Optimal Sharing Strategies of Idle Manufacturing Resource Considering the Effect of Supply-Demand Matching

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***Abstract*—Nowadays, service-oriented manufacturing systems (e.g., cloud manufacturing, product service systems, etc.) have attracted more and more interesting and attention of researchers from many different fields. However, because of the complex and dynamic environment, one of the most important issues that need to be addressed for the promotion and application of cloud manufacturing system is the dynamic supply-demand matching of manufacturing resource services. In this paper, the strategy problems of matching efforts are investigated for a supply chain with resource sharing, where the considered supply chain under cost sharing contract consists of two independent and competing manufacturers and a resource service platform. Firstly, we use a differential equation to model the evolution of manufacturing resources' sharing level and depict the effect of the matching efforts on market demand. By applying the two-stage differential game, the optimal matching strategies are obtained based on the presented optimal control model. Subsequently, the cost sharing contract is designed to coordinate and improve the performance of the supply chain. Finally, a numerical example is provided to illustrate the impacts of the platform transaction fee and the purchasing cost on the feasible region of the corresponding contract.**

***Index Terms*—Sharing economy; Supply-demand matching; Idle manufacturing resource; Cloud manufacturing; Differential game.**

I. INTRODUCTION

Nowadays, the sharing economy is the most active part of innovation in the emerging economy. Driven by Internet technology, market demand, capital and other factors, its field continues to expand. The sharing economy is moving from consumption to production, and extending to supply chain, which brings a new mode of production, consumption and operation management. As a result, a new form of economy emerged in the sharing economy, namely, the sharing supply chain. From the perspective of sharing economy, supply chain resources such as warehousing and inventory of enterprises exist in the form of finished products. If these manufacturing resources are slowed down or idle for a long time in any place, it will result in the waste of social resources. Therefore, as a sub-area of the sharing economy, the sharing supply chain is essentially the reallocation of surplus products and idle manufacturing resources in the supply chain.

The manufacturing industry is undergoing a major transformation enabled by cloud computing. The main thrust of cloud computing is to provide on-demand computing services with high reliability, scalability and availability in a distributed environment.With the introduction and application of new information technologies in manufacturing, an advanced manufacturing mode has been put forward and paid more and more attention.Learning from cloud computing, researchers have proposed a model of 'cloud manufacturing', in which uniform manufacturing resources are shared through online networking. In this model, manufacturing capabilities and resources are shared via a cloud platform. The status of idle resources is updated and released in real time to facilitate online transactions and identify the most sustainable and robust manufacturing route possible [1]. The cloud manufacturing architecture has three common roles (although the exact nomenclature for each role varies in the literature): the supplier (which offers services or resources on the platform), the demander (which requests services or resources through the cloud) and the platform manager [2-4]. The demander utilises resources or services for manufacturing purposes and the supplier provides these resources or services by renting, leasing or lending equipment or other resources for short-term periods. The cloud platform manages the use, performance and delivery of services and negotiates the relationship between supply and demand; it acts as an intermediary, providing connectivity and transport to enable the exchange of services between consumers and providers [5].

In this regard, cloud manufacturing and e-commerce share some similarities, the main difference being that commodities are traded on an e-commerce platform whereas manufacturing services are exchanged on a manufacturing platform. In the re-allocation process, idle manufacturing resources and capabilities are connected through cloud computing and other information technologies, eventually forming a supply chain for manufacturing resource sharing.A number of platforms have

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already implemented business models that closely resemble cloud manufacturing. For example, MFG.com, the world's largest contract manufacturing marketplace, provides a fast and efficient platform for exchanging manufacturing resources. Similarly, 1688.com, China's leading e-commerce platform for domestic small enterprise trading, adopted similar strategies for sharing manufacturing resources. As of 2018, 1688.com's business model covered 16 industries and a wide range of supply services, from raw materials to industrial products, clothing, apparel and household items. Manufacturing resource sharing has obvious benefits for resources supplier, resources demander and platform operator. However, it also introduces new management challenges. One of the most critical issues is optimising the dynamic matching of supply and demand to maximise cooperation between the various parties while considering matching costs.

