How do manufacturing companies foster platform ecosystems?

Abstract

Manufacturing firms can transform into platforms through servitization. After introducing structural and characteristic differences of the two most promising servitization schemes, K-mode and R-mode, we develop stylized servitization ecosystem models consisting of a product-service system platform (PSSP), service suppliers (SSs), and a user group. A two-stage game approach analyzes and compares two modes. After PSSP determines its baseline supply level, the SS-User game follows, where SSs and the user group choose strategic responses: 'cooperative' or 'competitive.' Our analysis of several scenarios and equilibria in each mode suggests that the servitization ecosystems in both modes can achieve a cooperative equilibrium in a wide range of parameters. While the cooperative equilibrium is well maintained by a high baseline supply from PSSP in K-mode, a high PSSP supply in R-mode cannot be guaranteed without a considerable value co-creation factor. This implies a strategic position of K-mode in the migration toward a more platform-like servitization.

Keywords: Servitization, PSS (Product-Service System), PSS Archetypes and Modes, Evolutionary Game Model, Equilibrium Analysis

1. Introduction: Backgrounds and Motivation

As platform business models and similar business practices expand in ICT (Information and Communication Technology) and various sectors, significant changes are underway in the production schemes of products and services. In the traditional manufacturing domains, there have been efforts, called "servitization," to differentiate by boldly incorporating service features into design and operations. The representative cases include Rolls-Royce and Pratt & Whitney's aircraft engine rental services, GE's Predix and Siemens' Industrial Edge (industrial platforms), and Xerox's transformation into an office solution service provider. These companies stimulated the stagnant market and pioneered new markets through innovations by utilizing service features based on their products or converting them into service-centered value processes. Such transition efforts are rooted in the idea that products are eventually consumed for services. Thus, restructuring a business model in the opposite direction, starting from the product's ultimate purpose, meets consumers' needs (service-dominant logic, Vargo and Lusch, 2008). The widespread use of ICT has also created an environment for a more straightforward implementation of this reverse idea, constituting a solid foundation for the transition. For example, big tech platforms with cloud infrastructure, such as hyperscalers (e.g., Google and Amazon), join this trend by providing cloud-manufacturing fabric (Huang et al., 2013, Ren et al., 2015, Wei et al., 2020).

As suggested by Hagiu and Altman, 2017, Zhu and Furr, 2016, and others, it is not easy for manufacturing firms to transform into platforms, nor is there a one-size-fits-all approach or strategic direction. Considering the business conventions of manufacturing companies bound by traditional linear value chains, switching to non-linear value networks such as two-sided markets or multi-sided platforms requires prudent planning and strategic approaches (D. Kim, 2018, Zhu and Iansiti, 2019, van Alstyne et al., 2016). In this context, it is noteworthy that many manufacturing firms are trying to change their business activities into platforms on the basis of the notion of servitization. For example, the *Product-Service System* (PSS) framework was suggested a long time ago for deploying servitization in practice. As briefly introduced above, there have been many cases of successful implementation of PSS, such as Durugbo, 2013, S.-H. Kim et al., 2007, and Kuo et al., 2010. Along this line, the servitization of manufacturing businesses is usually classified into several conceptual forms based on a scheme of implementing PSS (Chiu et al., 2019). Different PSS schemes develop different value networks, resulting in different ecosystem architectures, behavior, and performance (D. Kim, 2016).

This study looks at several promising scenarios in which manufacturing firms transition to platform ecosystems by introducing and implementing PSS. In particular, we will develop styled models of the ecosystem according to the servitization levels and present a couple of scenarios in which they are embodied around two proposed modes. By analyzing the equilibria in the scenarios and focusing on some factors that determine the transitions, we are able to identify the conditions that will most likely lead to a specific mode (Hagiu and Wright, 2019, O'Mahony and Karp, 2022, and Zhou et al., 2023). Assuming that the PSS player, which started as a typical manufacturing firm, takes the initiative of its ecosystem, our model and approach are to understand the equilibria and conditions by which participants' (such as service providers and users) cooperative behavior is enhanced in an ecosystem corresponding to a specific mode.

2. Models

Our stylized models comprise three types of agents: *PSS Player* (PSSP, PSS Providers, or Platforms), *service suppliers* (SSs), and *a group of users*. PSSP is a traditional manufacturing firm (e.g., GE, Siemens, Rolls Royce, Xerox, Ikea, Samsung Electronics, etc.) or a service provider (e.g., a taxi company). Here, it is assumed that the PSSP acts as a keystone player that organizes, configures, and leads the ecosystem. [1] SSs encompass traditional big tech enterprises (e.g., hyperscalers like Google and Amazon) that provide service features such as cloud APIs and complementors that provide service components or functional elements.

2.1. Ecosystem Players

2.1.1. PSS Players (PSSP)

A *PSS player* (PSSP) can choose either K-mode or R-mode. The PSSP's payoff structures are different across the modes since the revenue and cost structures are different.

