Journal of
Theoretical and Applied Electronic Commerce Research

MDPI

Article

Interplay between Platform Providers and Complementors via Affordance, Autonomy, and Super-Modularity: The Empirical Investigation of the Korean Digital Industry

Dongnyok Shim

Department of Advanced Industry Fusion, Konkuk University, Neungdong-ro 120, Gwangjin-gu, Seoul 05029, Republic of Korea; sk4me@konkuk.ac.kr; Tel.: +82-2-450-3477

Abstract: This study examines the dynamic interplay between platform providers and complementors in the context of digital ecosystems, focusing on the complementary factors of affordance, autonomy, and super-modularity. Using national survey data from the Korean digital industry, the study applied multivariate ordered probit and k-mode clustering models to analyze what determines these factors and how these factors are interrelated from the perspective of platform providers and complementors, respectively. The results indicate that platform providers with open APIs promote affordance, but providing an SDK inhibits affordance. In terms of complementors, choosing a platform providing APIs increases super-modularity. And affordance increases when using the platform for logistics and new product development. In addition, we found that affordance and autonomy have a trade-off relationship from the perspective of both platform providers and complementors. Finally, we classified platforms and complementors into subgroups with respect to affordance, autonomy, and super-modularity using cluster analysis and found that the size of a complementor's firm, such as revenue and number of employees, influences which platform it chooses. Conversely, the size of a platform provider also influences how much autonomy and collaboration it offers. This study contributes to the understanding of digital platform ecosystems and provides insights for practitioners on how to leverage platform dynamics to enhance competitive advantage.

Keywords: platform; complementor; affordance; autonomy; super-modularity; multivariate ordered probit model; K-mode clustering

Citation: Shim, D. Interplay between Platform Providers and Complementors via Affordance, Autonomy, and Super-Modularity: The Empirical Investigation of the Korean Digital Industry. *J. Theor. Appl. Electron. Commer. Res.* **2024**, *19*, 975–992. https://doi.org/10.3390/jtaer19020051

Academic Editor: Julían Chaparro-Peláez

Received: 2 March 2024
Revised: 18 April 2024
Accepted: 22 April 2024
Published: 26 April 2024

1. Introduction

The interaction between platform providers and complementors has evolved beyond a simple supply and-demand relationship into a collaborative ecosystem [1]. This shift is especially significant for ICT companies including software-based start-ups, where open innovation through partnerships with digital platform companies is crucial for leveraging limited resources to enable rapid growth and development [2–4]. The trend towards collaboration with digital platform companies is gaining global attention among ICT companies as a method of innovation. Platform companies are offering alternatives to traditional hardware investments by providing services such as cloud infrastructure, software development, operational infrastructure, and intermediary function. In this environment, it is essential to scrutinize the platform as an ecosystem centered around participant interaction, allowing for mutual value creation. Such value creation can be created not only in financial terms, but also through user base expansion, idea commercialization, and the scale and pace of outputs resulting from interactions between platform providers and users like complementors [5]. These interactions are often technically supported by boundary resources such as Application Programming Interfaces (APIs) and Software Development Kits (SDKs) [6,7].

A critical factor for a digital platform's success from an ecosystem perspective is the provider's ability to cultivate complementary relationships with complementors, facilitated by the strategic deployment of boundary resources [8]. This complementary relationship consists of affordances, autonomy, and super-modularity. Affordance is particularly pertinent to the dynamics between platform providers who entities that own and operate the digital platform and complementors, such as third-party developers or companies that augment the platform's value through the provision of additional services, applications, or products [9]. Affordances significantly influence how complementors can innovate, distribute, and monetize their contributions on a platform [10]. These affordances are determined by the platform's architecture, governance policies, and other supporting tools provided by the platform [11]. Such resources encompass development tools and comprehensive support, including the quality and user-friendliness of these tools, alongside documentation and developer assistance. The criticality of understanding affordances stems from their direct impact on innovation levels and types within the ecosystem, as they empower platform providers to shape the diversity, quality, and innovation of ecosystem offerings [9,12].

Secondly, autonomy is critical interaction factor in digital platform ecosystem, which refers to the degree of freedom that complementors have in developing, offering, and managing their products or services within the platform [13]. Autonomy is closely associated with the openness of the platform, which can range from highly open systems that allow for a wide-ranging freedom to complementors, to more closed systems that impose strict controls and limitations [14]. Autonomy also plays a crucial role in the sustainability of a platform ecosystem. Too much control can stifle innovation and discourage participation, while too little control can lead to a fragmented user experience or issues with quality and security [15]. Despite the importance of autonomy, little is known about what determines the level of autonomy of each platform providers or what makes complementor select the platform which support certain level of autonomy.

Lastly, as a form of interaction between platform providers and complementors, super-modularity in digital platform ecosystems refers to the degree to which the value of a platform increases as more complementary products or services are added to it [16]. This principle is based on the idea that the platform plus its complementors' offerings is more valuable than the sum of its parts [17]. Super-modularity underscores the interdependencies between the platform core and the complementary offerings, illustrating how each additional complement enhances the platform's overall value and utility [18].

Despite its theoretical and conceptual rigor on affordance, autonomy, and super-modularity, empirical evidence on which factors them is very scarce, and how they are correlated in the real-world dynamics has thus far not yet been examined. In particular, the factors evaluated by the platform provider and the complementors using the platform are likely to be different for them. Moreover, these factors are likely to be highly interrelated in a firm's decision-making process like other success factors of firms, rather than independent and exclusive. In other words, there may exist trade-offs relationship between these outcomes that constitute the complementary effect of a platform ecosystem, such as the pursuit of higher affordance at the expense of lower autonomy. It is therefore necessary to understand the process of determining the complementary effect comprehensively and simultaneously, rather than analyzing each variable independently.

To bridge the gap between theory and real-world dynamics, this study attempts to model which factors affect the affordance, autonomy, and super-modularity of platform providers and complementors, respectively, by employing multivariate-ordered probit and k-mode clustering models on Korean digital industry survey data, considering simultaneity. Specifically, the multivariate ordered probit model allows us to estimate the three difference equations simultaneously, taking into account the correlation between the three outcome variables, rather than estimating the equation independently for each of them. In addition, we employ the k-mode clustering method on platform providers and complementors to classify them into several subgroups based on the level of affordance, autonomy, and super-modularity, and the result of this analysis will provide information about stylized characteristics on platform providers and complementors.

2. Research Background

2.1. Theoretical Foundation on the Interrelationships between Platform Providers and Complementor

In a digital platform, participant interdependence is a significant factor influencing ecosystem stability and growth, and, in turn, value creation [19]. Platform ecosystem theory, from an academic standpoint, conceptualizes a dynamic and complex interplay among various participants within a value chain, emphasizing networking and co-evolution as pivotal elements [20,21]. Within this ecosystem, a platform acts as both a foundational technology and a business model, facilitating interactions among diverse stakeholders. Jansen and Cusumano [22] described a digital platform as the underlying technology for providing online services, and such underlying technology is characterized by the ability to bring together heterogeneous participants.

Economically, digital platforms are often analyzed through the lens of two-sided market effects [23]. However, from a technological perspective, digital platforms serve as a foundational infrastructure attracting a broad spectrum of stakeholders, making the support for SDKs and open APIs crucial for understanding the platform ecosystem. SDKs are instrumental in aiding software developers to create applications efficiently [8]. By providing SDKs publicly, platform companies significantly enhance the efficiency of development process and success rate for utilizer companies [24]. Without SDKs, the development process becomes laborious, time-consuming, and resource intensive. For instance, SDKs, like Apple's Xcode for iOS, encapsulate essential tools and libraries, facilitating seamless integration of device-specific features, thereby expediting development and troubleshooting. Similarly, APIs serve as vital conduits for interaction between different software or services, offering a standardized method for integrating platform features into various applications. The opening of APIs by platform providers not only expands their reach and influence, but also fosters service innovation and collaboration, strengthening network effects and enabling data-driven service development. The provision of APIs by platform companies is thus a strategic endeavor rooted in enhancing openness, fostering an ecosystem-centric approach, and gaining a competitive edge.