The goal of matching is to connect consumer demand to the right products or services. To improve matching, all parties in the supply chain (supplier, demander and platform manager) must invest in the matching effort. Each party in the cloud manufacturing system incurs a distinct set of matching costs [6, 7]: (i) the supplier (the resource or service provider) incurs service-realisation costs, i.e., the cost of updating the platform to reflect the current status (availability and quality) of the resources, services and capabilities; (ii) the platform manager incurs aggregation and generation costs, i.e., the costs of computing, storage and scheduling; and (iii) the platform demander incurs invocation costs related to business operations, i.e., consultation, market analysis and investigation, purchase, insurance, etc. Optimising the allocation of resources and services for the supply chain is complex because it requires ensuring that the supplier, demander and platform manager each benefit. In the process of re-allocating supply chain resources, how to integrate, share and optimise the allocation of supply chain resources so that the resources provider, cloud platform and resources consumers can get the greatest benefits is an important issue faced by supply chain enterprises. The aim of this paper is therefore to identify matching strategies that can achieve this optimal solution.

There has been extensive research on performance analysis and supply–demand matching for manufacturing resources and services. In cloud manufacturing, operators use searching and matching algorithms to find suitable services to satisfy users' requests. Several resource service discovery frameworks are described in the literature. Tao et al. [8] proposed a four-phase method for resource service matching and searching on service-oriented manufacturing system platforms. A genetic algorithm based model to search for the result that best matches a customer's request is proposed in Zhang et al. [9]. Based on grey correlation theory, a machine tool supply–demand matching method is proposed in Xiao et al. [10]. Wang [11] investigated the cloud manufacturing resource discovery mechanism and proposed a manufacturing resource discovery framework based on the Semantic Web. Capturing user requirements and cloud services matching are important steps for realising on-demand resource service provision that require the semantic description of manufacturing tasks. Other studies related to supply–demand matching problem could be found in [12-15] The abovementioned studies have mainly examined issues of matching and scheduling with static manufacturing tasks and static candidate resource services in a given period. The dynamic changes typical of the practical process of supply–demand matching and scheduling have not been considered. Cheng et al. [16] proposed a supply–demand matching hypernetwork of manufacturing services, comprising a manufacturing service network, a manufacturing task network and hyper-edges between those two networks. Subsequently, based on the results in [16], Cheng et al. [17] formulated a model for revealing the matchable correlations between each service (supply) and each task (demand), subject to dynamic demand. Cloud manufacturing systems contain many dynamic elements. The number of users and the number of manufacturing tasks change dynamically. Additionally, in an environment of distributed resources, the relative independence of various economic entities also leads to dynamic changes in the sharing relationship. Cheng at al [16, 17] only consider the dynamic complexity caused by changes in the numbers of users and manufacturing tasks. They analysed supply–demand matching in cloud manufacturing from a technical perspective but neglected operations management concerns. From the latter perspective, the goal of matching is to connect consumer demand to the right products or services. This generally involves facilitating information exchange between a supplier and a demander. As matching becomes more successful, sharing increases. To improve matching, all parties in the supply chain (supplier, demander and platform manager) must invest in the matching effort. However, this investment becomes an issue as the platform's matching abilities improve. Crucially, when the number of sharing transactions on the platform increases, the matching costs also increase. Matching costs have not been considered in previous studies. Thus, our study has an important difference from the abovementioned studies, which is that we investigate the complex relations and conflicts of interest arising from the sharing of resources through cloud manufacturing from the perspective of operations management.

The paper makes three primary contributions, which can be summarised as follows. First, we investigate operational problems for a sharing supply chain from a dynamic matching perspective. Second, we design a coordination contract for the supply chain by accounting for the impact of resource-sharing levels, which can be used to coordinate the decentralised system in dynamic environments. Finally, to the best of our knowledge, our study is the first to explore supply–demand matching issues by applying optimal control theory and game theory to derive optimal solutions.

II. The Problem Description and the Basic Model

A. Problem formulation

We consider a supply chain formed of two independent and competing manufacturers, labelled d and s , and a resource-service platform, labelled p, in which manufacturer d (i.e., the supplier) has surplus manufacturing resources, whereas manufacturer s (i.e., the demander) lacks such resources. The platform has a strong reputation and the supplier sells its manufacturing resources to the demander through the platform. Ultimately, the two manufacturers produce homogeneous products and sell them to consumers. Deciding the optimal efforts for matching to enhance sharing is the primary objective of the players, which wish to increase demand and subsequently profits by adopting the optimal operational strategies.