K-mode:

$$\Pi = \Pi(Q|S, t_P, f) = t_P Q + \zeta_{K0}(S, \Delta) - C_{PK}(Q) \tag{1}$$

R-mode:

$$\Pi = \Pi(Q|S, t_P, f) = t_P Q + \zeta_{R0}(S, \Delta) - C_{PR}(Q) \tag{2}$$

First, PSSP's strategy is to determine Q, which will be simplified to choose Q_H or Q_L (Section 2.2). t_P represents the unit revenue from users, and $t_P Q$ is the direct revenue from the user group. Users and suppliers (SSs) generate additional net revenue bases Δ and S, respectively. S represents the total amount of complementary services provided by SSs. In particular, S represents the scale of SSs' sales (in K-mode) or inputs (in R-mode) determined at a game between SSs and Users (Figure 1 and Sections 2.2.1 and 2.2.2). Δ represents an additional value co-created by the user group on the basis of SSs' complementary services.

Q and S have different meanings for each mode since the forms and compositions of the product and service package offered in each mode are different. In K-mode, Q is the direct production scale of the base product (separated by S), while Q and S in R-mode represent the amount of product-service package offered to the user group. We assume that Q's in the two modes are commensurable units for each other. Though the meanings of S are differentiated from each mode (Section 2.1.2), as in the case of Q, they are assumed to be commensurable to each other. [2]

$\zeta_{\cdot 0}()$ represents the PSSP's *generic* connection to the interactions between SSs and users. Specific functional forms of $\zeta_{\cdot 0}()$ will be presented after introducing the SS-User stage game together with game scenarios (Figure 1 and Section 2.2; they will be specified in the corresponding scenarios). For now, $\zeta_{K2}()$ in K-mode is related to the benefits of SSs and users, which ultimately depends on the total service sales of SSs. On the other hand, $\zeta_{R0}()$ in R-mode also relies on the resulting value co-created by users (e.g., PSSP's ads revenue), including the total purchase of additional service features from SSs.

Lastly, $C_{P\cdot}(Q)$ is a cost function with economies of scale in Q, and specific forms (such as parameter values) may vary by mode. More specific expressions of those equations will be presented after the scenarios are introduced in Section 2.2.

[1] Cloud manufacturing is still centered on manufacturing companies, and hyperscalers are supporting them.

[2] It is assumed that once the PSSP determines the production scale Q, all the units produced will be accepted in the market (i.e., there is no inventory left over).

2.1.2. Service Suppliers (SS) An SS in K-mode provides additional service offerings to the user group. [3] On the other hand, SSs in R-mode provide PSSP with complementary services, which are integrated into a customized product-service package by PSSP according to a specific user's request. Actual delivery or offering of the product-service packages may be carried by SSs (e.g., Uber drivers supported by the platform features) or by the platform itself (e.g., Prat & Whitney's engine rentals with remote maintenance services). From the perspective of the ecosystem initiative and power structure of this study, R-mode will consider the latter case only.

SSs have two strategic options: '*cooperative*' and '*competitive*.' When an SS takes a cooperative stance, it provides user-supporting tools and other additional services (e.g., training, maintenance, etc.) at its own costs or efforts (to be represented by e and/or s below). From the user group's perspective, SSs' customer support improves users' experience and contributes to an increase in overall value (to be represented by the $\delta()$ function in the user's payoff). On the other hand, a competitive SS in K-mode provides only the basic level of services and/or minimizes the supporting efforts. a competitive SS in R-mode also provides basic service functions predefined in a product-service package.

The payoffs differ when SSs are in a particular mode. A representative SS in K-mode has the following *generic* payoff structure:

$$\pi = \pi(s, t_S, e) = (t_S - e)s - f(e) - C_{SK}(s) \quad (3)$$

, where t_S is the unit revenue from the sale of optional service features and e is the unit cost of supporting users. The latter may include non-monetary activities (such as time and effort) as well as direct pecuniary expenses. s represents the level of complementary services, which are aligned with the PSSP's production level Q. f is the access charge paid to PSSP for using its platform when $e > 0$ since SSs need to access and use the PSSP's platform resources to provide auxiliary tools or support services. We assume that $f(e)$ is a strictly concave function of e and $f(\bar{e}) = 0$, where $\bar{e}$ represents the maximum possible support effort. This implies that the higher an SS's supporting effort, the greater the PSSP's favor given to the SS. [4] However, there will also be no access charge when an SS takes a fully competitive stance (i.e., $e = 0$).

The *generic* payoff structure of an SS in R-mode is as follows:

$$\pi = \pi(s) = f(s) - C_{SR}(s) \quad (4)$$

Here, an SS receives a reward from PSSP in exchange for providing complementary service features (s) to PSSP. (Thus, $f()$ has a different meaning from the sales amounts that the traditional supplier receives when supplying some inputs.) [5] We assume that $f()$ is strongly convex in s, which also means PSSP's incentives to encourage SSs' cooperative behavior (refer to footnote 4).

