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Evolution of the Software-as-a-Service Innovation System Through Collective Intelligence

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TEMEP Discussion Paper No. 2013:108

서울대학교

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Finally, the current editor of this series would like to thank Prof. Dr. Almas Heshmati for establishing this working paper series in January 2009 and for guiding its development during the course of the first 55 issues. In particular, Prof. Heshmati provided invaluable contributions for setting up the local IT infrastructure, registering the series with RePEc, disseminating the working papers, and setting the quality requirements.

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Evolution of the Software-as-a-Service Innovation System Through Collective Intelligence

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December 2013

Abstract: One of the notable trends in the software industry is that software vendors provide their software on a platform as a service. Software users consume those software services or compose new services by combining those existing software services. The software vendors, their services, software users, and the platform represent an open innovation system. Collective intelligence is the underlying mechanism for the cooperation between the users of the system, i.e. their continuous reuse of existing software services for the creation of new services. A successfully working software services system is a system that is continuously adapted by its users to meet their needs. The evolution of this software-as-a-service (SaaS) innovation system and the behavior of SaaS users within this system are still unknown. In this paper, we describe the evolution of a SaaS network. The SaaS network consists of nodes (i.e. software services with open interfaces) and links (i.e. the co-development relationships of software services with open interfaces). The results suggest that the SaaS network has gradually grown into a scale-free network with a slight concavity in its cumulative degree distribution. The results also suggest that the topology characteristics are invariant over time except for the early time periods. Furthermore, the results suggest that the SaaS network is not as open (i.e. inter-operable) as its technology let us expect. Considering these results, we imply that SaaS innovation is achieved by platform providers striving to capture users with a few, leading SaaS services. That means, SaaS innovation is not achieved through the possibilities of potential combinations between any kind of SaaS services as could be expected theoretically. These findings are expected to stir further research on the actual structure of open innovation systems that are driven by collective intelligence.

Keywords: Software-as-a-Service; Service Composition; Composite Services; Mashup; Network Evolution; Scale-Free Network; Openness; Collective Intelligence; Software Industry; Software Platforms.

JEL Classification Numbers: D85, L14, L86, O31, O32, O33.

1. Introduction

Although the software-as-a-service (SaaS) concept, which allows users to run the software installed remotely via the Internet, emerged with commercial computing a long time ago, it has been in the downturn with the rise of personal computers. With the proliferation of cloud computing in recent years however, it moved again into the limelight in a variety of service areas ranging from office software (e.g., Google docs) to computing resources (e.g., Amazon S3).[1] ¹ Furthermore, based on the emergence of information-technology-related business models that motivate consumers to participate in innovation processes, software vendors started providing their SaaS services even with open interfaces. It allows interconnecting SaaS services of different vendors.

One type of a SaaS implementation is based on Web services, following the Service Oriented Architecture (SOA) concept. SOA defines how users can compose and reuse services through open interfaces.[2] [3] For example, Google makes available its global map service (Google Maps) through an open application programming interface (API). This way, users can get geographic data and combine it with their own information or other software services.² Therefore, the SOA concept together with the software vendors, their services, software users, and the platform represent an open innovation system. The SOA concept allows all users to participate in service innovation, i.e., in service innovation through “collective intelligence”. [4] [5]. Users’ participation can be even further stimulated through the provisioning of marketplaces (e.g., mashape) and API management platforms (e.g., mashery).[6] [7]

Collective intelligence is defined as “the capacity of human collectives to engage in intellectual cooperation in order to create, innovate and invent” [5] voluntarily for economic return, fame, or self-contentment, and it serves as the key to open innovation.[8] The collective intelligence approach allows reusing existing innovation resources, which resource owners developed but might not use anymore. This approach works with no or low payments.[9] With the help of collective intelligence, innovation resources can be captured that are hard to commercialize due to a low return on investment or high costs. Prior research already showed that collective intelligence in the open innovation platform leads to the success of a platform leader.[10]

In the context of SaaS, collective intelligence is the underlying mechanism for the cooperation between the users of the SaaS innovation system, i.e., for their continuous reuse of existing software services for their service innovations. Therefore, extending the definition of collective intelligence,[8] we define a successfully working collective intelligence system to be a system that is continuously adapted by its users to meet their needs. The evolution of this software-as-a-service (SaaS) innovation system and the behavior of SaaS users within this system are still unknown. It is unclear how the SaaS innovation system evolves over time through collective intelligence. Existing work only analyzed the SaaS service network at a specific point in time so far.[14] [11] [12] [13] [17] [18] [15] These analyses include descriptive analyses, complex network analyses, and social network analyses. In this paper, we investigate research questions that are related to the changes of the results of these analyses over time. This will enable us to evaluate whether certain properties are invariable and unique properties of the network. In detail, we examine whether the SaaS network shows over time the scale-free network property like usual complex networks, in which a few hubs lead the innovation? We also investigate, using a new social networking measure, whether SaaS providers open their SaaS services to other SaaS service providers as the open innovation paradigm says and whether the openness changes over time?

To answer these questions, we investigate the structure and evolution of the SaaS innovation system. In detail, we analyze the topology of a SaaS network consisting of nodes, which represent SaaS services with open APIs, and links, which represent the composition of two SaaS services that are at the end of a link.[14] The SaaS network grows as new SaaS services enter the network and new SaaS services use existing SaaS services.

