \in \) \( \ldots \) \( 1 \) \( b \). \( \in \) \( \ldots \) \( b \) \( v \) \( i \) \( 1 \) \( b \) \( \in \) \( \ldots \) \( b \) \( \in \) \( \ldots \) \( n \) \( \in \) \( \ldots \) \( n \) \( \in \) \( \ldots \) \( n \) \( \in \) \( \ldots \) \( n \) \( \in \) \( \ldots \)

\[
\sum_{i=1}^{n} M_i^* = Q
\]  

\( Q \) represents the total demand of certain manufacturing capabilities for the sub-task and is provided by multiple suppliers eventually. And \( \varepsilon \) is introduced as an estimation parameter of available demand, which is based on the subjective estimation of the potential demand by resource providers.

### Pricing strategy function based on resource scarcity and premium price factor

In the basic model of the static Bayesian game, the bidder's optimal strategy function \( b(v) \) is a strictly increasing function of its valuation \( v \). For each bidder, the optimal strategy function is the same, except that they have different valuations \( v \), \( b_i = b_i(v_i) \), and there is \( b_i \in [v, v_i] \), that is, the bidder's actual bid cannot be higher than his own valuation of the manufacturing service, otherwise it would be unprofitable. For the CMSP, the optimal strategy function of the resource provider is the pricing strategy function for manufacturing capability, \( P_i = P_i(v_i) \), \( v_{min}, v_{max} \) are the lowest and highest possible values respectively. Each provider has his own valuation \( v_i, v_i \in [v_{min}, v_{max}] \).

The valuation of the manufacturing capability by a resource provider primarily depends on the vendor’s costing and marketing strategy. Based on the valuation by each provider, the pricing function is further determined by the premium price factor \( \alpha \) :

\[
P_i = P_i(v_i) = v_i(1 + \alpha)
\]  

(7)

Premium factor \( \alpha \) is an index to measure the price rise and fall based on the resource scarcity on the CMSP. The range of premium factors is assumed as \([-0.2, 9]\). The lowest premium factor is \(-0.2\), that is, the quotation is not less than 0.8 times the estimated value of manufacturing services, and the highest is 9, the quotation will not exceed 10 times the estimated value of manufacturing services. Although the CMSP is not a commodity, it creates value for users in the form of providing manufacturing service resources. In the operating mechanism of the CMSP, it can be clearly seen that the resources provided by the resource provider are integrated into the cloud service platform for the demander to select and use. The finiteness and imbalance of a certain resource on CMSP is defined as the scarcity of the resource, and scarcity is a reflection of the intrinsic value of commodities.

\[
S_c = \frac{R}{S}, \quad S_c \in (0, \infty)
\]  

(8)

\( R \) represents the platform requirement for a specific service resource, and \( S \) represents the platform supply for this service resource. From the perspective of the scarcity of economic, the demand side of CMSP can be regarded as the customer who buys goods on the market, and regards the cloud manufacturing resources as commodities. When the number of commodities in the market decreases, the scarcity of the goods increases, and the supply exceeds demand. The premium factor \( \alpha \) needs to be raised, thereby effectively suppressing the demand of the customers and appropriately increasing the supply of the products. When the number of commodities in the market increases, the scarcity of commodities declines, and there is a situation of oversupply. Merchants will stimulate the demand of users at the cost of lowering prices (with lower premium factor \( \alpha \)), so that the resources can be fully utilized.

This study considers that the premium factor is determined based on the scarcity information of the platform resources, so the premium factor has a mapping relationship with the resource scarcity. And based on the above definition and analysis, the mapping relationship between the premium factor and the scarcity has the following conditions. The range of premium factors is \([-0.2, 9]\), and the range of \( S_c \) is \((0, \infty)\). The premium factor \( \alpha \) and \( S_c \) have a unique and one-to-one functional relationship. The higher the scarcity of platform resources, the corresponding premium factor will increase. However, when the platform resource scarcity is very high or even tends to infinity, the premium factor will not rise continuously. The premium factor index has an upper bound value of 9. The mapping relationship between premium factor \( \alpha \) and resources scarcity \( S_c \) is as follows:

\[
0.2(S_c - 1) \times \cos(S_c) \quad 0 < S_c < 1
\]

\[
\alpha = \frac{1}{\pi} \arctan(S_c) - \frac{9}{2} \quad S_c > 1
\]  

(9)

Figure 2 shows the mapping relationship between \( \alpha \) and \( S_c \).