The following notation will be used in the paper:
$M_s(t)$: matching effort of supplier
$M_d(t)$: matching effort of demander
$M_p(t)$: matching effort of platform
$R(t)$: the sharing level of manufacturing resources
p_s: the margin profit of supplier
p_d: the margin profit of demander
c:transaction fee
ω: purchasing cost
Π: profit

The supply-demand matching in the supply chain is a complex issue. In a dynamic framework, the sharing level of manufacturing resources be investigated using the following dynamic equation:

$$R\left(t\right)' = \left\{\alpha M_s\left(t\right) + \beta M_p\left(t\right) + \gamma M_d\left(t\right)\right\} - \varphi R\left(t\right) \quad (1)$$

Where φ is the decay rate of sharing level,$R\left(0\right) = R_0 \geq 0$ and α, β, γ represent the marginal contribution of matching effort to sharing level, which we call matching effectiveness, respectively.

B. Demand function

The level of manufacturing resource-sharing has a positive external spill-over effect on the supply chain's supplier and demander. Customer demand depends on both the marginal profit and the level at which manufacturing resources are being shared (i.e., the sharing level). The demand functions can be expressed as follows:

$$D_s = a - p_s + \xi\left(p_d - p_s\right) + \eta_s R\left(t\right) \quad (2)$$

$$D_d = a - p_d + \xi\left(p_s - p_d\right) + \eta_d R\left(t\right) \quad (3)$$

Where a represents the market potential, and $\xi > 0$, $\eta > 0$ represent the effects on profit margin and the sharing level, respectively.

The matching costs of supply chain members are convex and increasing, indicating increasing marginal costs of the matching efforts, and are assumed to be quadratic, $C\left(M_s(t)\right) = \mu_s {M_s}^2\left(t\right)/2$, $C\left(M_p(t)\right) = \mu_p {M_p}^2\left(t\right)/2$, $C\left(M_d(t)\right) = \mu_d {M_d}^2\left(t\right)/2$, Where μ_s, μ_p,andμ_d are the positive cost parameters. This cost function is commonly applied in existing literature [18-19].

C. The Objective Function

Assuming an infinite time horizon and a positive discount rate ρ, the objective functions are:

$$\Pi_p = \max_{M_p} \int_0^\infty e^{-\rho t}\left\{cR\left(t\right) - C\left(M_p\right)\right\}dt \quad (4)$$

$$\Pi_s = \max_{M_s} \int_0^\infty e^{-\rho t}\left\{p_s D_s - C\left(M_s\right) + \omega R\left(t\right)\right\}dt \quad (5)$$

$$\Pi_d = \max_{M_d} \int_0^\infty e^{-\rho t}\left\{p_d D_d - C\left(M_d\right) - \left(\omega + c\right)R\left(t\right)\right\}dt \quad (6)$$

To recapitulate, (1),(4),(5) and (6) define a differential game with three players, three control variables $M_s(t)$, $M_d(t)$, $M_p(t)$, and one state variable $R(t) \geq 0$.

III. The Optimal Strategies under the Decentralized Decision

We start by analysing the first scenario, in which the players implement a non-cooperative program. Under decentralised decision-making, the supplier, platform and demander maximise their own profits, respectively. The platform is the channel leader and does not offer subsidies to the demander. We use the superscript 'N ' to signify the decentralised system scenario. The supply chain game can be conceptualised in two stages. In the first stage, the platform decides the matching efforts $M_p(t)$. In the second, both the supplier and demander make their decisions, respectively. In particular, the supplier determines the matching efforts $M_s(t)$ and the demander determines the matching efforts $M_d(t)$.

Now, we are in a position to propose the optimal strategies of supply chain under the decentralized decision. Proposition 1 characterizes the equilibrium strategies.