The SaaS network that is investigated in this paper is based on empirical data, collected from

¹Google docs is an online office service (www.google.com/google-d-s/b1.html), and Amazon S3 is an Internet storage service (aws.amazon.com/s3)

²The API information of Google Maps is introduced in developers.google.com/maps

the Web site www.programmableweb.com that lists information about SaaS services with open API and composite services (called mashups). Using this data set, we analyze the structure of the SaaS network with respect to the node degree. In particular, we analyze the cumulative degree distribution and the number of services, whose node degree is larger than a threshold degree. Besides, we also measure the enhanced version of the Krackhardt and Stern’s E-I index, comparing the number of external links (i.e., the links between nodes involved in different subgroups) with the number of internal links (i.e., the links between nodes involved in the same subgroup).[16] A subgroup represents a group of services that are owned by the same provider. This methodology is a substantial enhancement to the one used by Kim et al.[17] [18]

The analysis results suggest three novel findings. First, the topology of the SaaS network resembles a scale-free network but the degree distribution has a slight concavity, which was not observed in prior research.[14] [13] Second, the SaaS network does not show full openness, although prior research on open innovation through “collective intelligence” states differently. Prior research bases its findings only on the existing interoperability of technologies used (e.g., RSS and XML).[15] [4] Finally, the network topology characteristics are invariable over time except for the topology fluctuation at the early stage.

These findings have both pragmatic and academic implications. From a pragmatic perspective, the findings show the effect of collective intelligence on the open SaaS innovation system. The findings (i.e., the scale-free topology of the SaaS network and the reduced openness) suggest that collective intelligence’s re-use of SaaS services is different from the expectation based on technical interoperability. Some SaaS services are very frequently reused to create composite services while a majority of SaaS services are not. In addition to this, a SaaS service is likely to be connected with the SaaS service possessed by the same company. From an academic perspective, therefore, the three findings suggest further studies about the factors causing the deviation from the design of platform and further studies about the effect of network structure on innovation performance. The studies should target a system design that is beneficial to all stakeholders.

The remainder of this paper is organized as follows. In the next section, we introduce SaaS services, prior research on innovation capacity of a SaaS system through collective intelligence, and the impact of network structure on innovation. In section 3, we describe how to form the SaaS network with the data gathered and how to measure and analyze the network structure. In section 4, we present the analysis results. In section 5, we conclude the paper with a discussion on the implications of our research on innovation from an academic and a pragmatic perspective.

2. Conceptual Background

2.1. Mashing up SaaS services with Open APIs

Software-as-a-Service concept allows customers to run “software remotely, via the Internet, using the service provider’s programs and computer infrastructure.[1] The most popular SaaS providers are Salesforce.com (which offers customer relationship management services) and Google (which offers email, calendar, office applications).[1] SaaS concept arose with time sharing approaches for computing (e.g., GE Timeshare Inc.) in the mid of 1960. After the boom of personal computers (PCs) in 1980s and the emergence of the Internet with application service providers (ASP) in 1990s, SaaS become popular over the last decade in the context of Cloud computing. Cloud computing provides computing resources on demand, eliminates the “up-front commitment by users”, and charges based on usage.[19] In an even broader sense, Cloud computing is described as an industry platform, in which companies open up the use of their technology to attract users or developers.[20]

As the SaaS concept is considered a business model from the perspective of resource management that an enterprise outsources, Service Oriented Architecture (SOA) is the concept of computing resource management from an architectural perspective of SaaS providers. SOA is defined as “a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains,” which entails two tasks, i.e., “establishing a service infrastructure” of a SaaS provider, and creating “composite services” for SaaS users through an

flexible “execution environment” and open interfaces.[3] This architecture emerged as a response to the demand for integrating computing resources across organizational boundaries, meeting the need to quickly and inexpensively adopt to rapidly changing market conditions.[21]

Figure 1. Example of a composite service that is mashed up from several SaaS services with open APIs.

A composite service is created by adding a unique value to an existing SaaS service or a combination of several SaaS services. This composite service is also called “mashup”.[22] An example of composite service is Weather Bonk, which provides information about current and future weather on a map (Fig. 1).³ It obtains weather information through open API from third parties, i.e., the NOAA Weather Service and the WeatherBug Service, and adds its own Webcam photo sharing service.⁴ In addition to this, Weather Bonk marks the information on maps of existing mapping services such as Google Maps. It also uses some functions from other SaaS services: geographical location of IP addresses from hostip.info and geographical location of postal addresses from Yahoo Geocoding.⁵

2.2. Innovation Capacity of SaaS Systems through Collective Intelligence

High quality and high quantity of innovation emerges in an environment, in which agents can exchange freely resources beyond the boundaries of formal organizations.[8] [10] For example, it is well-known that the innovation performance in Silicon Valley is one of the highest in the world, since knowledge freely flows between R&D organizations and start-up companies due to

³Weather Bonk is at www.weatherbonk.com

⁴The information of the NOAA Weather Service API is given at graphical.weather.gov/xml and the information of WeatherBug Service at weather.weatherbug.com/desktop-weather-api.html

⁵The information of hostip.info API can be found at www.hostip.info/use.html and the information of Yahoo Geocoding at developer.yahoo.com/maps/rest/V1/geocode.html

high mobility of human resources.[23] Chesbrough discussed in 2003 this innovation pattern, and defined innovation, which is based on knowledge sharing between agents, as “Open Innovation”.[8] This concept of open innovation is different from the old way of innovation, in which innovation works through vertical integration of research, development, and marketing within enterprises. Open innovation focuses on resource sharing and collaboration, even with its competitors,[24] to form an innovation ecosystem, in which the individual pursuit of each agent enhances the capability of the whole system.[10] In this innovation ecosystem, each agent utilizes the other agents as collective intelligence for its innovation.