### PRICING STRATEGY MODEL IN CLOUD MANUFACTURING SERVICE PLATFORM

The pricing strategy model of CMSP is completed and solved, and the optimal pricing strategy for resource providers is analysed in this section. Subsequently, we analyse the influence of model parameters on the optimal pricing strategy.
Pricing strategy model based on improved static Bayesian

The pricing strategy of this study is aimed at maximizing the profit of the resource provider in CMSP. The composition of its profit is the difference value between final transaction price (quotation price) and resource provider’s valuation price. Therefore, the objective function can be expressed as:

$$\max U_i = (P_i - v_i)M_i$$ (10)

$$U_i = \begin{cases} 
(P_i - v_i)M_i, & \text{if } P_i < P_j, j = 1, ..., i-1, i+1, ..., n \\
\frac{1}{n}(P_i - v_i)M_0, & \text{if } P_i = P_j, j = 1, ..., i-1, i+1, ..., n \\
(P_i - v_i)M_i^*, & \text{if } \exists j, P_i > P_j 
\end{cases}$$ (11)

The payoff function of the above three cases is explained as follows:

(1) When the i-th resource provider’s quotation is lower than the quotation of other providers, the lowest quoted resource provider’s revenue.

(2) When the i-th resource provider’s quotation is the same as that of other providers, the platform will limit choose the first quotation provider. At this time, the probability that the provider becomes the first bidder is 1/n, so the income is the expected return 1/n times.

(3) When the i-th resource provider’s quotation is higher than the quotation of other owners, and the other resource providers with lower quotation cannot fully meet the total demand of the platform order. The i-th resource provider completes the platform order of the remaining quantity. The order is completed by multiple providers.

Optimal pricing strategy analysis

According to Bayesian Nash Equilibrium, each resource provider’s pricing goal is to maximize the expected return. For each resource provider i, satisfy:

$$\max \{[(P_i - v_i)M_i]P(P_i < d|P_j = d) + \frac{1}{n}(P_i - v_i)M_i]P(P_i = d|P_j = d) + [(P_i - v_i)\varepsilon M_i]P(P_i > d|P_j = d)\}, (d \in [\alpha_j + \beta_jc_{\min}, \alpha_j + \beta_jc_{\max}])$$ (12)

Then $P_i, P_j(i \neq j)$ are Bayesian Nash equilibrium, that is, the optimal pricing strategy for i-th,j-th resource provider are $P_{i_b}, P_j$ respectively. For the resource providers, quotes are independent of each other:

According to the model hypothesis, the resource providers participating in the bidding are independent of each other, and the quotation of the other party cannot be known at the time of quotation. Therefore, $P(P_i < d)$ and $P(P_j = d)$ are two independent events, hence:

$$P(P_i < d|P_j = d) = \frac{P(P_i < d)}{P(P_j = d)} = \frac{P(P_i < d)}{P(P_i = d)} = P(P_i < d)$$ (13)

And formula (12) can be simplified as:

$$U = \max\{[(P_i - v_i)M_i]P(P_i < P_j) + [(P_i - v_i)\varepsilon M_i]P(P_i > P_j)\}$$ (14)

$V_i$ represents the valuation of the i-th provider and $V_i$ obeys truncated normal distribution $[v_{\min}, v_{\max}]$:

$$f(V_i; \mu, \sigma, v_{\min}, v_{\max}) = \frac{1}{\sigma \sqrt{2\pi}} \Phi(-\frac{v_{\min} - \mu}{\sigma}) - \Phi(-\frac{v_{\max} - \mu}{\sigma})$$ (15)
\[ \varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}, \quad \Phi(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt \] 

(16)

\[ P_i = v_i(1 + \alpha) \] 

(17)

\[ P(P_i < P_j) = 1 - P(P_i > P_j) = 1 - P \left( P_i > v_j(1 + \alpha) \right) \]

\[ = 1 - P \left( \frac{P_i}{v_j} < 1 + \alpha \right) \]

\[ = 1 - \int_{v_{\text{min}}}^{v_{\text{max}}} \Phi \left( \frac{v_{\text{max}} - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{min}} - \mu}{\sigma} \right) dx \]

\[ = 1 - \Phi \left( \frac{v_{\text{max}} - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{min}} - \mu}{\sigma} \right) \]

(18)

\[ U = \max \left\{ \left[ (P_i - v_i)M_i \right] P(P_i < P_j) + \left[ (P_i - v_i)\epsilon M_i \right] P(P_i > P_j) \right\} \]

\[ = \max \left\{ \left[ (P_i - v_i)M_i \right] [1 \right.