Since the SSs do not interact directly with users, only the costs required for service development, distribution, and operations through the platform are incurred. Thus, $C_{SR}(s)$ will be almost independent of actual usage and can be regarded as fixed costs: $C_{SR}(s) = C_{SR}$. We assume that C_{SR} is almost constant, at least over a certain range of small s's, and applies uniformly to all SSs. Specific forms of the payoff function will be described in the next section (Section 2.2) with introducing scenarios.

2.1.3. User Group Users are assumed to consume only one unit of the product-service package (or, for some users in K-mode, one unit of the product only). As with SS, a user's strategic option is either taking the '*cooperative*' or '*cooperative*' position on SSs' service offerings.

First, users in K-mode should decide whether to purchase additional service features from SS. Supposing that Q users purchase basic products (from the PSSP), a smaller number of users than Q purchase the extra service features in the end (i.e., $S \leq Q$). We call users who purchase the service features in K-mode '*cooperative users*.' That is, they contribute to enhancing the value of the service-product composition by choosing a cooperative strategy. Users who do not purchase the additional service features are said to have chosen the '*competitive strategy*.' The *generic* payoff function of a representative user in K-mode is presented below.

$$u = u(Q, e, t_P, t_S) = v(Q) - t_P + (\delta_K(e) - t_S)\mathbf{1}_{coop} \quad (5)$$

, where $\mathbf{1}_{coop} = 1$ if a user chooses the cooperative strategy and $\mathbf{1}_{coop} = 0$ otherwise (i.e., choosing the

[3] As described in the next section (Section 2.1.3), a user may or may not choose the options proposed by SS in K-mode. When a user determines to use SSs' additional services, the service level may also vary depending on the user's strategy: '*cooperative*' or '*competitive*.'

[4] This is an incentive presented by PSSP to encourage more SSs to engage in cooperative behavior. As a result, PSSP maneuvers the overall situation toward increasing the total number of complementary services (S), which, in turn, makes it more beneficial for PSSP to supply at a higher level (Q_H).

[5] Since the gross amount of SSs' service features, S, contributes to the network effects across the platform (Sections 2.1.3 and 2.2.2), SSs cannot be considered to act as a typical input supplier.

competitive strategy). Here, t_P and t_S are the unit costs (or service fees) paid to PSSP and SS, respectively. $\delta_K(e)$ is strongly convex in e, meaning that the more support from an SS (e), the more the potential benefits of purchasing the service offerings (i.e., choosing a cooperative strategy) increase. Competitive users are satisfied with only the basic product or service provided by PSSP (see $v(Q)$) and seldom purchase additional services from an SS or minimize the support even if it is required. As mentioned above, SSs can also respond to users' strategies by differentiating e according to their strategic positions (2.2.1).

Users in R-mode first decide whether to provide the platform with preferences, requirements, and other information. Users who provide this information and receive customized service-product packages are referred to as '*cooperative users*.' However, this requires extra work (ϵ). [6] Such extra efforts, of course, enhance user benefits and are also affected by network effects. Users who do not choose this option will be called '*competitive users*.' Competitive users are actually people who could have afforded the standard service-product offering in K-mode. Then, their *generic* payoff structure in R-mode can be described as follows:

$$u = u(Q, s, t_P, \epsilon) = v(Q) - t_P + (\delta_R(s) - \epsilon)\mathbf{1}_{coop} \quad (6)$$

Since PSSP seizes the initiative and manages the ecosystem and SSs as if they were input suppliers, PSSP is assumed to govern the indirect network effects between SSs and users. By simply aligning the total amount of auxiliary and complementary services at the PSSP's production scale, PSSP is able to utilize the indirect network effects. In particular, $\delta_R(s)$ is an increasing function of s.

More specific expressions of users' payoff functions above will be presented after the scenarios are introduced in the next section.

2.2. Game Models and Scenarios

We consider the situation where PSSP determines the production scale to one of two levels: high (Q_H) or low (Q_L) level of production. Here, Q_H is the level where the scale economies of PSSP's productions are maximized. We will examine and analyze the following four scenarios(Figure 1), each of which corresponds to a specific strategic option together with a mode choice of PSSP.

[6]For example, users should make efforts to prepare for the proper operations of a service-product complex or to configure a necessary system, such as an app or software install. We assume that ϵ is exogenously and uniformly given.

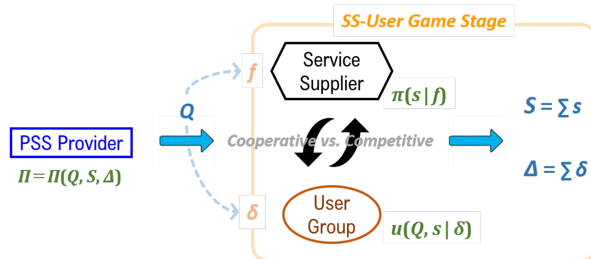

Figure 1. Game Outline

Analysis of the possible equilibria and their conditions in each scenario provides a foundation for comparing the strategic positions of PSSP leading the entire ecosystem. Candidate equilibria are influenced by ecosystems' specific conditions and parameter values. In particular, we will examine whether PSSP in K- or R-mode has the capability to enhance cooperation within its ecosystem by leveraging policy or coordination factors such as $f()$ against various contingencies.