However, the concept of open innovation does not mean that companies should open the access to all their resources they have produced.[10] [25] For example, some open source developers for embedded Linux code reveal a part of their code, in order to attract potential customers, while the code with more functionality, which helps the developers be competitive, is not published but sold to the customers.[26] In this system, the company, which opens access to part of their technology while keeping the access to its core technology, gains profit from an increased market size as the service users and even its competitors utilize the free resources to develop complementary technologies to its core technology.[10] Therefore, it can be stated that a business model, following open innovation, is separating its “subsidy side” from its “money side”.[27] It opens resources for free in the subsidy side, fertilizing the subsidy side and benefiting from the interaction between the two sides.[28]

An open innovation system motivates service users, customers, and even competitors, to act intensively on the subsidy side. It relinquishes the power to users and shares the benefit with them.[29] In this situation, users participate as collective intelligence in the innovation. With collective intelligence, innovation is achieved at low cost for the enterprise.[9] “Collective intelligence” is defined in a variety of perspectives, from “human collection” for “intellectual cooperation”,[5] via “human computer systems” for gathering a variety of knowledge,[30] to “swarm intelligence”,[31] and “crowd intelligence”.[32] Common to all definitions is that all point out the importance of the participation of service users and the effort of enterprises in motivating the participation. In our research, we use the term collective intelligence to specify the activity of users of SaaS services for developing new services through combining existing SaaS services with open APIs.

Figure 2. Provider-user value creation model for SaaS.

As users can participate in the innovation, the stakeholders, which have been traditionally either providers or users, need to be detailed in a SaaS environment (Fig. 2). SaaS providers can be grouped into SaaS providers offering its service with open APIs and into providers without offering open APIs. The latter group of SaaS providers deals with its service users only in a

traditional way, only provisioning services unidirectionally.[33] If the SaaS provider offers open APIs to allow access to its technology, SaaS users are able to shift from a traditional consumer to a developer, who can provide new services and consume services. The business model of SaaS services varies over SaaS providers and service categories. For example, Google provides developers with free access to their map service API for testing, gives noncommercial applications free access but with a cap on the number of requests, and charges commercial users for access to their API with higher performance than the free API.[34] On the other hand, the price of Amazon S3 is calculated on the basis of the amount of storage per month that users actually used.[35]

The developers can find APIs they need on marketplaces (e.g., mashape) and be supported by API management platforms (e.g., mashery and apigee).[6] [7] [36] These developers provide other users with new services, which are created through the addition of new value to an existing SaaS service with open API or a combination of existing SaaS services with open APIs. The motivation of developers to participate in the innovation varies, ranging from enjoying the development and gaining fame, to earning money.[9] [31] If the goal of a developer is gaining financial benefit, the developer could share the revenue earned through its new service with the providers of those SaaS services that are the basis of the new service. Sharing the profit with commercial developers, who utilize the SaaS services of providers, is a possible revenue model for SaaS service provider.[27] Therefore, the role of developers has become identical to that of SaaS service providers. In summary, the SaaS value chain does not only provide new services but also attracts users to become developers and even SaaS providers (Fig. 2).

2.3. Network Analysis

Network analysis studies investigate the heterogeneity of networks in two ways. First, homogeneity of network topologies is studied using the degree distribution, or the probability distribution of the numbers of links of nodes. The topologies of networks can be classified into two groups according to the homogeneity of degrees. The first group comprises regular networks (Fig. 3 a), small world networks (Fig. 3 b) and random networks (Fig. 3 c). The difference between these three topologies is that small world networks have more randomness than regular networks, and random networks more than small world networks. The second group includes networks, in which a majority of nodes are connected with each other through few central nodes. Examples of these networks are a tree network, a scale-free network, and a star network (Fig. 3 d, e, and f). In a star network, all nodes are connected with only one node. In a tree network, all nodes have hierarchical connections with almost identical degree. A scale-free network has few nodes with high degree, connecting the other nodes with low degree.

Empirical studies of a variety of networks (e.g., WWW, open source codes, social networks, and academic collaborations) suggest that a substantial number of real networks are scale-free.[37] [38] [39] [40] [41] [42] Scale-free networks are networks, whose distribution function $P(k)$ of node degree k decays by a power function with an exponent γ , i.e., $P(k) \sim k^{-\gamma}$. The distribution of a scale-free network is very inhomogeneous (i.e., highly skewed) compared to the distribution of random networks and small world networks. It implies that a few hubs have a large number of links and the majority of nodes has only a small number of links.[37] [43] In general, the scale-free topology offers the network enhanced communication performance and robustness. A scale-free network is “smaller” than a small world network, i.e., two nodes within a scale-free network are connected in average through shorter paths than two nodes in small world networks.[44] In a scale-free network, information diffuses quickly if the information initiates at a hub.[45] [46] Furthermore, the inhomogeneity of node degree makes the network robust to accidental failures comparing to small world networks and random networks because the probability of failure in a hub is extremely low in a large network.[47] [48]

Second, heterogeneity of networks is also studied, considering the heterogeneity in node attributes. Agents in social networks are usually of different types (e.g., men and women in a romantic relationship, as well as ethnic races in a friendship of school children).[49] In this network, “homophily” (i.e., the principle that a node is attracted by nodes with similar attributes) could govern the relationships between any two nodes.[?]] This heterogeneity of node attributes

Figure 3. Topologies of a) a regular network, b) a small world network, c) a Poisson random network, d) a tree network, e) a scale-free network, f) and a star network.

and the principle of homophily is important to identify the characteristics of network structures. For example, the network of Fig. 4 consists of ten nodes, which have only one of two attributes (that is represented either as box or dot). Under the assumption of homogeneous node attribution, the network looks simply like a tree-like network or a scale-free network. Considering the node attributes, however, it is clear that the two groups are highly exclusive so that the nodes tend to form an hierarchical network in each group independently.