\[ - \int_{v_{\text{min}}}^{v_{\text{max}}} \frac{1}{\sigma} \varphi \left( \frac{x - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{min}} - \mu}{\sigma} \right) dx \]

\[ + \left( P_i - v_i \right)\epsilon M_i \int_{v_{\text{min}}}^{v_{\text{max}}} \frac{1}{\sigma} \varphi \left( \frac{x - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{max}} - \mu}{\sigma} \right) dx \]

Solve the partial derivative of \( P_i \) of the above formula and make it equal to 0, the following result can be obtained:

\[ \frac{1}{1 - \epsilon} - \int_{v_{\text{min}}}^{v_{\text{max}}} \frac{1}{\sigma} \varphi \left( \frac{x - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{min}} - \mu}{\sigma} \right) dx \]

\[ = \frac{P_i - v_i}{1 + \alpha} \cdot \Phi \left( \frac{v_{\text{max}} - \mu}{\sigma} \right) - \Phi \left( \frac{v_{\text{min}} - \mu}{\sigma} \right) \]

According to the model calculation results, the final quotation price decision depends on:

\[ v_i: \text{The valuation of the i-th resource provider.} \]

\[ \mu, \sigma, v_{\text{max}}, v_{\text{min}}: \text{Estimation of the distribution parameters of competitors' quotation price.} \]

\[ \epsilon: \text{The Estimation of the available resource requirement quantity.} \]

\[ \alpha: \text{The premium factor based on the resource scarcity.} \]

The valuation price of each resource provider \( v_i \) can be obtained according to the resource cost. Due to the difference in cost and the strategic orientation of the resource provider, the valuation shows a large difference; the minimum value of the interval \( v_{\text{min}} \) can be determined by the industry’s lowest cost estimate for the resource. The maximum value of the interval \( v_{\text{max}} \) can be determined by the minimum value plus the industry’s largest profit bonus; the mean of the interval \( \mu \) can be estimated by the average historical transaction price of the resource on the platform; the estimated parameters of the demand obtained \( \epsilon \) are determined based on the resource provider’s subjective estimate of the likely demand. The premium factor \( \alpha \) is determined by the resource scarcity of the current state platform.

**SIMULATION EXPERIMENTS**

**Selection of experimental method**

This study intends to use computer simulation method, using Matlab to simulate the example to verify the validity of the above established pricing model, and through sensitivity analysis of the impact parameters of the final pricing of the model, to provide corresponding guidance and suggestions for the actual platform resource supplier quotation. The reasons for choosing the simulation method for the study are as follows:

Real data acquisition is difficult. The current cloud platform is still in the theoretical research stage. Although some cloud service platforms have been launched, their application has not been made popular. The existing cloud manufacturing service information platform has a small number of resource providers, and not every supplier will choose to submit their own price information on the platform. Therefore, it is difficult to obtain actual data from existing cloud platforms. The calculation method of some parameters in the model has yet to be studied. In the pricing strategy given in Section 4.2, the final quotation price decision depends on:

\[ v_i: \text{The valuation of the i-th resource provider.} \]

\[ \mu, \sigma, v_{\text{max}}, v_{\text{min}}: \text{Estimation of the distribution parameters of competitors' quotation price.} \]

\[ \epsilon: \text{The Estimation of the available resource requirement quantity.} \]
quantity.

α: The premium factor based on the resource scarcity. $v_{min}$ can be determined by the industry's lowest cost estimate for the resource. $v_{max}$ can be determined by the minimum value plus the industry's largest profit bonus. $\mu$ can be estimated by the average historical transaction price of the resource on the platform. The premium factor $\sigma$ is determined by the resource scarcity of the current state platform. However, $\sigma$ and $\varepsilon$ has not been studied in depth in this paper. Therefore, using the simulation method, all possible situations can be exhausted and explored through sensitivity analysis.

**Sensitivity analysis**

Since there is no analytic solution for the calculation results of the pricing model, a single variable is analysed by assigning other parameters. In this paper, by fitting the variation of a parameter in the limited range of the pricing model, the effect of the parameter on the optimal quotation is plotted and analyzed.

