Pricing Research on Cloud Manufacturing Service Based on Game Theory

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Abstract. The pricing of the cloud manufacturing service was critical for the success of service transaction. Firstly, based on the hotelling model, this paper discussed the pricing and revenue of providers on the cloud platform for service trading. In the cloud service transaction, the cloud platform is generally the leader of service providers. Therefore, we further proposed the stackelberg game model, in which the pricing of the manufacturing service was determined by the profit ratio of the cloud platform. Thirdly, basing on the utilization rate of the manufacturing service, we adjusted the determined pricing of manufacturing service dynamically to cope with unpredictable service demand. Finally, we compared the price and benefit between the proposed model and the traditional hotelling model. The result shows that the price and revenue of the manufacturing service are improved by introducing cloud platform. In the future, we should consider demanders’ revenue and other factors on the price.

Keywords: Cloud platform; Manufacturing service; Game model; Utilization

1. Introduction
Cloud manufacturing is an Internet-based manufacturing model that involves the cloud platform, the cloud service provider, and the cloud service demander. The cloud service provider provides the cloud platform with manufacturing resources to form manufacturing services by perception and virtual technology. Manufacturing resources that exist physically include hard manufacturing resources and soft manufacturing resources. Hard manufacturing resources include material, computing equipment and manufacturing equipment, such as Machine Tool and the production line. Soft manufacturing resources include software, knowledge, and human resource [1]. The cloud service provider publishes information about manufacturing resources on the cloud platform, such as production scale and type. The cloud service demander requests manufacturing services from the cloud platform. Then, the cloud platform searches for cloud services based on the demand request, and dynamically distributes the appropriate services to the demander [2]. In the cloud service transaction, the provider wants to get profit by offering services. When the price of cloud services is too low, the provider and cloud platform can’t obtain profit. Conversely, the demander can’t be attracted to join the cloud platform. Therefore, it is necessary to achieve the successful transaction by the appropriate service price. In addition, the price also regulates the required quantity of the service demander.

At present, there are mainly the following methods about the pricing research on the cloud platform. (1) Stackelberg model. Considering the unequal relationship, Xianwei Li et.al [3] proposed the stackelberg model to analyse the interaction between the provider and demander of cloud computing service, and the demander selected the service according to the price set by the provider. Lee I [4] presented that the provider of cloud computing service set price based on the price-demand functions of the demander to maximize the profit. Alia A et al. [5] modelled a stochastic Stackelberg game with
multiple leaders and incomplete information for the pricing in the BaaS-MEC (blockchain-as-a-service and mobile-edge computing) system.

(2) Hotelling model. Basing on the hotelling model, Daozhi Zhao et al. [6] discussed the impact of price sensitivity of the consumer on the pricing and profit of participants, such as cloud platform, the provider and the manufacturer. Considering some multi-homing developers and single-homing users of cloud computing service, Qi Li et al. [7] established a pricing model based on the bilateral market and the hotelling model. Ruijie Zhao [8] introduced network externalities and the symmetric transfer cost into the hotelling model and conducted a two-stage pricing study on IaaS (Infrastructure as a Service).

(3) The duopoly model. Bo Wang [9] proposed the Cournot model to determine the price of cloud resources to maximize the profit of the provider. Lee D H [10] established a price competition model among providers of cloud computing service by non-cooperative game. Mingfeng Li [11] maximized the profit of the provider and determined the price of cloud resources based on Burland model.

(4) Combination optimization method. Shin Y R [12] proposed the 0-1 backpack method to optimize the price of cloud computing service. Xuhong Zeng et al. [13] studied the pricing mechanism of cloud computing service by the Traveling Salesman Problem (TSP).

In addition, Guofang Nan et.al [14] discussed the optimal pricing strategies of SaaS in an incumbent-entrant setting under user upgrade cost and switching cost. Shang Di et al. [15] proposed a mechanism for pricing brokered cloud computing services. Jiang Rong et al. [16] proposed a pricing policy for the real-world cloud market and formulate it as a stochastic game. Meng Q N et al. [17] presented taxonomy of Value Measures and Metrics (VMMs) for pricing decisions over the product life cycle in a cloud manufacturing.