2.2.1. K-mode Scenarios When PSSP determines to choose either the high volume of production (Q_H) or the low volume production (Q_L), the game matrix among the ecosystem participants (between SSs and Users) is determined as shown in TABLE 1. (In the following table, we omit the subscripts that indicate K-mode since it is evident.)

Here, a cooperative SS is assumed to provide more supporting services together with a higher level of complementary service: $\bar{e} > e_1 > e_2$ and $\bar{s} > s_1 > s_2$. We have the following property based on the payoff structure in the game matrix (Table 1).

Property 1. *Suppose that $f(\bar{e}) = 0$ and $\delta_K(e_2) \leq t_S$. Then, there is a parameter range of e_2, in which the game of* TABLE 1 *is a typical* 'coordination game.' *Thus, with e_2 in the range, the SS-User stage game has two equilibria:* (cooperative, cooperative) *and* (competitive, competitive).

Accordingly, we employ the following payoff function for PSSP in the K-mode scenarios, where PSSP chooses either Q_H or Q_L. The payoff function below becomes more concretely specified since it explicitly considers the game's outcome between SSs and users. For example, the PSSP's payoff below explicitly reflects the benefits of the user group as well as the supplier group, which depends on the equilibria of the game in TABLE 1.

Table 1. Payoff matrix of SS-User stage game in K-mode ($Q = Q_H$ or Q_L)

		User			
		Cooperative		*Competitive*	
SS	*Cooperative*	$(t_S - \bar{e})\bar{s} - f(\bar{e}) - C(\bar{s})$	$v(Q) - t_P + \delta(\bar{e}) - t_S$	$(t_S - e_1)s_1 - f(e_1) - C(s_1)$	$v(Q) - t_P$
	Competitive	$(t_S - e_2)s_2 - f(e_2) - C(s_2)$	$v(Q) - t_P + \delta(e_2) - t_S$	$t_S s_2 - C(s_2)$	$v(Q) - t_P$

$$\begin{aligned}\Pi &= t_P Q_H + \zeta_f(S_H) + \zeta_\delta(\Delta_H) - C_{PK}(Q_H) \text{ or} \\ &= t_P Q_L + \zeta_f(S_L) + \zeta_\delta(\Delta_L) - C_{PK}(Q_L)\end{aligned} \tag{7}$$

, where given $Q_H[Q_L]$, $S_H[S_L]$ and $\Delta_H[\Delta_L]$ represent the total amount of complementary services and the total value co-created, respectively. (That is, the pair $\{S_H, \Delta_H\}[\{S_L, \Delta_L\}]$ is determined by an equilibrium of the SS-User stage game with given $Q_H[Q_L]$.) Suppose that the maximum values of $S_{H[L]}$ and $\Delta_{H[L]}$ are bounded by $Q_{H[L]}$. Now, if PSSP, for example, decided to supply Q_H and all SSs and users chose '*competitive*' as their best response strategy, then $\zeta_f(S_H) = f_{KH}(e_2)Q_H$ and $\zeta_\delta(\Delta_H) = 0$. [7] A more detailed description of the $\zeta.()$ functions in K-mode is provided in Section 3.1.

2.2.2. R-Mode Scenarios The game matrix in R-Mode with a high or low volume of service-product compounds (Q_H or S_H) is given in the following table. [8]

We have the following properties based on the payoff structure in the game matrix (TABLE 2).

Property 2. *Suppose that $\delta_R(s_2) < \epsilon < \delta_R(\bar{s})$. Then, there are parameter ranges of s_1 and s_2, where the game of* TABLE 2 *is a* 'stag-hunt game.' *Thus, with s_1 and s_2 in the range, the SS-User stage game has two equilibria:* (cooperative, cooperative) *and* (competitive, competitive).

Property 3. *Suppose that $\epsilon < \delta_R(s_2) < \delta_R(\bar{s})$. While $f()$ is convex and increasing in s, $C_{SR}()$ is concave and increasing in s. Then, there are parameter ranges of s_1 and s_2, where the game of* TABLE 2 *has only one Nash equilibrium of* (cooperative, cooperative).

Similar to the K-mode scenario, the *generic* payoff function of PSSP can be expressed more specifically as follows.

$$\begin{aligned}\Pi &= t_P Q_H - \zeta_f(S_H) + \zeta_\delta(\Delta_H) - C_{PR}(Q_H) \text{ or} \\ &= t_P Q_L - \zeta_f(S_L) + \zeta_\delta(\Delta_L) - C_{PR}(Q_L)\end{aligned} \tag{8}$$

, where given $Q_H[Q_L]$, $S_H[S_L]$ and $\Delta_H[\Delta_L]$ represent the total amount of additional features supplied to PSSP and the total value co-generated by users, respectively, which, similar to the K-mode scenario, is determined by an equilibrium of SS-User stage games. $S_{H[L]}$ and $\Delta_{H[L]}$ are also assumed to be bounded by $Q_{H[L]}$. Now, if PSSP, for example, decided to supply Q_H and all SSs and users chose '*cooperative*' as their best response strategy, then $\zeta_f(S_H) = f_{RH}(\bar{s})Q_H$ and $\zeta_\delta(\Delta_H) = \delta_{RH}(\bar{s})Q_H$. A more detailed description of the $\zeta.()$ functions in R-mode is provided in Section 3.2.