Proposition 1: Under the decentralized decision, the equilibrium results of the differential game among the supplier, the sharing platform and the demander are as follows:
①The equilibrium matching efforts and platform's support rate are given by: ${M_s}^{N*} = \frac{\alpha(p_s\eta_s+\omega)}{\mu_s(\rho+\varphi)}, {M_d}^{N*} = \frac{\gamma(p_d\eta_d-\omega-c)}{\mu_d(\rho+\varphi)}, {M_p}^{N*} = \frac{\beta c}{\mu_p(\rho+\varphi)}$
② The sharing level of manufacturing resources in the supply chain is given by:$R^{N*} = K^N + (R_0 - K^N)e^{-\varphi t}$.
③ The optimal profit function of resource supplier, sharing platform and demander are given by:${\Pi_s}^{N*} = e^{-\rho t}{V_s}^N, {\Pi_p}^{N*} = e^{-\rho t}{V_p}^N, {\Pi_d}^{N*} = e^{-\rho t}{V_d}^N$. Where, the parameters ${a_1}^N, {a_2}^N, {a_3}^N$ and ${b_1}^N, {b_2}^N, {b_3}^N$ are the coefficients of the linear value functions:${V_s}^N = {a_1}^N R^{N*} + {b_1}^N, {V_p}^N = {a_2}^N R^{N*} + {b_2}^N, {V_d}^N = {a_3}^N R^{N*} + {b_3}^N$

IV. The Optimal Strategies in the Centralized System

In this section, we examine the performance of the supply chain in the centralized system. Supply chain members integrate to set the optimal matching efforts in view of maximizing the total profit of supply chain. In this game, $M_s(t)$, $M_d(t)$, $M_p(t)$ are decision variables. We use the superscript "I" to signify "the centralized decision scenario".The objective function of the supply chain in the centralised system is given as:

$$\Pi_{sc} = \max_{M_s, M_d, M_p} \int_0^{\infty} e^{-\rho t} \left\{ \begin{array}{l} p_s D_s + p_d D_d - C(M_s) \\ -C(M_p) - C(M_d) \end{array} \right\} dt \tag{7}$$

Proposition 2 characterizes the equilibrium strategies.

Proposition 2: Under the decentralized decision, the equilibrium results of the differential game among the supplier, the sharing platform and the demander are as follows:

① The equilibrium matching efforts are given by: ${M_s}^{I*} = \frac{\alpha(p_s\eta_s + p_d\eta_d)}{\mu_s(\rho+\varphi)}, {M_d}^{I*} = \frac{\gamma(p_s\eta_s + p_d\eta_d)}{\mu_d(\rho+\varphi)}, {M_p}^{I*} = \frac{\beta(p_s\eta_s + p_d\eta_d)}{\mu_p(\rho+\varphi)}$.

② The sharing level of manufacturing resources in the supply chain is given by: $R^{I*} = K^I + (R_0 - K^I)e^{-\varphi t}$.

③ The optimal profit function of the supply chain system is given by: ${\Pi_{sc}}^{I*} = e^{-\rho t} {V_{sc}}^I$. Where, the parameters a^I and b^I are the coefficients of the linear value functions: ${V_{sc}}^I = a^I R^{N*} + b^I$.

Proposition 3: Compared with optimal strategies and profit functions in the decentralized and centralized systems, one has ${M_s}^{I*} > {M_s}^{N*}$, ${M_d}^{I*} > {M_d}^{N*}$, ${M_p}^{I*} > {M_p}^{N*}$, ${\Pi_{sc}}^{I*} > {\Pi_{sc}}^{N*}$.

Proposition 3 shows that the matching efforts are higher in the centralised system, which means that the total profit is lower in the decentralised system. Hence, there is a need to design an appropriate contract to improve system efficiency.

V. Coordination Contract

In this scenario the things platform is the leader of the channel and supports the demander"s matching efforts. We use the superscript "Y" to signify "Coordination contract scenario". $\theta(t)$ denotes the platform's support rate, which represents the amount that the platform contributes to the demander's matching efforts; its value exists within the interval [0,1]. Motivated by the coordination method in [10], a committed dynamic cost sharing contract is provided to coordinate the supply chain and improve the performance of the decentralized supply chain. Contract provisions are structured as follows. In the first stage of the game, the platform decides the matching efforts $M_p(t)$ and the support rate $\theta(t)$. In the second stage, both the supplier and demander make their decisions, respectively. In particular, the supplier determines the matching efforts $M_s(t)$and the demander determines the matching efforts $M_d(t)$.The objective functions of supply chain members under the coordination contract scenario are:

$$\Pi_p^Y = \max_{M_p, \theta} \int_0^{\infty} e^{-\rho t} \left\{ cR(t) - C(M_p) - \theta C(M_d) \right\} dt \tag{8}$$

$$\Pi_s^Y = \max_{M_s} \int_0^{\infty} e^{-\rho t} \left\{ p_s D_s - C(M_s) + \omega R(t) \right\} dt \tag{9}$$

$$\Pi_d^Y = \max_{M_d} \int_0^{\infty} e^{-\rho t} \left\{ \begin{array}{l} p_d D_d - (\omega + c) R(t) \\ -(1-\theta) C(M_d) \end{array} \right\} dt \tag{10}$$

Now, we are in a position to propose the optimal strategies of supply chain under the cost sharing contract. Proposition 4 characterizes the equilibrium strategies.