Prior research studied the network structure across subgroups (i.e., group of nodes with the same attribute) to understand its effect on innovation performance. Walter et al. surveyed previous literature on structural indicators (e.g., network density, structural hole, and centrality) with respect to inter-firm and intra-firm innovation.[50] They argued that a hub-client structure with a small number of core firms as hubs is most efficient for inter-firm innovation activities, while a structure with many redundant ties between departments (or groups) is an efficient structure for intra-firm innovation activities. To investigate the effect of openness of subgroups on the performance of an entire organization, Krackhardt and Stern developed the “E-I Index”.[16] The E-I Index is defined as the difference between the number of external and internal links divided by the total number of links, where an external link is a link between subgroups while an internal link is a link within a subgroup. The index is 1 if all members have external links only, and -1 if they have internal links only. Krackhardt and Stern applied the E-I Index to several friendship

Figure 4. Homophilic network represented a) without considering the attributes of agents, and b) considering the attributes of agents.

networks of organizations, and showed that organizations with more external links performed better than other organizations in a crisis.[16]

3. Network Definition, Measures, and Methodology

3.1. Definition of the SaaS Network

The SaaS network is defined as a set of nodes, representing SaaS services that opened up their APIs, and links between the nodes, indicating the existence of a composite service that uses the nodes being connected.[14] In other words, the creation of a composite service yields a complete graph of SaaS services that are used for the development of the composite service. For example, Weather Bonk in Fig. 1 generates 28 links among the eight SaaS services with open APIs (i.e., Google Maps, Microsoft Virtual Earth, WeatherBug, Google Adwords, hostip.info, Yahoo Geocoding, Yahoo Traffic, NASA). The links in SaaS networks are undirected and weighted. That is, a link does not show the information about the source and the destination of a relationship. The link shows the use frequency of the connection. For example, assuming another composite service is created using Google Maps and Microsoft Virtual Earth in addition to the SaaS network shown in Fig. 1, the weight of the link between Google Maps and Microsoft Virtual Earth is 2, while the other links still have a weight of 1.

One of the important characteristics of SaaS networks is that the node attributes are heterogeneous, and the nodes are categorized according to the node attributes. SaaS services are provided by enterprises, and some of the enterprises provide more than one SaaS service. Therefore, SaaS services can be grouped according to their ownership. For example, Google Maps and Google Checkout are classified into the group Google, while Yahoo Search and Yahoo Shopping are grouped into the group Yahoo. To define a connection between any two nodes i and j in a graph with node attributes l and m , let $a_{i,j}$ be the number of links between node i and j and $\Lambda_{i,j}^{l,m}$ be the dummy variable representing the homogeneity of node attribute. If nodes i and j belong to group l and m , respectively, the dummy variable $\Lambda_{i,j}^{l,m}$ is 1. If the nodes i and j belong to the same group, $\Lambda_{i,j}^{l,m}$ is -1 . This is expressed in the following equation:

$$\Lambda_{i,j}^{l,m} = \begin{cases} 1 & , l \neq m \\ -1 & , l = m \end{cases} \quad (1)$$

According to the definitions above, we classify the links in a network into three types: self, internal, and external links. A link between node i and j is external, if the two nodes belong to

different groups l and m ($a_{i,j \neq i} \neq 0$ and $\Lambda_{i,j}^{l,m} = 1$). A link is internal, if the two nodes are in the same group ($a_{i,j \neq i} \neq 0$ and $\Lambda_{i,j}^{l,m} = -1$). A link is self, if the nodes at the end of the link are identical ($a_{i,j=i} \neq 0$). The dummy variable for a self link is always -1 by definition ($\Lambda_{i,i}^{l,l} = -1$). Fig. 5 shows an example of external, internal, and self links in a SaaS network consisting of five nodes belonging to one of two groups. The weight of each link is marked with a number beside the link in Fig. 5. In the example, the link (γ, δ) is an external link with weight 3 ($a_{\gamma,\delta} = 3$ and $\Lambda_{\gamma,\delta}^{A,B} = 1$). The three links (α, β) , (β, γ) and (δ, ϵ) are internal links with weight 1, 2, and 2, respectively ($a_{\alpha,\beta} = 1$, $a_{\beta,\gamma} = 2$, $a_{\delta,\epsilon} = 2$, and $\Lambda_{\alpha,\beta}^{A,A} = \Lambda_{\beta,\gamma}^{A,A} = \Lambda_{\delta,\epsilon}^{B,B} = -1$). Nodes α and ϵ have self links with weights 1 and 3, respectively ($a_{\alpha,\alpha} = 1$ and $a_{\epsilon,\epsilon} = 3$).

Figure 5. Example of external, internal, and self links in a SaaS network (The number beside a link is the weight of the link).

Network analysis does not normally consider self links, as social networks are built up by the interaction among distinguished individuals. For example, within a friendship network, it is of interest to consider which person is friend with another person but it is meaningless to consider whether a person is a friend with himself. However, self links are significant in a SaaS network, since composite services cannot only be created with two or more existing SaaS services but also with just one existing SaaS service. The creation of a composite service with only one SaaS service generates a self link while the creation among two or more than two SaaS services yields external and internal links.