Several research has been conducted so far to examine the dynamics between platform providers and user companies in the digital platform. Haile and Altmann [25] used a system dynamics model to show that complementors' revenue increases exponentially during a platform provider's growth phase, but declines as the provider reaches maturity, with most ecosystem revenue accruing to the platform provider. Haile and Altmann [26] also simplified the participants in the platform ecosystem into platform providers, complementors, and users, and explicitly described the service delivery process and value distribution process between them. According to their analysis, the platform provider provides the technical environment for the utilizer to build the service, and the platform provider and the utilizer share the revenue paid by the user. Heimburg and Wiesche [27] conducted a review study on platform ecosystems and presented a diagram depicting the relationships between actors within a platform in six dimensions and nineteen relationships.

Open innovation theory was also frequently cited to explain collaboration between platform providers and complementors [2–4]. Open innovation is a strategy for digital companies to create new opportunities by actively utilizing external ideas and innovations and sharing internal ideas and technologies with others [2]. To promote open innovation, organizations are required to break down internal and external boundaries, allowing knowledge and technology to flow freely. In this process, collaboration and networking occurs between two organizations. The benefits of open innovation include (1) increasing the speed and scope of innovation [4], (2) reducing costs and spreading risk [1], and (3) improving market responsiveness [28]. The importance of open innovation in the digital platform ecosystem is largely related to the rapid changes in technology, the globalization of competition, and the shift to a data and network-driven economy [29].

In this environment, digital platform companies create and implement open innovation strategies in the following specific ways [2,30–32]. Firstly, platforms offer APIs [2,30]. As mentioned above, many platform companies make their APIs public so that external developers and platform users can utilize their platforms and services. This creates new applications, services, and business models in the digital world. Empirical analysis revealed that platforms providing robust SDKs and open APIs see a higher rate of innovation and a more diverse range of applications, underlining the strategic importance of boundary resources in ecosystem dynamics. Secondly, platform providers and complementors enter into strategic partnerships [31,32]. Platform providers gain access to new technologies and ideas through strategic partnerships with startups, universities, and sometimes competitors while complementors gain exclusive access to special features of the platform. These collaborations leverage complementary strengths to drive innovation.

2.2. Affordance, Autonomy, and Super-Modularity

Based on ecosystem theory and open innovation theory, the core mechanism of a digital ecosystem is the constant interaction between platform providers and third-party users. And value creation through interaction occurs through complementary mechanisms or complementary effect. The complementary effect can be classified affordance, autonomy, and super-modularity, according to the previous literature.

Affordance shapes how complementors can create, distribute, and monetize their offerings on a platform [9,33]. As Baym and Boyd [34] argued in their work on social network sites as a form of networked publics, affordances are shaped by four dimensions: persistence, replicability, scalability, and searchability. These affordances are dictated by the platform's design, policies, and boundary resources such as the APIs and SDKs which platform providers offer [35]. Access to platform features affect the ability of complementors to integrate their services with core features of the platform. More actively, seamless technical support by platform providers is a strategy for increasing affordance level because the quality and ease-of-use of the development tools provided by the platform, as well as documentation and support for developers, is a core factor in choosing a platform from a complementor perspective [10,12].

The mechanisms and policies in place for complementors to generate revenue through the platform, such as sales, subscription models, advertising, or in-app purchases. According to the Hein et al. [36], the rules and guidelines set by the platform that dictate what is allowed and what is not, influencing the scope of what complementors can develop, is associated with affordance of digital platform. Understanding what determines affordance levels on digital platforms is important for a number of reasons. Firstly, in perspective of innovation creation, affordances directly impact the level and types of innovation that can occur within a platform ecosystem. By enabling or restricting certain actions, platform providers can influence the diversity, quality, and novelty of the offerings within their ecosystem. And it also influences on strategic decision-making for complementors. For potential third-party users looking to participate in a platform ecosystem, understanding the affordances is critical for strategic planning. It affects decisions regarding which platforms to invest in, how to design products or services, and how to navigate the competitive landscape within the platform. In the broader market, platforms compete not just on their core offerings, but also on the richness of their ecosystems. In this context, affordances are a key factor in attracting and retaining complementors, which in turn enhances the value of the platform to end-users [11]. Secondly, affordance is also important from a regulatory perspective, as it highlights how platform policies and technical capabilities can shape market dynamics, competition, and potentially raise concerns around issues such as data privacy, market power, and fairness. In summary, affordance in digital platform ecosystems play a pivotal role in shaping the interactions between platform providers and complementors, influencing innovation, competitive strategy, and the overall health and sustainability of the ecosystem [37]. Understanding these affordances helps stakeholders navigate and succeed in the increasingly complex and interconnected digital economy.

The concept of autonomy in the context of digital platform ecosystems refers to the degree of freedom that complementors (third-party developers, businesses, or service providers) have in developing, offering, and managing their products or services within the platform [7]. This is closely associated with the openness of the platform, which can range from highly open systems that allow wide-ranging freedom to complementors to more closed systems that impose strict controls and limitations [15]. For complementors, autonomy offers strategic flexibility, allowing them to pivot, adapt, and respond to market changes more swiftly. This agility can be a critical factor in their success and survival within the dynamic environment of a digital platform ecosystem. Theoretically, autonomy is directly associated with creative freedom and operational controls of complementors. With high level of autonomy by platform providers, complementors can integrate their services or products easily and deeply with the core features and functionality of the platform.

Higher levels of autonomy often lead to a more vibrant and diverse ecosystem. When complementors have the freedom to innovate and experiment, they can introduce novel solutions and fill niche markets, enhancing the overall value proposition of the platform to end-users. This can also affect the satisfaction and long-term engagement of complementors with the platform. Platform providers that offer greater autonomy might be more attractive to innovative developers and businesses seeking to leverage the platform's capabilities without excessive constraints. According to Broekhuizen et al. [15], the level of autonomy provided by a digital platform can influence its competitive positioning in the market. Scholars also have shown that platforms that strike the right balance between openness and control can differentiate themselves and attract a larger and more diverse set of complementors, which in turn can attract more users [38–41]. Too much control can stifle innovation and discourage participation, while too little control can lead to a fragmented user experience or problems with quality and security. Hilkert et al. [42] stated that, in the long run, autonomy plays a critical role in the health and sustainability of a platform ecosystem. Boudreau et al. [39] also pointed out that finding the optimal level of autonomy is a key for maintaining a balanced and thriving ecosystem. Therefore, the degree of autonomy that platform providers grant to their complementors is a critical aspect of digital platform ecosystems, as it affects innovation, ecosystem diversity, complementor engagement, and competitive dynamics. Understanding and strategically managing autonomy is essential for both platform providers and complementors to thrive in the digital economy, ensuring the long-term health and growth of the ecosystem.

Modularity refers to interdependence, where the value of a digital platform increases significantly when it is integrated with complementary products or services [16]. Scholars emphasized what distinguishes ecosystems from other business constellations, including markets, alliances, or hierarchically managed supply chains, is their modularity [16,18,43]. In the same vein, super-modularity in digital platform ecosystem means that the value of the platform for each individual user drastically increases as the number of users or the number of services increases. This can lead to a virtuous circle of growth for the platform ecosystem. As more complementary products or services become available, they can add value to each other and to the platform [44]. Another facet of super-modularity is that it encourages innovation, as complementors seek to develop distinctive or superior products to stand out on the platform, thereby attracting more users and fostering a virtuous cycle of growth and innovation [45]. Within this ecosystem, the relationship between the platform provider and complementors is highly symbiotic, which means the platform relies on a diverse and high-quality range of complementary offerings to attract and retain users, while complementors benefit from a robust and popular platform to access a broader customer base [46]. Table 1 describes the operational definitions of affordance, autonomy, and super-modularity, as well as the questions in the survey. It should be noted that the survey questions in Table 1 refer to autonomy, affordability, and super-modularity as assessed from the perspective of the platform provider. Separately, from the complementor's perspective, the survey assessed whether the platforms that complementors primarily use provide affordability, autonomy, and super-modularity.