3. Analysis and Results

3.1. Equilibrium Analysis in K-mode

We apply the game framework of Evolutionary Stable Strategy (ESS) to the K-mode scenario summarized in TABLE 1. PROPERTY 1 presents a base for analysis, which results in the following equilibria. The proof of PROPOSITION 1 is provided in APPENDIX available in a separate document.

Proposition 1. *Under the conditions specified in* PROPERTY 1*, both equilibria*—(cooperative, cooperative) & (competitive, competitive)—*are ESS. However, the mixed strategy of the SS-User game of* TABLE 1 *is not ESS.*

In the respective ESS equilibria, $S_H[S_L]$ and $\Delta_H[\Delta_L]$ are determined as follows (with $Q = Q_H[Q_L]$):

$$\begin{aligned}(\textit{coop}, \textit{coop}) \text{ eq.: } & S_{H[L]} = \bar{s}Q_{H[L]} \quad \& \\ & \Delta_{H[L]} = \delta_{H[L]}(\bar{e})Q_{H[L]} \\ (\textit{comp}, \textit{comp}) \text{ eq.: } & S_{H[L]} = s_2 Q_{H[L]} \quad \& \\ & \Delta_{H[L]} = 0\end{aligned} \tag{9}$$

Thus, PSSP's payoffs are determined as follows

[7] $\zeta_\delta(\Delta_H) = 0$ since users with *competitive* do not purchase complementary services and thus do not participate in the value co-creation process, which results in $\Delta_H = 0$.

[8] Here, we also omit the subscripts that indicate the mode.

Table 2. Payoff matrix of SS-User stage game in R-mode ($Q = Q_H$ or Q_L)

		User			
		Cooperative		*Competitive*	
SS	*Cooperative*	$f(\bar{s}) - C(\bar{s})$	$v(Q) - t_P + \delta(\bar{s}) - \epsilon$	$f(s_1) - C(s_1)$	$v(Q) - t_P$
	Competitive	$f(s_2) - C(s_2)$	$v(Q) - t_P + \delta(s_2) - \epsilon$	$f(s_2) - C(s_2)$	$v(Q) - t_P$

(with $Q = Q_H[Q_L]$): [9]

$$\begin{aligned}\Pi &= t_P Q_{H[L]} + \delta_{H[L]}(\bar{e})Q_{H[L]} - C_P(Q_{H[L]}) \\ &\qquad\text{at } (\textit{coop}, \textit{coop} \text{ equilibrium}) \\ &= t_P Q_{H[L]} + f_{H[L]}(e_2)s_2 Q_{H[L]} - C_P(Q_{H[L]}) \\ &\qquad\text{at } (\textit{comp}, \textit{comp} \text{ equilibrium})\end{aligned} \tag{10}$$

Once PSSP determines the baseline supply scale (Q_H or Q_L), PSSP prefers one equilibrium depending on the relative sizes of $\delta(\bar{e})$ and $f(s_2)s_2$. In other words, if $\delta(\bar{e}) > f(s_2)s_2$, the cooperative equilibrium will be preferred; otherwise, the competitive equilibrium is preferred. For example, suppose the value co-creation effect from the user group is expected to be sufficiently big (i.e., high levels of $\delta()$), while the amount of complementary services created by suppliers responding to a low level of baseline supply is small. In that case, PSSP will likely enhance the baseline supply (i.e., to choose Q_H), inducing the proliferation of the complementary service market. Conversely, no matter how high the level of baseline supply is, the incentive to increase this supply is not significant if the value co-creation effect of users is expected to be meager. In this case, the complementary service market for completing the servitization process could not prosper.

Since PSSP prefers a high level of baseline supply in every equilibrium of the SS-user game, [10] it is only necessary to crosscheck the gains from different supply levels at the two equilibria. First, if the gap between Q_H and Q_L is sufficiently large and the users' value co-creation effect is not significant for the low baseline supply (e.g., $f_H(e_2)s_2 Q_H > \delta_L(\bar{e})Q_L$), providing high output at the competitive equilibrium is more likely to benefit PSSP than providing low output at the cooperative equilibrium. On the other hand, with a sufficiently large gap between Q_H and Q_L, the user's value co-creation effect is significant for the high baseline supply (e.g., $f_L(e_2)s_2 Q_L < \delta_H(\bar{e})Q_H$), [11] providing a high output in cooperative equilibrium is more likely to benefit PSSP than providing a low output in competitive equilibrium. Accordingly, in most cases where users' value co-creation effect is substantial, PSSP will try to provide a high level of baseline supply. Arranging the analysis above establishes the following PROPOSITION 2.