3.2. Network Measure: Degree Distribution

We analyze the degree distribution of our SaaS network to analyze the heterogeneity of the network topology. *Degree*, k_i , of a node i means in network analysis the number of links of node i , i.e., $k_i = \sum_j a_{i,j}$. [51] This indicator measures how central the node is in the network, if we call a node with higher degree more central. The degree distribution shows the distribution probability of each node degree. In our example network of Fig. 5, the degrees of the nodes are 2, 3, 5, 5, and 5 (listed from left to right). If k represents a value of a node degree and $P(k)$ the distribution function of the degree, the degree distribution of our example network is $P(2) = 1$, $P(3) = 1$, $P(5) = 3$, and $P(x) = 0$, where x is a natural number but $x \neq 1, 3, 5$. The degree distribution is used to determine the characteristic value of degrees and to measure how homogeneously links are allocated. Many empirical studies in the last decade showed that the degree distribution of real networks follow a power function. [37] [38] [39] [40] [41] [42]

As the low frequency of high node degree values fluctuates largely due to noise in empirical data, in this study, we measure the cumulative degree distribution $P(k_{>})$ instead of the degree distribution $P(k)$ according to Newman, [52] where the cumulative degree distribution is defined as:

$$P(k_{>}) = \int_k^{\infty} P(k) dk \quad (2)$$

A power function of the degree distribution, $P(k) \sim k^{-\gamma}$, generates a power function of the cumulative degree distribution, $P(k_{>}) \sim k^{-(\gamma-1)}$, since the integration of a power function is also a power function. Therefore, the cumulative degree distribution can be used to determine the fitting of node degrees to a power function without noise effect and without loss of generality. It describes the number of nodes $P(k_{>})$ whose degree is larger than a certain degree k .

The power law is tested with an ordinary linear regression of two empirically measured variables, i.e., degree and frequency, to a linear function in log-log scales. We statistically test whether the cumulative degree distribution is fitted to a linear function in log-log scale, in order to test whether the empirical data shows power decaying. The logarithm of the two variables transforms the function to a linear function, $\log P(k_{>}) \sim -(\gamma - 1) \log k$. In the linear regression, we check the slope, the explanation power (R^2) and the significance (i.e., the probability of a value in the Student's t-distribution).[53] The slope is the ratio of the cumulative frequency to the degree in the fitted linear function. The explanation power R^2 is the square of the correlation coefficient between the two variables, which is 1 if the two variables fit to a linear function well and 0 if they do not. The significance is the percentage representing how much the estimated parameter deviates from 0 with the normal standard t-distribution. If the estimated parameter is statistically significant, the significance value is 0. The significance value is 1, if the parameter is not significant at all.

3.3. Network Measure: Enhanced E-I-S Index

We also analyze the openness of our SaaS network with the enhanced Krackhardt and Stern's E-I Index. This extension addresses two limitations that occur if the Krackhardt and Stern's E-I Index is applied to our SaaS network. First, binary link weight, as used by Krackhardt and Stern's E-I Index, only shows the existence of relationships but do not represent the strength of ties between nodes. Therefore, the Krackhardt and Stern's E-I Index cannot consider multiple links between nodes. However, since the strength of a link in the SaaS network expresses the importance of the link or the innovation activity, the number of links between any two SaaS services should not be missed in the openness analysis of our SaaS network. Second, the original E-I Index identifies only internal and external links, so it does not represent the composite services which have been developed based on one single SaaS service. Therefore, we analyze the openness of the SaaS network with the Enhanced E-I-S Index, which is defined as:

$$\text{EIS}_r = (E - I - S) / (E + I + S) \quad (3)$$

where E , I and S are the number of external, internal, and self links in the SaaS network, respectively. Based on Equation (1), Equation (3) can be expressed as $\text{EIS}_r = \sum_{i,j \geq i} a_{i,j} \cdot \Lambda_{i,j}^{l,m} / \sum_{i,j \geq i} a_{i,j}$.

To distinguish the effects of the SaaS network structure on the Enhanced E-I-S Index, we introduce two more indexes, which are similar to the Enhanced E-I-S Index. One of the indexes considers the network size (i.e., the number of nodes) and the group structure by determining the maximum possible number of dichotomous external (internal, and self) links that a network can generate at most. For example, the network in Fig. 5 has 5 nodes, of which 3 nodes belong to subgroup 1 and 2 nodes to subgroup 2. Therefore, the network can at most generate 6 external dichotomous links, 4 internal dichotomous links, and 5 self-dichotomous links. By using the maximum possible number of external links (E^*), internal links (I^*), and self-links (S^*) of the dichotomous network, we define the Enhanced E*-I*-S* Index, EIS_g , as:

$$\text{EIS}_g = (E^* - I^* - S^*) / (E^* + I^* + S^*) \quad (4)$$

The result of EIS_g indicates the openness of a network that the group structure (i.e., the distribution of group sizes) allows. Therefore, as the maximum possible number of links depends on the distribution of the group sizes, we name this index also *Group Structure Index*. Considering our example of Fig. 5, we get $\text{EIS}_g = (6 - 4 - 5) / (6 + 4 + 5) = -0.2$.

The other index considers the normalized numbers of links, in order to exclude the effect of the group structure. The normalized number of external (internal, and self) links, or e (i and s) is defined as the ratio of the number of external (internal, and self) links and the maximum possible number of external (internal and self) links. For example, since the network shown in Fig. 5 has 3 external links, 5 internal links and 4 self-links, and since it can hold at most 6 external links, 4 internal links and 5 self-links, the normalized number of external (internal, and self) links is 0.5

(1.25, and 0.8). By applying the normalized numbers of external, internal, and self-links (e , i and s), we can define the Enhanced e-i-s Index, EIS_a , as:

$$EIS_a = (e - i - s)/(e + i + s) \quad (5)$$

Since the effect of the group structure is neutralized in this index, the result of EIS_a represents the openness of a network without the group structure effect. As a normalized number of links represent the average numbers of links of agents in the network, we also call this index *Agent Behavior Index*. In the example of Fig. 5, the Agent Behavior Index is calculated as $EIS_a = (0.5 - 1.25 - 0.8)/(0.5 + 1.25 + 0.8) = -0.6078$.