Table 1. Operational definitions of affordance, autonomy and super-modularity and question in the survey.

Dimension	Operational Definitions and Question in the Survey	Research
Affordance	- The opportunities and constraints that a digital platform offers to its users, with a particular focus on the interaction between platform providers and complementors that add value to the platform through additional services, applications, or products. - Does your platform check for technical issues with complementors from time to time and do its best to support uninterrupted use? ① None ② Support in case of technical issue ③ Support complementors irregularly regardless of technical issue ④ Support complementors regularly regardless of technical issue	[9,12,33]
Autonomy	- The degree of freedom complementors have in the development, delivery, and management of their products or services within the platform. - How much control does your platform have over its users? ① Constant monitoring and control ② Face-to-face contracts with complementors and authorization processes exists ③ Face-to-face contracts with complementors ④ No control and free access	[7,15]
Super-modularity	- The degree of interdependence between the platform provider and the complementors in terms of value co-creation. - Do you think your platform is synergistic with the complementors who use it? ① Not at all ② Some ③ A lot	[16,18]

Overall, this background lays the foundation for understanding the complex interplay between platform providers and complementors, emphasizing the significance of technological solutions and open innovation in shaping these relationships.

3. Methodology

3.1. Data

The data used in this study are from the 2022 Korean Digital Industry Survey approved by the National Bureau of Statistics. The 2022 Digital Industry Survey aims to monitor changes in the national industrial structure due to the acceleration of digital transformation, and to secure basic data for the establishment of digital industry policies. This survey focused on producing reliable statistics on the digital economy that meet international standards, such as those of the OECD. The Digital Industry Classification System according to the Digital Industry Survey is shown in Table 2. This survey followed the OECD guidelines to classify the digital industry into (1) digital-based industries and (2) digital platform industries. A complementor is a company in a digital-based industry that continues to use the platform for its business.

Table 2. Classification of digital industry in the survey.

Classification	Definition	Sub Dimensions
Digital-based industry	Industries that produce or provide a digital foundation, such as equipment, telecommunications, broadcasting, and software technologies that enable the production or sale of products and services using digital technology.	Digital-based devices and components (communication devices, semiconductors, etc.)
		Digital-based Service Infrastructure Services (Telecom, Broadcast, Cloud, information, SW)
Digital platform industries	Industries that provide information services, such as portals and social media, to a large number of users through digital technology, or that act as intermediaries for producers and consumers to trade in products and services they want, and industries that provide digital services that plan, aggregate, and deliver digital information to a large number of users for trading.	Information platforms (Portals, Social media, Communities, Messengers)
		Intermediary platforms (E-commerce, Delivery, hospitality, travel, real estate)
		Digital content platforms (Video, Music, Webtoon, E-book, Online game)

In particular, the 2022 Digital Industry Survey designed questions to measure affordance, autonomy, and super modularity from the perspective of platform companies and platform utilizers, respectively, to capture the platform ecosystem in line with digital transformation of Korea.

3.2. Model Specification

One of the main objectives of this study is to identify factors that influence affordance, autonomy, and super-modularity by considering simultaneity and trade-off relationships in the decision-making process of companies. In the digital industry survey, affordance, autonomy, and super-modularity were captured using ranked order data in a questionnaire. In order to achieve the research objectives, a flexible modelling framework for multiple ordinal measurements on the same subjects, a multivariate rank-ordered probit model, was applied, which takes into account the dependence among the multiple dependent variables by allowing error structures. This captures the heterogeneity in the error structure across subjects to be estimated, reflecting the relationship between affordance, autonomy, and super-modularity. The regression models for assessing the complementary effect of platform providers can be described as follows.

$$\begin{aligned}\widetilde{Y}_{Affordance} = {} & \beta_{supply_{API,1}} X_{supply_{API}} + \beta_{supply_{SDK,1}} X_{supply_{SDK}} + \beta_{Platform_{Info,1}} X_{platform_{Info}} + \\ & \beta_{platform_{transac,1}} X_{platform_{transac}} + \beta_{platform_{content,1}} X_{platform_{content}} + X^T \beta_{control,1} + \varepsilon_{Autonomy}\end{aligned} \quad (1)$$

$$\begin{aligned}\widetilde{Y}_{Autonomy} = {} & \beta_{supply_{API,2}} X_{supply_{API}} + \beta_{supply_{SDK,2}} X_{supply_{SDK}} + \beta_{Platform_{Info,2}} X_{platform_{Info}} + \\ & \beta_{platform_{transac,2}} X_{platform_{transac}} + \beta_{platform_{content,2}} X_{platform_{content}} + X^T \beta_{control,2} + \varepsilon_{Autonomy}\end{aligned} \quad (2)$$

$$\begin{aligned}\widetilde{Y}_{Supermodularity} = {} & \beta_{supply_{API,3}} X_{supply_{API}} + \beta_{supply_{SDK,3}} X_{supply_{SDK}} + \beta_{Platform_{Info,3}} X_{platform_{Info}} + \\ & \beta_{platform_{transac,3}} X_{platform_{transac}} + \beta_{platform_{content,3}} X_{platform_{content}} + X^T \beta_{control,3} + \varepsilon_{Supermodularity}\end{aligned} \quad (3)$$

$\widetilde{Y}_{Affordance}$, $\widetilde{Y}_{Autonomy}$, and $\widetilde{Y}_{Supermodularity}$ are underlying latent variables of observed categorical variables which platform provider evaluates. X^T includes control variables which are sales in 2021, number of employees, and number of employees working in the ICT department of firm. Since dependent variables are rank-ordered data, each equation can be estimated using ordered probit model following McCullagh [47]. In this case, however, heterogeneity cannot be captured. By extending the univariate cumulative link model to a multivariate setting by assuming the existence of multiple latent variables with joint error distributions [48,49], we estimate three equations simultaneously and estimate the error structure in this study, which provides more reliable regression coefficients and information about the error structure.

Similarly, the regression models for evaluating complementor's complementary effect can be described as follows.

$$\begin{aligned}\widetilde{Y}_{Affordance} = {} & \beta_{supply_{API,1}} X_{supply_{API}} + \beta_{supply_{SDK,1}} X_{supply_{SDK}} + \beta_{Use_{R\&D,1}} X_{Use_{R\&D}} + \beta_{Use_{OM,1}} X_{Use_{OM}} + \\ & \beta_{Use_{OR,1}} X_{Use_{OR}} + \beta_{Use_{Marketing,1}} X_{Use_{Marketing}} + \beta_{Use_{Logistic,1}} X_{Use_{Logistic}} + \\ & \beta_{Use_{NPD,1}} X_{Use_{NPD}} + X^T \beta_{control,1} + \varepsilon_{Affordance}\end{aligned} \quad (4)$$

$$\begin{aligned}\widetilde{Y}_{Autonomy} = {} & \beta_{supply_{API,2}} X_{supply_{API}} + \beta_{supply_{SDK,2}} X_{supply_{SDK}} + \beta_{Use_{R\&D,2}} X_{Use_{R\&D}} + \beta_{Use_{OM,2}} X_{Use_{OM}} + \\ & \beta_{Use_{OR,2}} X_{Use_{OR}} + \beta_{Use_{Marketing,2}} X_{Use_{Marketing}} + \beta_{Use_{Logistic,2}} X_{Use_{Logistic}} + \\ & \beta_{Use_{NPD,2}} X_{Use_{NPD}} + X^T \beta_{control,2} + \varepsilon_{Autonomy}\end{aligned} \quad (5)$$

$$\begin{aligned}\widetilde{Y}_{Supermodularity} = {} & \beta_{supply_{API,3}} X_{supply_{API}} + \beta_{supply_{SDK,3}} X_{supply_{SDK}} + \beta_{Use_{R\&D,3}} X_{Use_{R\&D}} + \beta_{Use_{OM,3}} X_{Use_{OM}} + \\ & \beta_{Use_{OR,3}} X_{Use_{OR}} + \beta_{Use_{Marketing,3}} X_{Use_{Marketing}} + \beta_{Use_{Logistic,3}} X_{Use_{Logistic}} + \\ & \beta_{Use_{NPD,3}} X_{Use_{NPD}} + X^T \beta_{control,3} + \varepsilon_{Supermodularity}\end{aligned} \quad (6)$$