Proposition 2. *When the user's value co-creation effect is large enough, PSSP in K-mode tries to increase the baseline supply and maneuver the ecosystem in the direction of a cooperative equilibrium. On the other hand, when the value co-creation effect is meager (i.e., both δ_H and δ_L are very low) and platform access charges are high (i.e., both f_H and f_L are high), PSSP tries to maneuver the ecosystem toward a competitive equilibrium.*

3.2. Equilibrium Analysis in R-mode

Following a similar procedure as in the previous K-mode case, we apply the ESS framework to the R-mode scenario summarized in TABLE 2. PROPERTIES 2 and 3 provide the basis for the analysis, which yields the following equilibria. Proof of PROPOSITION 3 is provided in a separate document.

Proposition 3. *Under the conditions specified in* PROPERTY 2*, both equilibria*—(cooperative, cooperative) & (competitive, competitive)—*are ESS. However, the mixed strategy of the SS-User game of* TABLE 2 *is not ESS. Under the conditions specified in* PROPERTY 3*, the* (cooperative, cooperative) *equilibrium is also an ESS.*

In the respective ESS equilibria with $\delta_R(s_2) < \epsilon < \delta_R(\bar{s})$, $S_H[S_L]$ and $\Delta_H[\Delta_L]$ are determined as follows (with $Q = Q_H[Q_L]$):

$$\begin{aligned}(\textit{coop}, \textit{coop})\text{ eq.: } & S_{H[L]} = \bar{s}Q_{H[L]} \quad \& \\ & \Delta_{H[L]} = \delta_{H[L]}(\bar{s})Q_{H[L]} \\ (\textit{comp}, \textit{comp})\text{ eq.: } & S_{H[L]} = s_2 Q_{H[L]} \quad \& \\ & \Delta_{H[L]} = 0\end{aligned} \tag{11}$$

In the case of single ESS equilibrium with $\epsilon < \delta_R(s_2) < \delta_R(\bar{s})$, $S_H[S_L]$ and $\Delta_H[\Delta_L]$ are determined only at the *cooperative* equilibrium above. Accordingly,

[9] Since it is contextually obvious, we suppress the use of subscripts '$_K$.'

[10] Note the assumption of PSSP's cost structure. Since it is assumed that $C_P(Q)$ shows scale economies and Q_H is the most efficient production scale, the benefit of enlarging the revenue at the high output is likely to exceed the benefit of cost reduction at the low output: $t_P(Q_H - Q_L) > C_P(Q_H) - C_P(Q_L)$.

[11] This inequality holds if $s_2 Q_L \leq Q_H$ and $f_L(e_2) < \delta_H(\bar{e})$.

PSSP's payoffs are determined as follows (with $Q = Q_H[Q_L]$): [12]

$$\begin{aligned}\Pi &= t_P Q_{H[L]} - f_{H[L]}(\bar{s})\bar{s}Q_{H[L]} + \delta_{H[L]}(\bar{s})Q_{H[L]} \\ &\quad - C_P(Q_{H[L]}) \\ &\qquad\qquad\qquad \text{at (}\textit{coop}\text{, }\textit{coop}\text{ equilibrium)} \\ &= t_P Q_{H[L]} - f_{H[L]}(e_2)s_2 Q_{H[L]} - C_P(Q_{H[L]}) \\ &\qquad\qquad\qquad \text{at (}\textit{comp}\text{, }\textit{comp}\text{ equilibrium)}\end{aligned} \tag{12}$$

Unlike the K-mode scenario, PSSP in R-mode favors the cooperative equilibrium in all baseline supply levels (Q_H and Q_L); that is, PSSP's payoff at the same supply level is always greater in the cooperative equilibrium. Though PROPERTY 2 has shown that some ranges of s_1 and s_2 exist, where two equilibria in the style of the *stag-hunt* game coexist, it is pretty limited that the competitive equilibrium sustains. [13] Therefore, in R-mode, it will suffice to consider only the cooperative equilibrium, and the following discussion will proceed only concerning the cooperative equilibrium.

Suppose that the conditions in *footnote* 10 also apply in R-mode. PSSP in R-mode employs complementary services from suppliers as inputs to complete servitization by offering various product-service packages customized for users' requests. [14] Different from K-mode, however, a high level of baseline supply (Q_H) does not guarantee greater benefits for PSSP than a low supply (Q_L) since the former incurs higher expenditure on the complementary services of suppliers. This point is also confirmed in our model. When the condition $\delta_H(\bar{s})Q_H - \delta_L(\bar{s})O_L > \bar{s}(f_H(\bar{s})Q_H - f_L(\bar{s})Q_L)$ holds, PSSP prefers a high output in the cooperative equilibrium. This condition implies that a big difference in the scale of value co-creation based on the baseline output (i.e., $\delta_H(s) > \delta_L(s)$) is able to offset the additional costs of supplier expenditure, which eventually provides some room for PSSP to provide higher output. Since $\delta_H(s) - \delta_L(s)$ also indicates the degree of network effect, the condition above suggests that PSSP will increase its output level when additional revenue sources, such as advertising and user data, could be expected from the user group through high network effects. The analysis above is summarized and presented as PROPOSITION 4 below.