Most of the above literature is about the pricing of the cloud computing service. There are three types of the cloud computing service [18], namely IaaS, SaaS (Software as a Service) and PaaS (Platform as a Service). Conversely, there is less pricing research on the cloud manufacturing service. The stackelberg model only describes the unequal relationship in cloud transactions, but does not illustrate the distribution of providers on the pricing of manufacturing services. On the contrary, the hotelling model does not illustrate the interaction relationship among the parties involved in the transaction by the cloud platform. The duopoly model only describes the pricing competition between cloud resources to maximize the benefits from the perspective of the supplier, without considering the cloud platform and the demander. And the combination optimization method is mainly used for the pricing research of cloud computing service. Therefore, the hotelling+stackelberg model is adopted, and the dynamic pricing of the cloud manufacturing service is further considered.

In practice, because the transactions of cloud manufacturing services are not yet popular, some providers still supply manufacturing services offline, but others provide manufacturing services by the cloud platform. Therefore, this paper constructs the hotelling model and determines the price of manufacturing services to maximize the revenue in two ways. In the cloud transaction, the provider of the manufacturing service is dominated by the cloud platform. Thus, according to the price of the manufacturing service, the stackelberg model is used to discuss the profit ratio charged by the cloud platform. Finally, according to the current utilization of manufacturing services [19], the price is dynamically adjusted to avoid the overloading and waste of manufacturing services. This method is more in line with the actual transaction situation of cloud manufacturing services, and considers the distribution of market demand and the interaction between various parties. It can be applied to the pricing analysis of products through two channels (online and offline). The research thinking is shown in figure 1.
2. Construct the Pricing Model

2.1. Construct the Hotelling Model of the Pricing of Cloud Manufacturing Services
According to the classical hotelling model, the pricing of the cloud manufacturing service is studied. Suppose there are two competing providers that provide the same manufacturing services, and their heterogeneity is reflected in different spatial locations. They are distributed at both ends of the linear city from 0 to 1 and can provide manufacturing services to the demander offline or by the cloud platform. Suppose that the provider A of the 0 endpoint leases the manufacturing service to the demander offline, while the provider B of the 1 endpoint publishes the manufacturing service by the cloud platform. When the demander obtains manufacturing services by the cloud platform, the quality and credit of manufacturing services can be ensured, which increases the utility of the demander. The cloud platform obtains intermediary cost from the revenue of the provider B in proportion. Demanders of manufacturing services are uniformly distributed in the interval [0,1]. The demander chooses the manufacturing service to maximize the utility. Namely, the sum of the price and the transportation cost of the manufacturing service is as small as possible. Transportation cost is a linear function of the distance. It is necessary to find a demander $x^*$ in the interval [0,1]. The demander leases the manufacturing service from the provider A and B and has the same utility. So the model is established:

$$u - p_1 - cx = u + u_0 - p_2 - c \times (1 - x)$$

$$x^* = \frac{p_2 - p_1 + c - u_0}{2c}$$

Where $u$ is the initial utility of the demander to use the manufacturing service. $u_0$ is the additional utility by the cloud platform. $p_1$ is the price of the provider A. $p_2$ is the price of the provider B. $c$ is the cost of unit transport distance.

The provider A can be selected by demanders in the interval [0, $x^*$] and the utility of choosing the provider A is higher than that of choosing the supplier B. On the contrary, demanders in the interval [$x^*$, 1] can choose the supplier B. Therefore, the profits of the supplier A and supplier B are expressed as in equation (3), (4).

$$y_1 = (p_1 - f_1) \times x^* = (p_1 - f_1) \frac{p_2 - p_1 + c - u_0}{2c}$$

$$y_2 = [p_2(1 - R) - f_2] \times (1 - x^*) = [p_2(1 - R) - f_2] \times (1 - \frac{p_2 - p_1 + c - u_0}{2c})$$

Where, $f_1$ and $f_2$ are respectively the expenditure cost of the supplier A and supplier B, including the management cost and storage cost. $R$ is the profit percentage that the cloud platform obtains from supplier B.