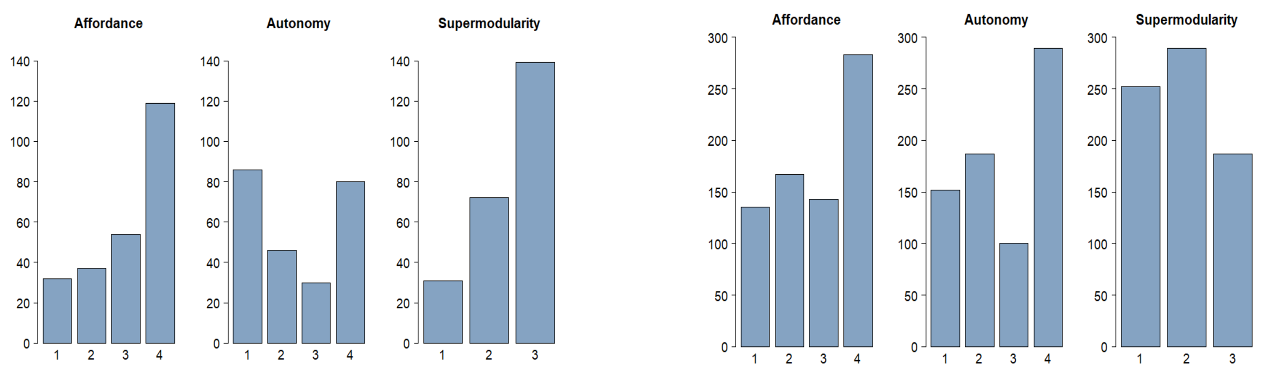
$\tilde{Y}_{Affordance}$, $\tilde{Y}_{Autonomy}$, and $\tilde{Y}_{Supermodularity}$ are also underlying latent variables of observed categorical variables which complementors evaluates. And these equations also can be estimated using multivariate rank ordered probit models.

Finally, we apply cluster analysis to classify platform providers and complementors in terms of their level of affordance, autonomy, and super-modularity. This analysis provides an empirical understanding of how digital platforms shape the affordance and autonomy of platform providers and complementors. As the variables used for clustering are categorical data, we use k-mode clustering instead of k-means clustering, which is used in the analysis of continuous variables. K-mode clustering is specifically designed for categorical data and overcomes the limitations of k-means, which is not suitable for non-numerical data types. The estimation algorithm is similar to k-means clustering, except for the updating criteria. The estimation procedure consists of three main steps: (1) selecting k initial modes, (2) assigning objects to modes, and (3) updating and iterating until the modes stop changing. The K-mode clustering algorithm can be more efficient than other clustering methods for categorical data because it uses simple matching dissimilarity measures and mode updates, which are less computationally intensive than the distance calculations and mean updates for continuous data.

3.3. Descriptive Statistics

The 2022 Digital Industry Survey sampled 420 platform providers, of which 242 had at least one boundary resource. These companies responded to affordance, autonomy, and super-modularity. For complementors, 1104 companies were surveyed, of which 728 used platforms that provided boundary resources, and only these companies answered affordance, autonomy, and complementarity are ranked as variables.

Figure 1 is a bar chart of complementarity effect comprising the dependent variables assessed by platform providers and complementors, respectively.



(**a**) (**b**)

Figure 1. Evaluation of complementarity between platform providers and complementor: (**a**) evaluation of platform providers, (**b**) evaluation of complementors.

Tables 3 and 4 show descriptive statistics and correlation of variables of platform providers and complementors. Supply APIs ask platform providers whether they offer an API, and the same question asks complementors whether the digital platform they primarily use offers an API. The provision of SDKs is similar. The results show that 68% of platform companies offer APIs and 29% of them offer SDKs. In contrast, 53% of complementors say their primary platform offers an API and 40% offer an SDK. Platform companies were asked whether the platform they offer is an information-based platform, an intermediary-based platform, or a digital content platform, and complementors were asked about the primary purpose of using the platform. The purpose of using the platform was categorized into six categories; (1) research and development (R&D), (2) organization management (OM), (3) operations management (OR), (4) marketing, (5) logistics, and (6) new product development (NPD). In terms of platform type classification, intermediary-based matching platforms were the most common (53%) among the three types, and information-based platforms (37%) followed. In terms of the purpose of using the platform, the platform was most commonly used by complementors for marketing (65%), followed by new product development (44%) and R&D (38%). And OR is the least (12%).

Table 3. Descriptive statistics and correlation of variables of platform providers.

N = 242	*Mean*	*S.D.*	Correlation Matrix										
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1. Affordance [min = 1, max = 4]	3.07	1.08	1	−0.29	0.16	0.18	−0.15	−0.2	0.05	0.2	−0.14	−0.16	−0.13
2. Autonomy [min = 1, max = 4]	2.43	1.27		1	−0.09	−0.08	0.03	0.02	0.28	−0.35	0.18	0.13	0.13
3. Super-modularity [min = 1, max = 3]	2.45	0.71			1	−0.03	−0.09	−0.14	−0.1	0.3	0.03	−0.02	0.00
4. Supply_API [no = 0, yes = 1]	0.68	0.47				1	0.19	−0.1	−0.11	0.22	0.03	0.02	0.05
5. Supply_SDK [no = 0, yes = 1]	0.29	0.45						0.12	−0.08	−0.02	0.13	0.14	0.16
6. Platform_info [no = 0, yes = 1]	0.37	0.48						1	−0.4	−0.27	−0.01	−0.04	−0.01
7. Platform_intermediary [no = 0, yes = 1]	0.53	0.50							1	−0.44	0.2	0.15	0.15
8. Platform_content [no = 0, yes = 1]	0.26	0.44								1	0.07	0.10	0.14
9. Sales 2021	2823	11,159									1	0.72	0.80
10. Employ	528	2334										1	0.92
11. Employ_ICT	244	827											1

Table 4. Descriptive statistics and correlation of variables of complementors.

N = 728	*Mean*	*S.D.*	Correlation Matrix													
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1. Affordance [min = 1,max = 4]	2.79	1.15	1	−0.2	0.18	0.05	0.03	−0.01	−0.08	0	0.04	0.09	0.1	0.02	0.07	0.05
2. Autonomy [min = 1, max = 4]	2.72	1.19		1	−0.34	−0.06	0.02	−0.02	0.11	0.06	0.01	0.00	−0.07	0.03	0.02	0.01
3. Super-modularity [min = 1, max = 3]	1.91	0.77			1	0.15	−0.01	0.07	−0.12	−0.02	−0.02	−0.02	0.1	0.02	0.02	0.01
4. Supply_API [no = 0, yes = 1]	0.53	0.50				1	0.17	0.15	−0.02	0.01	−0.05	−0.02	0.09	0.05	0.07	0.06
5. Supply_SDK [no = 0, yes = 1]	0.40	0.49					1	0.06	0.13	0.08	−0.03	0.05	0.03	0.04	0.04	0.05
6. Use_R&D [no = 0, yes = 1]	0.38	0.49						1	0.21	0.09	−0.21	−0.07	0.03	0.05	0.05	0.07
7. Use_OM [no = 0, yes = 1]	0.36	0.48							1	0.17	−0.03	0.01	0.02	−0.03	−0.02	−0.01
8. Use_OR [no = 0, yes = 1]	0.12	0.33								1	−0.03	0.24	−0.04	0.12	0.13	0.14
9. Use_Marketing [no = 0, yes = 1]	0.65	0.48									1	0.09	−0.08	0.02	0.00	0.00
10. Use_Logistic [no = 0, yes = 1]	0.18	0.39										1	0.1	−0.01	0.00	0.01
11. Use_NPD [no = 0, yes = 1]	0.44	0.50											1	−0.02	−0.01	−0.02
12. Sales 2021	6964	76,642												1	0.86	0.92
13. Employ	864	5446													1	0.97
14. Employ_ICT	579	4816														1