4. Analysis Results

4.1. Descriptive Statistics

Data has been gathered from the Web site www.programmableweb.com, which lists the information of stand-alone SaaS services and composite services (called APIs and mashups in the terminology of the Web site, respectively), the launch date of the services, and a brief description of the SaaS services. The version update of SaaS services has not been considered in our analysis, in order to focus on the network evolution after a node's first entrance into the network.

The first entry dates back to June 2005. The first composite service was added on September 14, 2005. We surveyed the information of SaaS services registered until September 30, 2012. Table 1 summarizes the numbers of SaaS services that were registered, the number of SaaS services that were used for creating composite services, the number of composite services, and the number of composite services that offered open APIs. Between June 2005 and September 2012, 7427 SaaS services have been registered, among which 1153 SaaS services were utilized to create composite services, while the remaining services were not used during the study period. That is, the number of SaaS services actually used for innovation is only a seventh of SaaS services provided with their open APIs. Besides, 6780 composite services have been registered between September 2005 and September 2012, among which only 124 composite services also offered open APIs.

SaaS services registered	SaaS services used in composite services	composite SaaS services	composite SaaS services offering open APIs
7427	1153	6780	124

The size of this SaaS network is the result of gradual growth from its initiation in September 2005. Fig. 6 shows the cumulative number of SaaS services and the cumulative number of composite services added over time. The number of SaaS services added per month increases exponentially. Between September 2010 and September 2012, about 213 SaaS services were added per month in average, while the average number of registered SaaS services per month is about 33 between June 2005 and August 2010. This implies that SaaS providers see the opportunity in the SaaS environment. However, the cumulative number of SaaS services used to create composite services increases only linearly. These results suggest that the motivation of SaaS providers is different from that of composite service developers. It seems that the innovation activity to build composite services lags behind the activity of building SaaS services.

In the remainder of this section, the SaaS services, which have been used to create composite services at least once, are used to analyze the network structure at each month. The SaaS services, which have not been used to create composite services are considered to be isolated. Furthermore, we assume for simplicity of our analysis that a SaaS service does not disappear once it enters the SaaS network.

The results above show an actual trend of SaaS innovation: Not all shared services are used for open innovation. According to Table 1, a lot of SaaS providers continuously share their SaaS services but only a seventh SaaS service among all the SaaS services registered during the study period were used for new composite services. Moreover, the rapid increase of the number of SaaS services does not lead to the soaring number of composite services as shown in Fig. 6. These results

Figure 6. Cumulative numbers of SaaS services registered and composite services developed during the time period September 2005 to September 2012.

are notable in open innovation theory. One of the important characteristics of open innovation, as described in the theory, is the reuse of existing services, which the providers allow to be used, drives creating new services,[8] But the theory does not address what happens if a service is shared. The results suggest that the trend of reuse of SaaS is inhomogeneous. There might be an underlying principle that determines which services are (frequently) reused. In other words, the results suggest that a SaaS provider should examine how to utilize collective intelligence for its shared services to be reused.

4.2. Trend of Scale-Free Property

Analyzing the degree distribution of the SaaS network (if the SaaS network is scale-free) shows the trend of the inhomogeneity of SaaS reuse. To examine the scale-free property of the SaaS network, we calculate the degrees for each node of the SaaS network on September 2012 (i.e., the latest network). Fig. 7 shows the cumulative degree distribution of the SaaS network in log-log scales (Equation (2)). The results indicate that the cumulative degree distribution looks like the distribution of an ordinary scale-free network. The regression results of the cumulative degree distribution on a linear function in log-log scale say that the distribution fits quite well to the linear curve with slope -0.9108. The explanation power of the regression is 0.9377 and the significance of the estimated slope is 0.0000. Since the differentiation of a power function is also a power function, $P(k) = P'(k_{>}) \sim dk^{-\gamma}/dt \sim k^{-(\gamma+1)}$, we can state that the degree distribution of the SaaS network decays by a power function with exponent -1.9377, which is similar to normal scale-free networks, whose exponents are between -2 and -3.[54]

The results also show another characteristic, namely that the cumulative degree distribution of the SaaS network is concave. The concavity appears in scientific collaboration networks too.[55] It is related with the fact that the number of links generated between existing nodes is higher than the number of links generated through nodes joining the network.[56] However, it is unclear whether the concavity is a normal disturbance of scale-free networks through exponential cut-off. Therefore, a detailed investigation is needed in the future.[57]

The evolutionary trend of the scale-free property of the SaaS network shows a fluctuation at the initial periods but stabilizes later on (December 2006). Fig. 8 illustrates the regression results of the degree distribution on a linear function in log-log scales over time. The slope of

Figure 7. Cumulative degree distribution of the SaaS network (k denotes the node degree).

the fitted line increases significantly from -0.9150 in September 2005 to -0.7592 in December 2005 and drops from -0.7624 in November 2006 to -0.8172 in December 2006. After that, the slope continues to decrease slightly to -0.9108 in September 2012. The explanation power remains stable around 0.95 from the beginning to November 2006, and drops to 0.8667 in December 2006. After that, the explanation power slightly increases and converges to 0.9377 in September 2012. We conjecture that the fluctuation in the initial period is due to the small size of the SaaS network. The significance is always 0.0000 during the study period except for September 2005, in which it is 0.0001. In conclusion, the power decaying degree distribution of the SaaS network is present from the beginning of the network.