Proposition 4: Under the coordination contract scenario, the equilibrium results of the differential game among the supplier, the sharing platform and the demander are as follows:

① The equilibrium matching efforts and platform's support rate are given by: ${M_s}^{Y*} = \frac{\alpha(p_s\eta_s + \omega)}{\mu_s(\rho+\varphi)}, {M_d}^{Y*} = \frac{\gamma(p_d\eta_d - \omega + c)}{2\mu_d(\rho+\varphi)}, {M_p}^{Y*} = \frac{\beta c}{\mu_p(\rho+\varphi)}, \varepsilon = \frac{-p_d\eta_d + \omega + 3c}{\pi_d\eta_d - \omega + c}$

② The sharing level of manufacturing resources in the supply chain is given by: $R^{Y*} = K^Y + (R_0 - K^Y)e^{-\varphi t}$.

③ The optimal profit function of resource supplier, sharing platform and demander are given by: ${\Pi_s}^{Y*} = e^{-\rho t} V_s^Y, {\Pi_p}^{Y*} = e^{-\rho t} V_p^Y, {\Pi_d}^{Y*} = e^{-\rho t} V_d^Y$. Where, the parameters ${a_1}^Y, {a_2}^Y, {a_3}^Y$ and ${b_1}^Y, {b_2}^Y, {b_3}^Y$ are the coefficients of the linear value functions: ${V_s}^Y = {a_1}^Y R^{Y*} + {b_1}^Y, {V_p}^Y = {a_2}^Y R^{Y*} + {b_2}^Y, {V_d}^Y = {a_3}^Y R^{Y*} + {b_3}^Y$

Next, we compare each supply chain member's profits and the total channel profits with the corresponding values in the above three scenarios. Our objective is to identify the effect of the cost-sharing contract on all channel members' profits to determine whether the cost-sharing contract increases profits and thus improves coordination. For notational convenience, let $\Psi_1 = (p_d\eta_d - \omega)/3$, $\Psi_2 = p_d\eta_d - \omega$ and the interval $(\Psi_1, \Psi_2)$is the coordination contract's feasible region. We then arrive at the following proposition.

Proposition 5: The strategies and payoffs in the decentralized scenario (N),cost sharing contract scenario (Y), and centralized decision scenario (I) are related as follows:

① The supplier equilibrium matching efforts:
${M_s}^{N*} = {M_s}^{Y*} < {M_s}^{I*}$;

② The platform equilibrium matching efforts:
${M_p}^{N*} = {M_p}^{Y*} < {M_p}^{I*}$;

③ The demander equilibrium matching efforts:
${M_d}^{N*} < {M_d}^{Y*} < {M_d}^{I*}$;

④ ${\Pi_s}^{N*} < {\Pi_s}^{Y*}$, ${\Pi_p}^{N*} < {\Pi_p}^{Y*}$, ${\Pi_d}^{N*} < {J_d}^{Y*}$, and ${\Pi_{sc}}^{N*} < {\Pi_{sc}}^{Y*}$ for $\Psi_1 < c < \Psi_2$.

Proposition 5 shows that all supply chain members incur higher profits in the cost-sharing contract scenario than the decentralised decision-making scenario. Clearly, cost-sharing with the platform provides the greatest benefit to the demander: when the platform manager cover any share of the matching costs, it helps improve the demander's profitability. As the matching costs are lowered, the demander can offer a higher level of matching effort, which subsequently drives up market demand for the resource or service. This increase in market demand more than compensates for the cost shared by the platform. This result illustrates why matching involves increased collaboration between the demander and the platform manager through cost-sharing contracts and other mechanisms. However, because the comparison of the supplier, platform, demander and supply chain profits poses some degree of analytical complexity, we now turn to numerical computation to verify our theoretical findings.