4. Results of Empirical Analysis of Platform Providers

Using firm-level data of platform providers, we analyzed dependent variables using multivariate ordered a probit model and k-mode cluster model. Table 5 shows the multivariate ordered probit analysis of the complementary effect by platform providers. Model 1 is an analysis based on whether the platform company provides APIs and SDKs, and Model 2 is an analysis based on the type of platform. Model 3 is a full model. Based on Model 3, it was found that platform companies that support APIs have a statistically significant higher affordance than companies that do not. This suggests that platforms that provide APIs are more proactive in helping complementors solve problems when they encounter problems using the platform than platforms that do not. In contrast, platforms that provide SDKs have a statistically significantly lower affordance than those that do not. This suggests that platforms that provide SDKs are less willing to support complements that use their platforms than those that do not. Next, we examined the complementor effect by platform type and found that intermediary-based platforms provide a higher degree of autonomy to complementors. In contrast, digital content delivery platforms provide higher levels of affordance and super-modularity to complementors, but lower levels of autonomy. In other words, digital content delivery platforms can be seen as controlling complementors. Intermediary-based platforms can be interpreted as having a strategy to increase the number of participants by giving complementors as much autonomy as possible in order to close more deals. Digital content based platforms, on the other hand, can be seen as increasing complementarity by actively collaborating with and controlling complementary firms that are the content creator.

Table 5. Analysis of multivariate ordered probit model of platform providers.

	Model I			Model II			Full Model		
	Affordance	Autonomy	Super Modularity	Affordance	Autonomy	Super Modularity	Affordance	Autonomy	Super Modularity
Supply_API	0.575 (0.174) ***	−0.244 (0.163)	−0.026 (0.185)				0.47 (0.183) **	−0.065 (0.17)	−0.223 (0.192)
Supply_SDK	−0.477 (0.169) ***	0.075 (0.166)	−0.262 (0.18)				−0.406 (0.183) **	0.06 (0.18)	−0.206 (0.188)
Platform_info				−0.206 (0.236)	0.064 (0.207)	−0.271 (0.236)	−0.141 (0.224)	0.05 (0.209)	−0.304 (0.236)
Platform_intermediary				0.338 (0.241)	0.435 (0.233) *	−0.048 (0.259)	0.338 (0.236)	0.432 (0.236) *	−0.098 (0.258)
Platform_content				0.682 (0.261) ***	−0.878 (0.238) ***	0.884 (0.284) ***	0.607 (0.251) **	−0.866 (0.244) ***	0.897 (0.281) ***
log(Sales_2021)	0.01 (0.058)	0.015 (0.059)	0.065 (0.057)	−0.053 (0.063)	0.073 (0.064)	0.002 (0.056)	−0.037 (0.062)	0.07 (0.065)	0.003 (0.059)
log(Employ)	−0.041 (0.144)	0.145 (0.118)	−0.185 (0.128)	−0.038 (0.141)	−0.048 (0.119)	−0.093 (0.127)	−0.044 (0.148)	−0.046 (0.12)	−0.103 (0.129)
log(EmployICT)	−0.056 (0.134)	−0.064 (0.107)	0.113 (0.12)	0.02 (0.128)	0.029 (0.1)	0.104 (0.117)	−0.013 (0.135)	0.032 (0.103)	0.127 (0.121)

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 6 is a correlation matrix of dependent variables as assessed by the platform providers. We found a statistically significant negative correlation between affordance and autonomy, and a statistically significant positive correlation between affordance and super-modularity. However, the correlation coefficient between autonomy and complementarity was not statistically significant. This suggests that there is a trade-off between affordance and autonomy in the decision-making of platform companies. Therefore, platform companies may provide a favorable environment for complementors to innovate while maintaining a high level of control, and these activities may lead to mutual innovation creation. Conversely, platform companies may give users as much autonomy as possible at the cost of limiting cocreation. In this case, the platform provider could expect more participation from potential users, and ultimately expect a network effect.

Table 6. Correlation matrix of affordance, autonomy, and super-modularity of platform providers.

	Affordance	Autonomy	Super-Modularity
Affordance	1.000	−0.362 ***	0.171 **
Autonomy	−0.362 ***	1.000	−0.037
Super-modularity	0.171 **	−0.037	1.000

Notes: ** $p < 0.05$; *** $p < 0.01$.

In the multivariate-ordered probit model, the outcomes are ordered categories, and thresholds are estimated to delineate the boundaries between these categories. The threshold estimates help to identify the points at which the probability of moving from one category to the next increases.

Table 7 shows the threshold coefficient estimates for the multivariate probit model of the complementarities of platform providers with the full model. The threshold coefficient indicates the points at which the predicted probability shifts from low to medium and from medium to high.

Table 7. Threshold estimation result of a multivariate ordered probit model of platform providers.

	Coeff.	S.E.	z-Value	*p*-Value	
Affordance 1∣2	−1.177	0.309	−3.814	0.000	***
Affordance 2∣3	−0.584	0.304	−1.923	0.054	*
Affordance 3∣4	0.063	0.301	0.211	0.833	
Autonomy 1∣2	−0.124	0.285	−0.435	0.664	
Autonomy 2∣3	0.436	0.280	1.554	0.120	
Autonomy 3∣4	0.783	0.280	2.796	0.005	**
Super-modularity 1∣2	−1.348	0.347	−3.891	0.000	***
Super-modularity 2∣3	−0.320	0.349	−0.919	0.358	

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

We then performed clustering analysis with respect to affordance, autonomy, and super-modularity. As each response variable is a categorical variable, we applied a K-mode clustering analysis. According to the silhouette index, which evaluates the model fit of clustering, we can see that the indicator has a maximum value when there are two clusters. Table 8 shows the centroids of the clusters. Cluster 1 represents a cluster with relatively high affordance, low autonomy, and high super-modularity, while cluster 2 represents a cluster with relatively low affordance and high autonomy. This means that platform providers in cluster 2 grant more autonomy to companies using their platform.

Table 8. Centroid of clusters of platform providers and their share.

	Affordance	Autonomy	Super-Modularity	Share
Cluster 1	4	1	3	0.554
Cluster 2	3	4	3	0.446

In order to examine the differences in firm characteristics between clusters, we performed independent *t*-tests. Table 9 shows the results of independent *t*-tests between clusters. The results show that cluster 2 is statistically significantly larger than cluster 1 for both 2020 turnover and 2021 turnover. The share of ICT expenditure in turnover shows that Cluster 2 spends statistically significantly more than Cluster 1. The number of employees is also statistically significant, with cluster 2 on average more than three times larger than cluster 1. We find that platform firms, which are relatively small in terms of number of employees and turnover, need to seek innovation through reciprocal relationships with complementors. This allows platform firms to maintain higher levels of affordance and control. It can be interpreted that relatively large platforms provide user firms with more autonomy while loosening the relationship with complementors compared to cluster 1. Looking at the difference in share by platform type, we found that cluster 1 has fewer intermediary platforms and more digital content platforms.

Table 9. Independent two-sample *t*-test results between clusters.

Variables	Mean of Cluster 1	Mean of Cluster 2	*p*-Value
Sales 2020	1038.783	3946.463	0.028 **
Sales 2021	1428.035	4554.411	0.046 **
Sales 2021_digital	1320.857	3194.208	0.110
Share_B2C	47.045	52.176	0.328
R&D_investment	261.994	471.744	0.263
Share_ICTexpenditure	16.91	28.648	0.039 **
Employ	270.194	847.093	0.086 *
EmployICT	168.142	337.926	0.147
Share_digital_order	68.955	73.639	0.292
Share of information platform	0.373	0.361	0.848
Share of intermediary platform	0.463	0.620	0.014 **
Share of digital content platform	0.299	0.204	0.089 *

Notes: * $p < 0.1$; ** $p < 0.05$.