The cloud platform provides the supply and demand information of the manufacturing service to the provider B and demanders. The provider B is charged in proportion by the cloud platform, but the cloud platform is free for demanders to attract a larger number of demanders. So the revenue function of the cloud platform is as in equation (5).
The overall revenue of the cloud transaction is as in equation (6).

\[ y_{23} = y_2 + y_3 = [p_2(1 - R) - f_2] \times (1 - x^*) + p_2 R (1 - x^*) = (p_2 - f_2)(1 - x^*) \] (6)

The provider A determines the pricing \( p_1 \) to maximize its profit, so equation (3) finds the first derivative of \( p_1 \):

\[ \frac{\partial y_1}{\partial p_1} = -\frac{2p_1 + p_2 + f_1 + c - u_0}{2c} \] (7)

\[ \frac{\partial^2 y_1}{\partial p_1^2} = -\frac{1}{c} < 0, \quad y_1 \text{ is a concave function, so there exists an optimal reaction function } p_1^* \text{ as in equation } (8). \]

\[ p_1^* = \frac{p_2 + f_1 + c - u_0}{2} \] (8)

Similarly, equation (4) finds the first derivative of the price \( p_2 \) of the provider B as in equation (9).

\[ \frac{\partial y_2}{\partial p_2} = \frac{f_2 - (1 - R)(2p_2 - p_1 + c - u_0)}{2c} + (1 - R) \] (9)

\[ \frac{\partial^2 y_2}{\partial p_2^2} = -\frac{1 - R}{c} < 0, \quad y_2 \text{ is a concave function, so there is an optimal reaction function } p_2^* \text{ as in equation } (10). \]

\[ p_2^* = \frac{f_2}{2(1 - R)} + \frac{p_1 + c + u_0}{2} \] (10)

The equilibrium points of the prices of the provider A and B can be obtained by equation (8) and (10) as shown in equation (11).

\[ \begin{cases} p_1^{**} = \frac{f_2}{3(1 - R)} + \frac{2f_1 + 3c - u_0}{3} \\ p_2^{**} = \frac{2f_2}{3(1 - R)} + \frac{f_1 + 3c + u_0}{3} \end{cases} \] (11)

Deviating from the equilibrium points, the provider A and B can’t maximize their profits. The market demand segmentation point can be solved by equation (2) and (11).

\[ x^{**} = \frac{f_2}{6c(1 - R)} - \frac{f_1}{6c} - \frac{u_0}{6c} + \frac{1}{2} \] (12)

2.2. Consider Master-slave Relationship for the Pricing

Suppose that there is only cloud platform in the cloud transaction and all cloud transactions are processed by the cloud platform. Therefore, the provider of the manufacturing service is dominated by the cloud platform. Since the price is interacting between the provider A and B, the provider A and B are followers of the cloud platform. At first, the cloud platform predicts the price of the provider B as in equation (11). Then, the profit ratio \( R \) obtained from the supplier B is determined according to the maximum profit of the cloud transaction. So the profit of the cloud transaction is shown as in equation (13) by equation (6) and (11).

\[ y_{23} = \left( \frac{2f_2}{3(1 - R)} + \frac{f_1 + 3c}{3} + \frac{u_0}{3} - f_2 \right) \frac{1}{2} - \frac{f_2}{6c(1 - R)} - \frac{f_1}{6c} + \frac{u_0}{6c} \] (13)

Equation (13) finds the first derivative of \( R \) as in equation (14).