Figure 8. Trend of the slope, explanation power, and significance of the regression of the cumulative degree distribution of the SaaS network over time.

The results suggest a trend in the inhomogeneity of SaaS reuse. In a scale-free network, few hubs connect a majority of links while most nodes are connected through few links. In case of the SaaS network, only few SaaS services are highly frequently reused. The most frequently reused services in our analysis are Google Maps, Twitter, YouTube, Flickr, and Facebook. They can be classified into three service categories: one belongs to the mapping service category, two to the social networking service category, and two to the image service category. Their common point is that they are the services provided by leading companies in SaaS, i.e. Google, Yahoo, Facebook, and Twitter. It means that the SaaS innovation is led by some platform leaders. It also means that SaaS innovation trend combines SaaS services of the mapping, social networking, and image service category during the study period. In addition to this, the topology of the SaaS network is consistent. The slope, significance, and explanation power of the degree distribution are almost invariant except for the initial time periods. It means that the network topology is independent of the change in the business environment. For example, although social networking services, Twitter and Facebook, started opening their APIs from 2007 at the mid of study period and became hubs by the end of the study period, the scale-free network structure has not been affected.

4.3. Trend of Openness

To analyze impact of ownership on the innovation system of the SaaS network, SaaS services are grouped into ownership groups. An ownership group is a set of SaaS services, whose ownership attributes are identical (i.e., the SaaS services belong to the same provider). The programmableweb site lists 63 companies, which provide two or more than two SaaS services with open APIs. 750 SaaS services are provided by these 63 companies. The remaining SaaS services are offered by companies that offer only one service. That is, each of these SaaS services belongs to a group consisting of only one SaaS service. There are 6677 groups, whose size is 1. The group size is defined as the number of members of the group.

Measuring the ownership group size distribution helps to understand the group structure of the SaaS network. Fig. 9 describes the cumulative distribution of group sizes in log-log scales. It shows that the cumulative distribution of group sizes fits well to a linear curve in log-log scale. According to the linear regression of the cumulative distribution of group size on a linear function, the slope of the curve is -1.41, and the significance of the estimated slope 0.0000 with 93 % of explanation power. The results mean that a small number of companies provide a lot of SaaS services while a majority of companies provide only a few. That is, the group size is heterogeneous. For example, only 8 groups including Google, Yahoo, and Amazon consists of more than 20 SaaS services.

To calculate the openness with respect to the ownership attribute, we measure the number of links for each type (i.e., external, internal, and self links) in the SaaS network for each SaaS service. Table 2 summarizes the results of our index calculation. The numbers of external, internal, and self links for the SaaS network of September 2012 are 20709, 2864, and 3516, respectively. According to the numbers of these links, the Enhanced E-I-S Index is 0.5290, which is quite high with respect to the fact that the range of the Enhanced E-I-S index is between -1.0000 and 1.0000. The group size distribution, as shown in Fig. 9, can yield a maximum possible number of external, internal, and self links of 55127978, 24924, and 7427, respectively. Therefore, the Group Structure Index is calculated to be 0.9988, where the index ranges from -1.0000 to 1.0000. This result shows that the SaaS network is organized such that new composite services are very likely to be created through the combination of the SaaS services belonging to different groups. In other words, the group structure of the SaaS network guarantees very high openness.

Enhanced E-I-S Index	Group Structure Index	Agent Behavior Index
0.5290	0.9988	-0.9987

However, looking at the Agent Behavior Index, the openness is contrarily to the other indexes. The normalized numbers of external, internal, and self links are 0.0004, 0.1149, and 0.4734, respectively. Therefore, the Agent Behavior Index is -0.9987. This value is very small, compared to the range of the Agent Behavior Index which is -1.0000 to 1.0000. The results imply that a

Figure 9. Cumulative distribution of group sizes of the SaaS network (s denotes the group size).

SaaS service with open APIs is very likely to be connected with other SaaS services, if the effect of group structure is eliminated, which suggests that users are captivated within a company. These results comply with the theory that agents are more likely to make relationships with colleagues of the same group. In this case, they share a common culture and a strong communication channel.[16] Similarly, we can state that a user, who is familiar with the interface of the platform provided by a specific company (e.g., Google App Engine and Amazon Web Services), may tend to use the SaaS services of this company. The use of the SaaS services of the same company is easier to learn (i.e., less costly). The low openness is due to the captivation of users in each group despite the positive group structure (i.e., high Group Structure Index).

Figure 10. Trend of the Enhanced E-I-S Index (EIS_r), the Group Structure Index (EIS_g), and the Agent Behavior Index (EIS_a) of the SaaS network.

In order to illustrate the trend of openness in the SaaS network, we calculate the E-I-S Index, the Group Structure Index, and the Agent Behavior Index over time. Fig. 10 summarizes the results of our index calculations. The Enhanced E-I-S Index fluctuates considerably in the initial period, from the launch of the SaaS network until November 2006. The value of the Enhanced E-I-S Index starts around 0.0000 in September 2005 but drops from 0.1173 in October 2005 to -0.1337 in February 2006. Then, the index value jumps again to 0.0181 in March 2006 and slightly increases until October 2006. It jumps again from 0.1272 in November 2006 to 0.4898 in December 2006. After that, the Enhanced E-I-S Index remains stable between 0.4011 and 0.5290. The Group Structure Index and the Agent Behavior Index depict more stable results. The value of Group Structure Index starts from 0.8503 in September 2005, which is very high compared to its range $(-1, 1)$, and converges to 0.9988 in September 2012. The value of the Agent Behavior Index starts from a low value (-0.8895) compared to its range $(-1, 1)$ in September 2005, and converges to -0.9987 in September 2012.