Platform providers with larger revenues or more employees tend to have more resources and stronger brands. They have an established position in the market and can offer a high degree of autonomy to encourage innovation and creative use. This can be a strategy to increase the flexibility of the platform, attract more partners, and expand the ecosystem. On the other hand, platform providers with relatively small revenues or number of employees may have limited resources and a relatively small market presence. If these companies want to quickly gain market share or a competitive advantage in a particular market segment through their platform, they may want to tightly control how their platform is used to ensure consistent quality and service. This is a strategy that focuses on building brand credibility and ensuring platform stability.

5. Results of Empirical Analysis of Complementors

Similarly, using firm-level data of complementors, we analyzed the dependent variables using multivariate ordered probit model and k-mode cluster model. Table 10 shows the results of the multivariate ordered probit analysis of the complementary effect that complementors value. Model 1 is an analysis based on whether the platform company provides complementors with APIs and SDKs, and Model 2 is an analysis model based on the purpose of platform usage. Model 3 is a full model. According to the result of the full model, in terms of complementors, companies using platforms that provide APIs show significantly more super-modularity, while companies using platforms that provide SDKs show less super-modularity but are statistically insignificant. One of the possible reasons for this result is that the technical differences between APIs and SDKs lead to differences in how they are used. In other words, APIs facilitate connections between the platform and external applications, allowing the leveraged companies to integrate the platform's features directly into their services, but SDKs are a collection of more purpose-built development tools which are used to help complementors develop platform-specific applications.

Table 10. Analysis of multivariate ordered probit model of complementors.

	Model I			Model II			Full Model		
	Affordance	**Autonomy**	**Super Modularity**	**Affordance**	**Autonomy**	**Super Modularity**	**Affordance**	**Autonomy**	**Super Modularity**
Supply_API	0.109 (0.086)	−0.144 (0.086)	0.338 (0.087)				0.085 (0.088)	−0.108 (0.089)	0.289 (0.09) ***
Supply_SDK	0.07 (0.087)	0.052 (0.087)	−0.081 (0.089)				0.084 (0.09)	0.02 (0.089)	−0.048 (0.091)
Use_R&D				0.071 (0.091)	−0.133 (0.093)	0.23 (0.095)	0.058 (0.092)	−0.118 (0.095)	0.191 (0.097) **
Use_OM				−0.175 (0.092)	0.239 (0.093)	−0.312 (0.095)	−0.182 (0.093) *	0.231 (0.094) **	−0.294 (0.097) ***
Use_OR				−0.057 (0.139)	0.175 (0.142)	0.008 (0.137)	−0.065 (0.139)	0.175 (0.142)	0.008 (0.138)
Use_Marketing				0.072 (0.093)	0.016 (0.093)	0.006 (0.093)	0.074 (0.094)	0.017 (0.093)	0.004 (0.094)
Use_Logistic				0.25 (0.119)	−0.019 (0.112)	−0.064 (0.111)	0.246 (0.119) **	−0.022 (0.113)	−0.061 (0.113)
Use_NPD				0.204 (0.085)	−0.15 (0.086)	0.234 (0.088)	0.196 (0.086) **	−0.141 (0.087)	0.212 (0.088) **
log(Sales_2021)	0.074 (0.027)	−0.004 (0.027)	−0.018 (0.027)	0.07 (0.027)	−0.009 (0.028)	−0.014 (0.028)	0.071 (0.027) ***	−0.01 (0.028)	−0.012 (0.028)
log(Employ)	−0.002 (0.062)	−0.103 (0.056)	0.124 (0.057)	−0.005 (0.062)	−0.099 (0.057)	0.122 (0.058)	−0.004 (0.063)	−0.099 (0.057) *	0.123 (0.059) **
log(EmployICT)	0.002 (0.052)	0.054 (0.045)	−0.019 (0.046)	0.016 (0.053)	0.055 (0.046)	−0.02 (0.048)	0.009 (0.053)	0.059 (0.046)	−0.03 (0.048)

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Next, looking at differences by purpose of platform usage, we found that complementors' super-modularity with the platform is higher when the platform is used for R&D purposes. On the other hand, when the complementor uses the platform for OM purposes, autonomy is highly valued but affordance and super-modularity are low. On the other hand, we found that if a complementor uses a specific platform for logistics or new product development purposes, affordance is high. In other words, when a platform is used for R&D, logistics, or new product development, complementors are more likely to receive ongoing management and support from the platform providers.

Table 11 is a correlation matrix of dependent variables as assessed by complementors. Similar to the results found in the analysis of platform providers, we found a statistically significant negative correlation between affordance and autonomy, and a statistically significant positive correlation between affordance and super-modularity. In addition, we found that autonomy and super-modularity were also negatively correlated. This suggests that there is also a trade-off relationship between affordance when complementors choose a particular platform, because platform companies that provide a lot of autonomy to complementors are less likely to have affordance with platform users, while platforms that limit complementors' autonomy seek more innovation opportunities through collaboration with complementors.

Table 11. Correlation matrix of affordance, autonomy, and super-modularity of complementors.

	Affordance	Autonomy	Super-Modularity
Affordance	1.000	−0.362 ***	0.171 **
Autonomy	−0.362 ***	1.000	−0.037
Super-modularity	0.171 **	−0.037	1.000

Notes: ** $p < 0.05$; *** $p < 0.01$.

Table 12 shows the threshold coefficient estimates for the multivariate probit model of complementary effect by platform provider with the full model. The threshold coefficient indicates the points at which the predicted probability shifts from low to medium and from medium to high.

Table 12. Threshold estimation result of a multivariate ordered probit model of complementors.

	Coeff	S.E.	z-Value	*p*-Value	
Affordance 1∣2	−0.316	0.162	−1.946	0.052	*
Affordance 2∣3	0.385	0.160	2.407	0.016	**
Affordance 3∣4	0.902	0.162	5.557	0.000	***
Autonomy 1∣2	−1.151	0.173	−6.642	0.000	***
Autonomy 2∣3	−0.406	0.167	−2.430	0.015	**
Autonomy 3∣4	−0.057	0.167	−0.341	0.733	**
Super-modularity 1∣2	0.162	0.162	0.997	0.319	
Super-modularity 2∣3	1.258	0.168	7.478	0.000	***

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

As in the previous analysis of the platform providers, a clustering analysis was carried out based on the complementarity indicators assessed by complementors. We assessed the model fit using the silhouette index and found that the model fit is best when there are three clusters.

Looking at the centroid of each cluster in Table 13, we see that cluster 1 is relatively low in affordance, high in autonomy, and medium in complementarity. Cluster 2 is low in affordance, autonomy, and super-modularity. Cluster 3 is characterized by high affordance, high autonomy, and high super-modularity. The proportion of each cluster is not significantly different, with cluster 3 having the highest proportion of 35.3%.

Table 13. Centroid of clusters of complementors and their share.

	Affordance	Autonomy	Super-Modularity	Share
Cluster 1	2	2	2	0.335
Cluster 2	1	4	1	0.312
Cluster 3	4	4	3	0.353

An ANOVA was carried out to analyze whether there is a difference between the clusters in the variables related to the characteristics of the firms. Table 14 shows ANOVA results. It was found that there is a statistically significant difference in sales in 2020, with cluster 3 being the highest, followed by cluster 1 and cluster 2. It can be interpreted that there is a correlation between the sales volume of complementors and the type of platform that complementors choose. Cluster 2 spends the least of its turnover on ICT investments and has the lowest average number of employees.

Table 14. Analysis of variance of mean differences between clusters.

Variables	Cluster 1	Cluster 2	Cluster 3	*p*-Value
Sales 2020	3362.065	1505.613	13,197.454	0.096 *
Sales 2021	3622.955	1729.686	14,759.463	0.124
Sales 2021_digital	2115.253	723.369	11,817.170	0.204
Share_B2C	37.270	30.802	34.556	0.192
R&D_investment	384.681	96.390	1186.213	0.222
Share_ICT expenditure	24.598	16.991	24.953	0.015 **
Employ	675.410	228.568	1605.078	0.017 **
EmployICT	427.090	135.740	1113.790	0.069 *
Share_digital_order	57.053	58.841	63.549	0.113

Notes: * $p < 0.1$; ** $p < 0.05$.