\[ \frac{\partial y_{23}}{\partial R} = -\frac{4f_2^2}{18c(1 - R)^2} + \frac{2f_2(f_1 + 3c)}{18c(1 - R)^2} - \frac{f_2(f_1 - 3f_2 + 3c - u_0)}{18c(1 - R)^2} = 0 \] (14)

\[ R^* = 1 - \frac{4f_2}{f_1 + 3f_2 + 3c + u_0} \] (15)
Basing on the profit ratio $R$ of the cloud platform, the provider A and B determine their prices by equation (11) and (15) as shown in equation (16)

$$
\begin{align*}
    p_1^{***} &= \frac{f_2}{3} + \frac{2f_1 + 3c + u_0}{3} \\
    p_2^{***} &= \frac{f_2}{3} + \frac{f_1 + 3c + u_0}{3}
\end{align*}
$$

Where $R^*$, $p_1^{***}$, $p_2^{***}$ are the equilibrium points of the model. The benefits of participants can’t reach the maximum without this equilibrium. The revenues of the provider A and B, the cloud platform and the cloud market are as in equation (17)-(20).

$$
\begin{align*}
    y_1 &= \left( \frac{f_2}{3f_1 + 3f_2 + 3c + u_0} \right) + \frac{3c - f_1 - u_0}{3} \times \left( \frac{f_2}{4f_2} - \frac{f_1}{6c} - \frac{u_0}{6c} + \frac{1}{2} \right) \\
    y_2 &= \left[ \frac{2f_2}{3f_1 + 3f_2 + 3c + u_0} + \frac{f_1 + 3c + u_0}{3} \right] \times \left( -\frac{f_2}{6c} - \frac{f_1}{4f_2} + \frac{u_0}{6c} + \frac{1}{2} \right) \\
    y_3 &= \left( \frac{2f_2}{3f_1 + 3f_2 + 3c + u_0} + \frac{f_1 + 3c + u_0}{3} \right) \left( 1 - \frac{4f_2}{f_1 + 3f_2 + 3c + u_0} \right) \left( -\frac{f_2}{6c} - \frac{f_1}{4f_2} + \frac{u_0}{6c} + \frac{1}{2} \right) \\
    y_{23} &= \left( \frac{2f_2}{3f_1 + 3f_2 + 3c + u_0} + \frac{f_1 + 3c + u_0}{3} - \frac{f_2}{6c} - \frac{f_1}{4f_2} + \frac{u_0}{6c} + \frac{1}{2} \right)
\end{align*}
$$

2.3. Dynamic Pricing Strategy

According to the hotelling model and master-slave relationship between the cloud platform and the provider, the provider A and B set the basic prices $p_1^{***}$, $p_2^{***}$. Then, providers adjust the price considering the utilization rate of manufacturing services. The price of manufacturing services becomes lower with the low utilization rate of manufacturing services, which encourages demanders to use manufacturing services and avoids the waste of manufacturing services. When the utilization rate is high, the price becomes higher to decrease the use of manufacturing services [20]. The upper and lower limit of the utilization rate are set and the pricing of manufacturing services remains the basic price within the threshold. The utilization rate can be represented as in equation (21).

$$
U = \frac{\text{num}}{\text{total}}
$$

Where $\text{num}$ represents the number of manufacturing services in use, and $\text{total}$ is the total number of manufacturing services.

The price function can be expressed as in equation (22).

$$
\begin{align*}
    p_{if} &= \begin{cases} 
        \frac{u}{u_{\text{high}}} p_1^{***}, U > U_{\text{high}} \\
        p_1^{***}, U_{\text{low}} \leq U \leq U_{\text{high}} \\
        \frac{u}{u_{\text{low}}} p_1^{***}, U < U_{\text{low}}
    \end{cases}
\end{align*}
$$

Where $i = 1, 2$ denote respectively the provider A and B.