**The effect of $\mu$ variable on optimal quotation**

$\mu$ is the estimation of the distribution parameter of competitors’ quotation price. In this study, the truncated normal distribution is chosen as the quotation distribution function of the platform supplier. $\mu$ as a mean parameter reflecting the quotation of resource providers, its changes will greatly affect the final quotation strategy. As shown in the Figure 3, by setting $v_i = 500$, $v_{min} = 10$, $v_{max} = 1000$, $\sigma = 50$, $\alpha = 0.5$, the optimal quotation corresponding to the change of $\mu$ in this scenario is finally obtained. As $\mu$ continues to increase, the corresponding optimal quotation is higher under the same conditions, but the trend of synergistic growth gradually slows down. In practice, $\mu$ can be estimated by the average historical transaction price of the resource on the platform. Uniform distribution has no average parameters of quotation information, only the upper and lower bounds of quotation range. Therefore, in this case, the historical average transaction price will not affect the optimal quotation of resource providers at all. Here we can see one of the advantage of choosing truncated normal distribution. Truncated normal distribution can optimize the optimal bidding model by measuring the average bidding information of platform resource providers.

As shown in the Figure 4, the quotation curves $v_i-p_i$ for $\mu=200$, $\mu=400$, and $\mu=600$ are plotted respectively, and other parameter values remain the same. It can be seen from the Figure that when the value of $\mu$ is different, the curve of the quotation basically has the same trend. The
higher the value of $\mu$, the higher the corresponding optimal quotation for the same valuation. However, as the valuation increases, the effect of the $\mu$ value on the quotation will decrease, and the last three curves will continue to approach. In practice, it is not difficult to understand that when the resource provider’s valuation of a resource reaches the maximum value of the industry valuation, the impact of the average quotation level will be minimal.

**The effect of $\alpha$ variable on optimal quotation.**

Premium factor $\alpha$ is an index to measure the price rise and fall based on the resource scarcity on the CMSP. The value of $\alpha$ is mapped from $Sc$, and $Sc$ is the ratio of the requirement and supply of a certain resource on the platform. Therefore, this paper analyses the influence of $\alpha$ on the optimal quotation by controlling the value of $Sc$ and with the help of the mapping relationship between $\alpha$ and $Sc$. It can be seen from the Figure 5 that when $sc$ is greater than 15 or so, the change in the optimal quotation tends to be flat, indicating that when the demand exceeds supply, the price does not increase without limit, which is also in line with market rules. For different distributions, the overall trend is almost the same, but from the comparison in the Figure, it can be seen that for $Sc \in (3,10)$, the quotation increase under the truncated normal distribution is significantly stronger than the uniform distribution. At this point, it is difficult to directly determine which distribution is better, often based on the actual situation, specific resources and the real market. But the truncated normal distribution can adjust the curve by changing the value of $\sigma$ parameter, as shown in Figure 6. Here we can see another advantage of choosing truncated normal distribution. The truncated normal distribution can be adapted to a certain resource or market by flexible
parameter adjustment, thus having a better ability to guide the actual quotation.

CONCLUSION

This study analyzes the transaction process of CMSP, and compares the characteristics of the CMSP transaction process with the product auction, then proposes the optimal pricing strategy model of the CMSP for resource providers. This model is based on the basic Bayesian model, how it improves and innovates from three aspects: the distribution function of competitor valuation, the existence of multiple winners and the scarcity of platform resources according to the cloud platform trading environment. By solving the model, it is concluded that the final quotation price decision of resource providers depends on: the resource evaluation value based on cost accounting, the estimation of the distribution parameters of competitors’ quotation price, the estimation of available quantity and the resource scarcity index of the platform. The main contributions of this study are concluded as follows. Based on the CMSP environment, the optimal pricing model for resource providers is proposed. The truncated normal distribution is selected in the improved basic Bayesian model, and the advantages of the truncated normal distribution compared to the traditional uniform distribution are proved by simulation. Considering the resource information in the CMSP—the scarcity, the resource information of the platform is included in the pricing model by constructing the correspondence between the resource scarcity and the premium factor. On the basis of this study, the issues to be further studied. In the conclusion of this study, the final quotation decision depends on: \( v_1, \mu, \sigma, V_{\text{max}}, V_{\text{min}}, \varepsilon, \alpha \). The estimation of \( v_1, \mu, V_{\text{max}}, V_{\text{min}} \) and \( \sigma \) are all elaborated in the study. However, for the estimated parameters of \( \varepsilon \) and the variance \( \sigma \), this paper explores the influence of its change on quotation by means of simulation experiment, and does not give a specific method to determine it. In the subsequent research, the specific estimation method of the parameters can be further studied to provide guidance for the resource provider in CMSP.

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REFERENCES


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