These results can be explained in two ways: (1) resource availability, and (2) entry strategy. Firstly, firms with lower revenues and fewer employees are likely to have limited resources. They may choose a platform with greater autonomy to increase their access to external resources and to pursue rapid innovation. This gives them more flexibility to respond to market changes and strengthen their own innovation capabilities. On the other hand, large companies with high revenues and scale may seek complementary relationships with platforms to create synergies based on the resources and internal capabilities that they already have. They may have a strategy of using platforms to improve their products or services and further extend their market dominance. Secondly, in terms of market entry strategy, if small firms want to enter a new market or grow rapidly, a platform with a high degree of autonomy allows them to experiment and innovate. For them, autonomy is key to responding nimbly to market changes and creating differentiated value quickly. Large companies want to strengthen their market position and increase complementarities by collaborating with platforms as part of their strategy for steady growth. They may want to explore new market opportunities or strengthen their existing business by collaborating with platforms based on their established market position and brand equity.

6. Summary

This study empirically investigated the interplay between affordance, autonomy, and super-modularity in digital platform ecosystems from the perspectives of both platform providers and complementors using firm-level survey data from the Korean digital industry. By applying multivariate ordered probit and k-mode clustering models, the study examined the factors influencing these complementary dimensions and how they are interrelated.

The findings revealed that platform providers offering APIs enhance affordance, while those providing SDKs may limit it, highlighting the need to balance enabling innovation and maintaining platform coherence. A significant negative correlation was found between affordance and autonomy for both platform providers and complementors, suggesting a trade-off in their decision-making processes. Cluster analysis showed that the size and resources of firms influence their strategic choices regarding autonomy, affordance, and super-modularity.

The study contributes to the growing literature on digital platform ecosystems by empirically examining the complex relationships between key complementary factors and the role of strategic choices made by platform providers and complementors in shaping these dynamics. The insights gained can inform platform providers in strategizing resource allocation for cultivating innovation and guide complementors in selecting platforms aligned with their goals.

7. Implication and Conclusions

The findings of this study contribute to the growing body of literature on digital platform ecosystems by empirically examining the interplay between affordance, autonomy, and super-modularity from the perspectives of both platform providers and complementors. The results expand our understanding of how these factors influence each other and how they are shaped by the strategic choices made by platform providers, such as the provision of APIs and SDKs.

The study confirms the importance of boundary resources, such as APIs and SDKs, in enabling collaboration and value creation within digital platform ecosystems, as highlighted by previous research [6–8]. However, the findings also reveal a more nuanced relationship between these resources and the complementary factors. While providing APIs enhances affordance, offering SDKs may limit it. This suggests that platform providers must carefully consider the trade-offs involved in their design choices to strike a balance between enabling innovation and maintaining platform coherence.

The negative correlation found between affordance and autonomy for both platform providers and complementors aligns with the findings of Broekhuizen et al. [15], who emphasized the need for platforms to balance openness and control. This study extends this notion by highlighting the trade-off between affordance and autonomy in the decision-making processes of both platform providers and complementors. Platform providers may choose to provide a conducive environment for complementor innovation while maintaining a high level of control or grant more autonomy to complementors at the cost of limiting co-creation opportunities.

The cluster analysis reveals that the size and resources of platform providers and complementors influence their strategic choices regarding autonomy, affordance, and super-modularity. This finding is consistent with the work of Cenamor and Frishammar [13], who suggested that openness in platform ecosystems is related to the innovation strategies of complementary products. The present study extends this idea by demonstrating how firm size and resources shape the way platform providers and complementors navigate the trade-offs between these factors. Additionally, the association between firm size and complementary effect can be interpreted from the perspective of resource availability and entry strategy. Firms with limited financial resources and human capital, as evidenced by lower revenues and employee counts, may opt for platforms that offer greater autonomy. This choice allows them to leverage external resources and pursue accelerated innovation, enabling them to adapt swiftly to market dynamics and enhance their innovative capabilities. Conversely, larger enterprises with substantial revenues and scale may pursue complementary partnerships with platforms to generate synergies by capitalizing on their existing resources and internal capabilities. Their strategic objective may involve leveraging platforms to enhance their offerings and further solidify their market dominance.

From a market entry perspective, smaller complementors seeking to penetrate new markets or achieve rapid growth may find platforms with higher levels of autonomy more appealing, as they provide the freedom to experiment and innovate. For these firms, autonomy is crucial for responding agilely to market shifts and quickly creating differentiated value propositions. On the other hand, larger complementors may aim to bolster their market position and increase complementarities by collaborating with platforms as part of their steady growth strategy. Their goal may be to explore new market opportunities or strengthen their existing business by leveraging their established market position and brand equity through platform partnerships.

However, the study has several limitations that should be considered when interpreting the results. First, the focus on the Korean digital industry may limit the generalizability of the findings to other contexts. Future research could explore these dynamics in different geographic and industry settings to validate and extend the insights gained from this study. Second, the analysis relies on cross-sectional survey data, which limits the ability to establish causal relationships and address potential endogeneity issues. Future studies could employ longitudinal designs or panel data to better capture the dynamic nature of these relationships over time. Additionally, while the study provides valuable insights into the interplay between affordance, autonomy, and super-modularity, it does not fully explore the mechanisms through which these factors influence innovation outcomes and ecosystem performance. Future research could delve deeper into these mechanisms and examine how they relate to specific measures of innovation, such as the quantity, quality, and diversity of complementary products and services.

Despite these limitations, the study makes important contributions to our understanding of digital platform ecosystems by empirically examining the complex relationships between key complementary factors and by highlighting the role of strategic choices made by platform providers and complementors in shaping these dynamics.

Funding: This research was funded by Konkuk University.

Institutional Review Board Statement: Ethical review and approval were waived for this study, because this study did not consider biological human experiment and patient data.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that have been used are confidential.

Acknowledgments: This paper was supported by Konkuk University in 2023.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. De Falco, S.E.; Renzi, A.; Orlando, B.; Cucari, N. Open collaborative innovation and digital platforms. *Prod. Plan. Control* **2017**, *28*, 1344–1353. [CrossRef]
2. Nambisan, S.; Siegel, D.; Kenney, M. On open innovation, platforms, and entrepreneurship. *Strateg. Entrep. J.* **2018**, *12*, 354–368. [CrossRef]
3. Osorno, R.; Medrano, N. Open innovation platforms: A conceptual design framework. *IEEE Trans. Eng. Manag.* **2020**, *69*, 438–450. [CrossRef]
4. Abbate, T.; Codini, A.P.; Aquilani, B. Knowledge co-creation in open innovation digital platforms: Processes, tools and services. *J. Bus. Ind. Mark.* **2019**, *34*, 1434–1447. [CrossRef]
5. Reinsberg, R.; Solem, B.A.; Pedersen, P.E. Value creation in digital platform business models: Value conceptualizations, value dimensions and value logics. *Res. Handb. Digit. Strategy* **2023**, 194–210.
6. Ghazawneh, A.; Henfridsson, O. Balancing platform control and external contribution in third-party development: The boundary resources model. *Inf. Syst. J.* **2013**, *23*, 173–192. [CrossRef]
7. Karhu, K.; Gustafsson, R.; Lyytinen, K. Exploiting and defending open digital platforms with boundary resources: Android's five platform forks. *Inf. Syst. Res.* **2018**, *29*, 479–497. [CrossRef]
8. Alaimo, C. The Role of Boundary Resources in Ecosystem Innovation: A Study of Facebook's Evolution. Available at SSRN 4026712. 2022. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4026712 (accessed on 1 March 2024).
9. Abhari, K.; Davidson, E.; Xiao, B. Inventing together: The role of actor goals and platform affordances in open innovation. *J. Assoc. Inf. Syst.* **2022**, *23*, 264–302.
10. Bucher, T.; Helmond, A. The affordances of social media platforms. *SAGE Handb. Soc. Media* **2018**, *1*, 233–253.
11. Krancher, O.; Luther, P.; Jost, M. Key affordances of platform-as-a-service: Self-organization and continuous feedback. *J. Manag. Inf. Syst.* **2018**, *35*, 776–812. [CrossRef]
12. Abhari, K.; Davidson, E.J.; Xiao, B. Co-innovation platform affordances: Developing a conceptual model and measurement instrument. *Ind. Manag. Data Syst.* **2017**, *117*, 873–895. [CrossRef]
13. Cenamor, J.; Frishammar, J. Openness in platform ecosystems: Innovation strategies for complementary products. *Res. Policy* **2021**, *50*, 104148. [CrossRef]
14. Benlian, A.; Hilkert, D.; Hess, T. How open is this platform? The meaning and measurement of platform openness from the complementors' perspective. *J. Inf. Technol.* **2015**, *30*, 209–228. [CrossRef]
15. Broekhuizen, T.L.J.; Emrich, O.; Gijsenberg, M.J.; Broekhuis, M.; Donkers, B.; Sloot, L.M. Digital platform openness: Drivers, dimensions and outcomes. *J. Bus. Res.* **2019**, *122*, 902. [CrossRef]
16. Hein, A.; Schreieck, M.; Riasanow, T.; Setzke, D.S.; Wiesche, M.; Böhm, M.; Krcmar, H. Digital platform ecosystems. *Electron. Mark.* **2019**, *30*, 87. [CrossRef]
17. Amir, R. Super-modularity and complementarity in economic theory. *Econ. Theory* **2019**, *67*, 487–496. [CrossRef]
18. Jacobides, M.G.; Cennamo, C.; Gawer, A. Towards a theory of ecosystems. *Strateg. Manag. J.* **2018**, *39*, 2255. [CrossRef]
19. Wulf, J.; Blohm, I. Fostering value creation with digital platforms: A unified theory of the application programming interface design. *J. Manag. Inf. Syst.* **2020**, *37*, 251–281. [CrossRef]