3. Analysis of the Pricing Model

3.1. Numerical Analysis of the Pricing Model

Taking NC machine tool as an example, NC machine tool is connected to the cloud platform through perception and virtual technology to form manufacturing services. When the provider A and B provide NC machine tool to the demander offline (providers do not trade on the cloud platform), the pricing of NC machine tool can be obtained according to the hotelling model as in equation (23).
The profits of the provider A and B can be expressed as in equation (24).

\[
\begin{align*}
\pi_A^{***} &= \frac{2f_1 + f_2 + 3c}{3} \\
\pi_B^{***} &= \frac{f_1 + 2f_2 + 3c}{3}
\end{align*}
\]  

(23)

The profits of the provider A and B can be expressed as in equation (24).

\[
\begin{align*}
y_1' &= \left(\frac{f_2 - f_1 + 3c}{3}\right) \left(\frac{f_2 - f_1 + 3c}{6c}\right) \\
y_2' &= \left(\frac{f_1 - f_2 + 3c}{3}\right) \left(\frac{f_1 - f_2 + 3c}{6c}\right)
\end{align*}
\]  

(24)

Suppose \( f_1 = 4, f_2 = 4.5, c = 8, u_0 = 1 \), and the comparison process diagram of two ways (the provider A provides NC machine tool offline and the provider B by the cloud platform, both A and B provide NC machine tool offline) is showed in figure 2.

\[
\begin{align*}
\text{The provider A offline} & \quad \text{Hotelling Model} & \quad \text{The provider B offline} \\
\text{Compare the pricing and revenue} & \quad \text{Compare the pricing and revenue}
\end{align*}
\]

Figure 2. The comparison process diagram of two ways

Revenues and prices of two ways are showed in table 1. When the provider B doesn’t join the cloud platform, the revenue of the cloud platform is 0 and the revenue of the cloud transaction is the revenue of the provider B.

Table 1. The pricing and revenue comparison of two models.

| index                      | the provider B doesn’t join the cloud platform(million yuan) | the provider B joins the cloud platform(million yuan) |
|----------------------------|------------------------------------------------------------|-----------------------------------------------------|
| the pricing of the provider A | 12.1667                                                   | 13.8750                                             |
| the pricing of the provider B | 12.3333                                                   | 16.7500                                             |
| the revenue of the provider A | 4.1684                                                    | 6.0947                                              |
| the revenue of the provider B | 3.8351                                                    | 0.9931                                               |
| the revenue of the cloud platform | 3.8351                                                    | 3.6964                                               |
| the revenue of the cloud transaction | 3.8351                                                    | 4.6895                                               |
| overall revenue            | 8.0035                                                    | 10.7842                                              |

In table 1, it can be seen that the provider B increases the pricing after the provider B joins the cloud platform. The provider B needs to pay a certain service fee to the cloud platform, so the provider B has to further increase the pricing in order to ensure the revenue. Because the provider A competes with the provider B in the transaction market, the provider A also increases the pricing. In addition, all revenues are increased except the revenue of the provider B. The price of the service is increased, so the revenue
of the provider A and the revenue of the cloud transaction will increase. Although the provider B can reduce the information cost and negotiation cost by the cloud platform, the cloud platform maximizes the revenue of the cloud transaction and ignores the revenue of the provider B.

### 3.2. Dynamic Pricing

According to Section 2.3, the threshold of the utilization rate $U$ of NC machine tool for the provider A and B is set to $[30\%, 70\%]$, so the utilization rate—price curves are shown in figure 2.

![Figure 2: Utilization rate—price curves](image)

In figure 3, $U$ represents the utilization rate of NC machine tool, and $p_{1f}, p_{2f}$ denotes respectively the pricing of the provider A and B. When the utilization rate is less than 30%, providers charge a discount for NC machine tool to encourage demanders to use NC machine tool. When the utilization rate is higher than 70%, demanders pay an additional fee for the use of NC machine tool.

### 4. Conclusion

Based on game theory, this paper compares the prices and profits of the manufacturing service in two ways. The result shows that prices of manufacturing services and revenues are increased except the revenue of the provider B. Considering the fairness of the provider B, the cloud platform needs to pay the extra revenue to the provider B.

There are two related research areas worth investigating in future. First, although this model increases the revenue from the perspective of the supply side, it does not take into account the revenue change of demanders. It seems reasonable for paying close attention to the revenue of demanders. Second, this work only considers the impact of the utilization rate on the price, but does not consider other factors that affect the price, such as the urgency of the demander for the manufacturing service. It provides the direction for our future research.

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