Proposition 4. *In R-mode, PSSP is likely to pursue a* cooperative *equilibrium. When a sufficiently large network effect can be expected from the user group, PSSP provides a high baseline output. Otherwise, it manages the total cost while keeping the output level low. Even in the case where the level of the baseline supply is low, SSs and users are likely to choose a* cooperative *equilibrium (especially under the condition specified in* PROPERTY 3*), and the level of servitization remains high ($\bar{s}$) in the ecosystem.*

4. Discussion and Conclusions

This study has considered the two most promising PSS schemes—K-mode and R-mode—that implement a servitization ecosystem centered around the manufacturing enterprise. We also employed a two-stage game model and conducted equilibrium analysis following the evolutionary game framework. In a spectrum over which manufacturers migrate toward a platform organization, K-mode is closer to the conventional form of the manufacturer, while R-mode is closer to the service-oriented platform. From the perspective of the PSS framework, K-mode and R-mode can be seen as the stylized models of a product-based PSS archetype and a usage- or result-based PSS archetype, respectively (Chiu et al., 2019, Durugbo, 2013, Kuo et al., 2010). From the perspectives of users and SSs, this means that their business relationships with PSSP, which plays the role of the keystone in the ecosystem, are substantially different across the two modes. Indeed, our model reflects these structural and relational differences as the differences in the participants' payoff functions as well as the game structures (see TABLES 1 and 2).

First, in the equilibrium analyses of the SS-User games, each ecosystem mode produced different outcomes. In K-mode, both '*cooperative*' and '*competitive*' equilibria could be an ESS as in the typical coordination games, while in R-mode, only 'cooperative' equilibrium remained a meaningful ESS in a generally acceptable parameter range. (Remind that the equilibria of K-mode's coordination game differ in their characteristics from those of R-mode's stag-hunt game, which could exist only in a far limited range. [15]) This inevitably leads to PSSP's differentiated strategies (the scale of baseline product supply). Assuming that the users' value co-creation effect ($\delta_{H[L]()}$, which

[12] Since it is contextually obvious, we suppress the use of subscripts '$_R$.'

[13] More precisely, the parameter ranges of s_1 and s_2 for which the competitive equilibrium may exist are fairly limited and are also greatly affected by SS's revenue and cost functions—$f_R(s)$ and $C_{SR}(s)$.

[14] In this respect, the PSS platform differs from the conventional matching platform, organized mainly around services from one end to the other. Refer to our explanation in the introduction section.

[15] In the SS-User stage game of K-mode, the *cooperative* equilibrium is relatively more beneficial to a user, while the *competitive* equilibrium is relatively more beneficial to an SS. See TABLE 1.

can also be interpreted as the strength of network effect) is sufficiently large, PSSP in K-mode is able to induce a cooperative equilibrium that PSSP prefers relatively to a competitive equilibrium by increasing the baseline supply. Even if δ is insignificant, it is more advantageous for PSSP to induce a competitive equilibrium by increasing the supply. Thus, for any circumstance or contingency, PSSP will increase the supply and try to maneuver its ecosystem toward the desired equilibrium. As a result, there is a high possibility that the servitization ecosystem will proliferate as complementary services increase in a state of abundant standard supply.

In R-mode, where the state in which both SSs and users cooperate is the only meaningful equilibrium, PSSP can maximize its payoff by adjusting the baseline output level according to the relative size of the key parameters (e.g., $\delta_{H[L]}()$ and $f_{H[L]}()$). For example, PSSP can increase its profits by linking its output level to the extent of network effects. Facing a meager value co-creation effect, PSSP tries to reduce output for the sake of maximizing its gain, thereby resulting in a limited total amount of complementary services despite the incentive for SSs to provide many service features that can complement platform functions and baseline products. Accordingly, the overall proliferation of the servitization ecosystem is more affected by factors outside PSSP's ecosystem. For example, suppose a privacy regulation makes it challenging to utilize user data. [16] In that case, PSSP will rather maximize profits by reducing output and controlling platform investment and operating costs. This may limit the development of the overall servitization ecosystem despite its growth potential.

The analysis of the players' decisions and ecosystem equilibrium states regarding PSSP's behavior, which are keystone moves in each servitization ecosystem, suggests that it is necessary to reconsider K-mode's strategic position. When manufacturers attempt to transit into platforms through servitization, K-mode can be an essential stepping stone. Based on our model analysis, K-mode presents more room to cultivate and foster the ecosystem through the active role of PSSP regardless of key parameters and external factors, compared to R-mode. This means that taking an evolutionary path using K-mode as an intermediate step could reduce risk and increase the likelihood of success rather than attempting to transfer directly to R-mode at once in the course of manufacturers' platform transition. Indeed, several large manufacturers and network industries with heavy assets are gradually pursuing the transition to a platform by utilizing a subscription model. Such practices and moves are in line with the results of this study. For example, global home appliance makers in Korea, such as Samsung and LG Electronics, provide rental and subscription services for their home appliances and devices, with maintenance support often provided by third-party service partners.