Consequently, the results show that the SaaS network is not as open as expected according to open innovation theory. The Agent Behavior Index is almost -1 according to Table 2, which means it is almost closed. That is, the services are not as freely combined as they could be without the effect of ownership.

SaaS innovation is open innovation through collective intelligence. That is, users combine existing services to develop new services if SaaS providers allow users to access the services.[4] [8] However, the innovation theory does not state how frequently existing services are combined across company boundaries. Our results suggest that company ownership of SaaS services has an impact on the openness. In detail, the answer to our research question on openness of SaaS services is that simply opening APIs of SaaS services just does not lead to users reusing those services. Actually, a majority of composite services have been developed by slight modification of only one service (e.g. Google Maps). Moreover, this trend is consistent during the study period, as shown in Fig. 10.

5. Discussion and Conclusion

For understanding innovation in SaaS networks, we have studied the structural evolution of a SaaS network, focusing on the heterogeneity of network topology and the heterogeneity of node attributes. The heterogeneity of the network topology has been analyzed by using the measure degree distribution. The effect of the heterogeneity of node attributes on the network topology was investigated by using three openness indexes, i.e., the extended Krackhard-Stern Index EIS_r , the Group Structure Index EIS_g , and the Agent Behavior Index EIS_a . As SaaS services belong to different providers (who are the actual agents in the SaaS network), we also investigated the impact of ownership on innovation.

The results can be summarized as follows: First, the SaaS network grows gradually through continuous emergence of new SaaS services. However, only a small part of the existing SaaS services is utilized to create composite services. Second, the SaaS network shows a scale-free property but the cumulative degree distribution is concave in the log-log scales. Common scale-free networks have an exact linear curve in log-log scales.[37] [38] [39] [40] [41] [42] Finally, the SaaS network is impacted by the ownership of the SaaS service. The openness analysis shows that the SaaS network is not open. The agent behavior index reveals that the few groups with more than one service are not as open as expected from the interoperability of the technology used.

From a theoretical perspective, our results suggest that the SaaS network grows while keeping its properties, especially with respect to degree distribution and openness. The results show that the scale-free topology and the level of openness across ownership groups are stable except for the fluctuation in the initial time periods. Therefore, we conclude that the topology and the openness are invariable, unique properties of the SaaS network studied. Prior research on network analysis proposed that scale-free networks are generated by a simple rule (e.g., the preferential attachment rule or the random group formation model). [58] [59] Therefore, it can be suggested that the SaaS network could also evolve into a scale-free network that is not fully open. This is supported by the result that the SaaS network evolution also depends on the openness across ownership groups.

It affects the structure of the network, as shown in previous literature.[56]

Our results have interesting implications in the study of information systems. One of the key points of the SaaS environment is that the innovation (i.e., creation of new SaaS services) works with vigorous reuse of existing SaaS services through collective intelligence. However, our analysis results show that the reuse of SaaS services is limited to a small part of existing SaaS services. In detail, it is limited to a seventh of all SaaS services registered during the study period. This result suggests that the SaaS services with open APIs are not as much re-used as expected based on the technical interoperability. Moreover, the SaaS network is led by a few SaaS services (i.e., Google Maps, YouTube, and Flickr) only. The detailed analysis of the cumulative degree distribution shows that these few SaaS services have a large number of links while the majority of SaaS services have only few links. For example, the degree of Google Maps, YouTube and Flickr are 2625, 2015, and 1940, respectively, while 229 SaaS services are connected with only one or two SaaS services. This might be caused by the fact that the SaaS network might not be completely open over ownership subgroups. Therefore, we can state the following: The underlying innovation mechanism in the SaaS environment, which is the sharing of technology developed by one enterprise with other enterprises, is beneficial.[8] [10] [24] However, our openness analysis results suggest that the SaaS services are not shared across company boundaries. These results could be due to the effort of companies in attracting composite service developers and captivate them on their platforms through the provisioning of easy-to-use development environments.

This paper orients the interest of information systems studies to the structural evolution of the SaaS environment in the perspective of network science. However, our work has limitations in the strictness of the analysis, requiring further studies. First, future research should extend the analysis with more network metrics (e.g., PageRank,[60]). The node degree and the E-I-S index describe only a fraction of the topology. Second, future research should test through statistical method whether the SaaS network topology is strictly stable and whether the power decay of the cumulative degree distribution is concave. Third, the description of the structural evolution should be explained theoretically. Future research should derive the exponentially decaying degree distribution from mathematical assumptions and should also analyze the effect of openness on the network evolution. Fourth, future research should track the movement of the network positions of nodes on the invariant network topology, in order to examine whether the network position is stable and, if it is not stable, examine the trend of the node's network position. Finally, the results of the empirical and theoretical analysis of the network topology and the node position are expected to be related with the innovation performance of each agent and the entire system. Overall, our results are expected to motivate further studies on the evolution of innovation systems in the software industry that is driven by collective intelligence.

Acknowledgements

This work has partly been funded by the Korea Institute for Advancement of Technology (KIAT) within the ITEA 2 Project 10014 EASI-CLOUDS and the BK+ program of the National Research Foundation (NRF) of Korea.

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