VI. Numerical Example

In this section, we conduct numerical analyses to gain managerial insights. Set $p_s = 5$, $p_d = 5$, $\mu_s = 10$, $\mu_p = 15$, $\mu_d = 14$, $\eta_s = 0.9$, $\eta_d = 1.7$, $R_0 = 0.25$, $\alpha = 2$,

$\beta = 2$, $\gamma = 3$, $\varphi = 0.5$, $\xi = 0.5$, $a = 5$, $c = 4$, $\omega = 0.6$, $\rho = 0.9$. Before we proceed further, we recall that the profit functions are linear in value function V,and can be written as an exponential function times the value function, i.e. $\Pi = e^{-\rho t}V$. It is therefore sufficient to compare the value function. Thus, to compare ${\Pi_s}^*$, ${\Pi_p}^*$, ${\Pi_d}^*$, and ${\Pi_{sc}}^*$, we compare the values of ${V_s}^*$, ${V_p}^*$, ${V_d}^*$, and ${V_{sc}}^*$, respectively. Define $\Delta V_s{=}{V_s}^{Y*} - {V_s}^{N*}$, $\Delta V_p{=}{V_p}^{Y*} - {V_p}^{N*}$, $\Delta V_d{=}{V_d}^{Y*} - {V_d}^{N*}$, and $\Delta \Pi_s{=}{\Pi_s}^{Y*} - {\Pi_s}^{N*}$, $\Delta \Pi_p{=}{\Pi_p}^{Y*} - {\Pi_p}^{N*}$, $\Delta \Pi_d{=}{\Pi_d}^{Y*} - {\Pi_d}^{N*}$. Similarly,a comparison between ΔV_s, ΔV_p, and ΔV_d, is equivalent to a comparison between the profit functions $\Delta \Pi_s$, $\Delta \Pi_p$, and $\Delta \Pi_d$, respectively.

A. *Comparison of Profits*

In this subsection, the comparison of profits in three models is performed and the result is shown in Figure 1. It can be found that the profit of supply chain system in centralized decision scenario is the highest, followed by the cost sharing contract scenario, and channel' profit in the decentralized scenario is the lowest, which verifies Proposition 5.

Figures 2 presents a comparison between each supply chain member's profits before and after cost-sharing. The equilibrium values in the cost-sharing contract are in the following order in comparison with the decentralised supply-chain values: ${V_s}^{Y*} > {V_s}^{N*}$, ${V_p}^{Y*} > {V_p}^{N*}$, ${V_d}^{Y*} > {V_d}^{N*}$ for $\Psi_1 < c < \Psi_2$. This indicates that the supplier, platform manager and demander all enjoy higher profits in the cost-sharing contract than in the decentralised supply-chain case. The cost-sharing contract effectively improves the performance of the decentralised supply chain. The cost-sharing contract achieves Pareto improvement for the supplier, the platform manager and the demander under certain conditions. Any share of matching costs helps improve the demander's profitability. As such, the demander can provide a higher matching effort; this increases market demand, which more than compensates for the cost shared by the platform.

B. *Impact of the platform transaction fee (c)*

We first investigate the effects of platform transaction fees on the sharing level. In Figure 3, the sharing level $R(t)^*$ is plotted as a function of the platform transaction fee c. The sharing level decreases as the transaction fee increases in the decentralised decision system due to the fact that the demander's marginal profit decreases with the increase of the transaction fee. As in Assumption 2, the demand function depends on the marginal profit and the sharing level. Thus, the larger the transaction fee, the smaller the market demand. Accordingly, in Figure 4, we see that the profit in the decentralised decision system decreases when the transaction fee c is raised. In contrast, the sharing level increases in tandem with the platform transaction fee in the cost-sharing contract scenario because the platform's support rate θ increases with the transaction fee c (see Proposition 4). The larger the transaction fee, the larger the support rate. As such, the demander has a greater incentive to increase its matching efforts; this drives up the market demand, which more than compensates for the cost shared by the platform. Accordingly, Figure 4 shows that in the cost-sharing contract scenario, profit increases with.

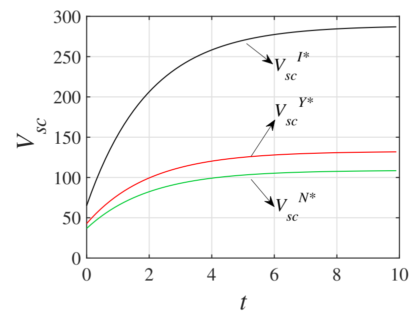

Fig. 1. Optimal profit comparison in scenarios N,Y and I.