20. Cutolo, D.; Kenney, M. Platform-Dependent Entrepreneurs: Power Asymmetries, Risks, and Strategies in the Platform Economy. *AMP* **2021**, *35*, 584. [CrossRef]
21. Teixeira, J. On the openness of digital platforms/ecosystems. In Proceedings of the 11th International Symposium on Open Collaboration, San Francisco, CA, USA, 19–21 August 2015. [CrossRef]
22. Jansen, S.; Cusumano, M.A.; Brinkkemper, S. *Software Ecosystems: Analyzing and Managing Business Networks in the Software Industry*; Edward Elgar Publishing: Cheltenham, UK, 2013.
23. Li, S.; Liu, Y.; Bandyopadhyay, S. Network effects in online two-sided market platforms: A research note. *Decis. Support. Syst.* **2010**, *49*, 245–249. [CrossRef]
24. Isckia, T.; De Reuver, M.; Lescop, D. Orchestrating platform ecosystems: The interplay of innovation and business development subsystems. *J. Innov. Econ. Manag.* **2020**, *32*, 197–223. [CrossRef]
25. Haile, N.; Altmann, J. Value creation in software service platforms. *Future Gener. Comput. Syst.* **2015**, *55*, 495. [CrossRef]
26. Haile, N.; Altmann, J. Structural analysis of value creation in software service platforms. *Electron. Mark.* **2015**, *26*, 129. [CrossRef]
27. Heimburg, V.; Wiesche, M. Relations between actors in digital platform ecosystems: A literature review. In Proceedings of the 30th European Conference on Information Systems-New Horizons in Digitally United Societies, Timisoara, Romania, 18–24 June 2022.
28. Cavallo, A.; Burgers, H.; Ghezzi, A.; Van de Vrande, V. The evolving nature of open innovation governance: A study of a digital platform development in collaboration with a big science centre. *Technovation* **2022**, *116*, 102370. [CrossRef]
29. Mubarak, M.F.; Petraite, M. Industry 4.0 technologies, digital trust and technological orientation: What matters in open innovation? *Technol. Forecast. Soc. Change* **2020**, *161*, 120332. [CrossRef]
30. Aitamurto, T.; Lewis, S.C. Open innovation in digital journalism: Examining the impact of Open APIs at four news organizations. *New Media Soc.* **2013**, *15*, 314–331. [CrossRef]
31. Han, K.; Oh, W.; Im, K.S.; Chang, R.M.; Oh, H.; Pinsonneault, A. Value cocreation and wealth spillover in open innovation alliances. *Mis Q.* **2012**, *36*, 291–315. [CrossRef]
32. Shaikh, M.; Levina, N. Selecting an open innovation community as an alliance partner: Looking for healthy communities and ecosystems. *Res. Policy* **2019**, *48*, 103766. [CrossRef]
33. Earl, J.; Kimport, K. *Digitally Enabled Social Change: Activism in the Internet Age*; MIT Press: Cambridge, MA, USA, 2011.
34. Baym, N.K.; Boyd, D. Socially mediated publicness: An introduction. *J. Broadcast. Electron. Media* **2012**, *56*, 320–329. [CrossRef]
35. Hein, A.; Setzke, D.S.; Hermes, S.; Weking, J.; Kernstock, P.; Krcmar, H. Building digital platform leadership through affordances and generativity. In *Digitalization and Sustainability*; Edward Elgar Publishing: Cheltenham, UK, 2023; pp. 240–256.
36. Hein, A.; Soto, D.; Hermes, S.; Weking, J. The Influence of Digital Affordances and Generativity on Digital Platform Leadership. In Proceedings of the ICIS 2019, Munich, Germany, 15–18 December 2019.
37. Wang, N.; Wan, J.; Ma, Z.; Zhou, Y.; Chen, J. How digital platform capabilities improve sustainable innovation performance of firms: The mediating role of open innovation. *J. Bus. Res.* **2023**, *167*, 114080. [CrossRef]
38. Cennamo, C. Building the value of next-generation platforms: The paradox of diminishing returns. *J. Manag.* **2018**, *44*, 3038–3069. [CrossRef]
39. Boudreau, K. Open platform strategies and innovation: Granting access vs. devolving control. *Manag. Sci.* **2010**, *56*, 1849–1872. [CrossRef]
40. Gawer, A.; Cusumano, M.A. *Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*; Harvard Business School Press: Boston, MA, USA, 2002.
41. Hagiu, A.; Wright, J. Controlling vs. enabling. *Manag. Sci.* **2019**, *65*, 577–595. [CrossRef]
42. Hilkert, D.; Benlian, A.; Sarstedt, M.; Hess, T. Perceived software platform openness: The scale and its impact on developer satisfaction. In Proceedings of the ICIS 2011, Shanghai, China, 4–7 December 2011.
43. Valdez-De-Leon, O. How to develop a digital ecosystem: A practical framework. *Technol. Innov. Manag. Rev.* **2019**, *9*, 43–54. [CrossRef]
44. Giustiziero, G.; Kretschmer, T.; Somaya, D.; Wu, B. Hyperspecialization and hyperscaling: A resource-based theory of the digital firm. *Strateg. Manage.J.* **2023**, *44*, 1391–1424. [CrossRef]
45. Ojala, A.; Lyytinen, K. How do entrepreneurs create indirect network effects on digital platforms? A study on a multi-sided gaming platform. *Technol. Anal. Strat. Manag.* **2022**, *36*, 886–901. [CrossRef]
46. Autio, E. Orchestrating ecosystems: A multi-layered framework. *Innovation* **2022**, *24*, 96–109. [CrossRef]
47. McCullagh, P. Regression models for ordinal data. *J. R. Stat. Soc. Ser. B Methodol.* **1980**, *42*, 109–127. [CrossRef]
48. Bhat, C.R.; Varin, C.; Ferdous, N. A comparison of the maximum simulated likelihood and composite marginal likelihood estimation approaches in the context of the multivariate ordered-response model. In *Maximum Simulated Likelihood Methods and Applications*; Emerald Group Publishing Limited: Bingley, UK, 2010; Volume 26, pp. 65–106.
49. Kenne Pagui, E.C.; Canale, A. Pairwise likelihood inference for multivariate ordinal responses with applications to customer satisfaction. *Appl. Stoch. Model. Bus. Ind.* **2016**, *32*, 273–282. [CrossRef]