As the modeling process implies, relationships among the participants and players that constitute the servitization ecosystem may lead to diverse architectures and further changes. Even after an ecosystem has settled down into a certain equilibrium, it can still evolve anew in response to external shocks and changes in the competitive landscape. In particular, changes in leadership potentials and power structures within the ecosystem may lead to a scenario different from those discussed earlier; for example, the innate service-oriented platforms or matching platforms may also extend into the servitization areas in the manufacturing industries. On the other hand, a business domain through manufacturing servitization can be created and compete with traditional service channels; for example, Nvidia's chip subscription model will erode storage-based cloud services. Accordingly, it may be necessary to develop more scenarios that consider more diverse potential power structures and business models in line with potentially emerging trends. However, even in these cases, the overall frame and approach proposed in this study can remain substantially the same.

Lastly, for possible presentations at the conference, we will conduct various experiments on all scenarios and complete the analysis. In particular, focusing on the critical parameter functions mentioned above—e.g., $\delta()$ and $f()$—and PSSP's decision variable, we delve into their relationships with respect to ecosystem equilibria. Comparative analysis across both K- and R-mode scenarios will present more generalized implications for the manufacturing industry's servitization and the manufacturing company's platform transformation. For example, the platform transition through the servitization has a noteworthy connection to the service factories (e.g., telecommunications and distribution & logistics) that rely on heavy assets and operate in a similar way to the manufacturing firms. We will also investigate more cases pertaining to the analysis and experimental results and suggest deeper understandings and rich insights that can be helpful for business practice.

[16] For example, target advertising becomes fundamentally tricky due to the DSA (Digital Service Act) in the EU.

References

Chiu, M.-C., Chu, C.-Y., & Kuo, T. C. (2019). Product service system transition method: Building firm's core competence of enterprise. *International Journal of Production Research*, *57*(20), 6452–6472.

Durugbo, C. (2013). Competitive product-service systems: Lessons from a multicase study. *International Journal of Production Research*, *51*(19), 5671–5682.

Hagiu, A., & Altman, E. J. (2017). Finding the platform in your product. *Harvard Business Review*, *95*(4), 94–100.

Hagiu, A., & Wright, J. (2019). Controlling vs. enabling. *Management Science*, *65*(2), 577–595.

Huang, B., Li, C., Yin, C., & Zhao, X. (2013). Cloud manufacturing service platform for small-and medium-sized enterprises. *The International Journal of Advanced Manufacturing Technology*, *65*, 1261–1272.

Kim, D. (2016). Value ecosystem models for social media services. *Technological Forecasting and Social Change*, *107*, 13–27.

Kim, D. (2018). A novel stylized model for platform ecosystem dynamics: Understanding it service transformation from firm theory perspective. *Journal of Enterprise Transformation*, *8*(3-4), 211–237.

Kim, S.-H., Cohen, M. A., & Netessine, S. (2007). Performance contracting in after-sales service supply chains. *Management science*, *53*(12), 1843–1858.

Kuo, T. C., Ma, H.-Y., Huang, S. H., Hu, A. H., & Huang, C. S. (2010). Barrier analysis for product service system using interpretive structural model. *The International Journal of Advanced Manufacturing Technology*, *49*, 407–417.

O'Mahony, S., & Karp, R. (2022). From proprietary to collective governance: How do platform participation strategies evolve? *Strategic Management Journal*, *43*(3), 530–562.

Ren, L., Zhang, L., Tao, F., Zhao, C., Chai, X., & Zhao, X. (2015). Cloud manufacturing: From concept to practice. *Enterprise Information Systems*, *9*(2), 186–209.

van Alstyne, M. W., Parker, G. G., & Choudary, S. P. (2016). Pipelines, platforms, and the new rules of strategy. *Harvard Business Review*, *94*(4), 54–62.

Vargo, S. L., & Lusch, R. F. (2008). Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science*, *36*, 1–10.

Wei, W., Zhou, F., & Liang, P.-F. (2020). Product platform architecture for cloud manufacturing. *Advances in Manufacturing*, *8*(3), 331–343.

Zhou, X., Liu, H., Li, J., Zhang, K., & Lev, B. (2023). Channel strategies when digital platforms emerge: A systematic literature review. *Omega*, 102919.

Zhu, F., & Furr, N. (2016). Products to platforms: Making the leap. *Harvard Business Review*, *94*(4), 72–78.

Zhu, F., & Iansiti, M. (2019). Why some platforms thrives... and others don't what alibaba, tencent, and uber teach us about networks that flourish. the five characteristcs that make the difference. *Harvard Business Review*, *97*(1), 118–125.