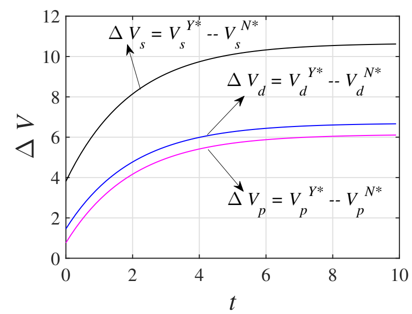

Fig. 2. Profit comparison for supply chain parties before and after cost-sharing.

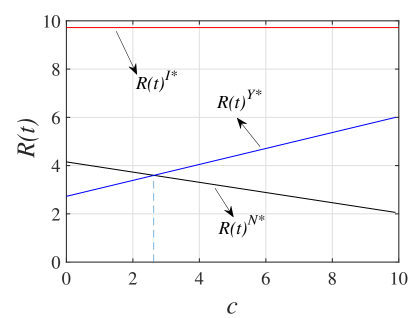

Fig. 3. The impact of the transaction fee on manufacturing resources sharing level.

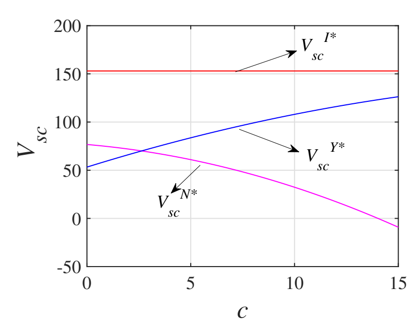

Fig. 4. The impact of the transaction fee on optimal profit.

However, we also find that the cost-sharing contract does not always achieve Pareto improvement for all parties (i.e., the value can fall outside the feasible region). Figure 5 shows that only when the value of c is between Ψ_1 and Ψ_2 can the cost-sharing contract adequately coordinate the supply chain such that all parties benefit. Specifically, when the purchasing cost ω increases, the win-win region becomes smaller in Figure 6. This implies that as the value of increases, the degree of flexibility in coordinating the supply chain decreases.

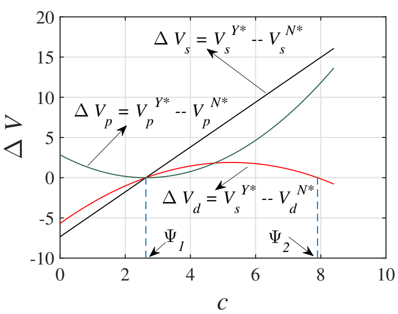

Fig. 5. Pareto improvement effect of transaction fee to cost sharing contract.

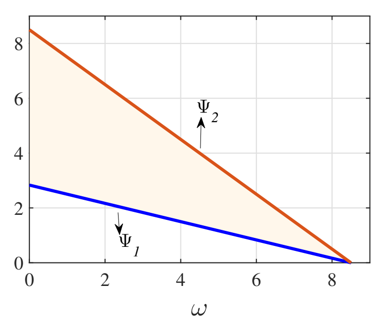

Fig. 6. The impact of ω on the feasible region of cost sharing contract.

VII. Conclusions

In this paper, we have discussed the decision problems of supply chain subject to the sharing level of manufacturing resources under the complex and dynamic environment. By applying the optimal control theory, the strategies of optimal matching efforts have been presented in the decentralized decision, centralized decision, and cost sharing contract systems. We have obtained the following results: ① A cost-sharing contract effectively improves the performance of the decentralised supply chain. All channel members (i.e. the manufacturing resource or service supplier, platform manager and resource or service demander) incur higher profits in the cost-sharing contract system than the decentralised system. ②The cost-sharing contract does not always achieve Pareto improvement for all parties. ③ Numerical analysis shows that the platform transaction fee Numerical analysis shows that the platform transaction fee and purchasing costs affect the win-win region and optimal strategies. A larger purchasing cost will limit the degree of flexibility with which supply chain members coordinate the supply chain, thus providing manufacturers and the service platform with guidance to improve profitability. Our study contributes to the burgeoning field of idle manufacturing resource-sharing within supply chains and collaboration between channel partners.

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