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Uncovering the Role of External APIs in Driving Dynamic Ecosystem Growth*

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Ⅰ. Introduction

Contemporary platform companies, such as Google and Apple, have recognized the importance of building digital ecosystems to ensure dynamic growth (Kang et al. 2022; Parker et al., 2017). These companies have taken a proactive approach to creating digital ecosystems that support the development of products. A digital ecosystem is comprised of a focal platform, complementary products (e.g., applications), design resources (e.g.,

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Application Programming Interfaces [APIs]), and actors, including the platform owner, consumers (i.e., users), and third-party developers (i.e., developers) (Gawer and Cusumano, 2014; Lee, 2023; Kim et al., 2022: Tiwana, 2018). The platform owner prioritizes increasing product variety created by developers to improve the functionality of a platform (Boudreau, 2012). Greater product variety is achievable by attracting many developers to the digital ecosystem, driving increased user interest and adoption and vice versa (Kim and Kim, 2021: Parker and Van Alstyne, 2005). In particular, leveraging diverse APIs as design resources empowers developers to create multiple applications (Tiwana, 2018). Existing studies on digital innovation have emphasized the impact of APIs on the dynamic growth of a digital ecosystem as new APIs are introduced and used in combination with existing APIs (Yoo et al., 2010). However, a thorough understanding of how specific APIs play crucial roles in triggering the evolution of a digital ecosystem is still lacking; other APIs that may have minor influences still need to be enhanced.

External APIs, which are APIs introduced from outside a digital ecosystem, have the potential to continuously enhance product variety in a digital ecosystem (Xue et al., 2019). API designers aims to integrate their xternal APIs as core APIs that will be frequently used with others in ecosystems in order to attract a substantial user base for their service offerings in diverse ecosystems. The use of the Google Maps API in the Airbnb app for Apple iOS exemplifies how a digital ecosystem can offer product variety by leveraging external APIs to enhance its functionality. Instead of building everything from scratch, developers can leverage the functional usefulness of various external APIs to create new products integrated with other services and platforms (Baldwin et al., 2006; Haefliger et al., 2008). This leads to faster development, reduced costs, and improved user experience. However, while existing studies on digital innovation have primarily focused on the role of platform owners and developers in product variety, the impact of external APIs as primary design resources has yet to be adequately explored as a critical design factor (Parker et al., 2017). By examining the effect of external APIs integrated into a digital ecosystem, this study aims to bridge the knowledge gap and expand the understanding of the contemporary development pattern of products. Hence, understanding the role of external APIs in product development is crucial for creating modern and scalable products that meet the diverse functional needs of users and take advantage of the full potential of existing APIs or services (Tiwana et al., 2010). This approach enables developers to build innovative products that integrate with other systems and platforms, providing users with a more immersive and personalized experience.

This study adopts an evolutionary network biology perspective to investigate how external APIs impact increasing product variety continuously, ultimately leading to dynamic growth in a digital ecosystem (Kauffman, 1993; Levinthal and Marino, 2015). Using the evolutionary network biology perspective, this study aims to identify the circumstances under which external APIs trigger structural changes in a digital ecosystem. The findings will contribute to understanding how the use of external APIs enhances product variety in a digital ecosystem. The primary research question is as follows:

RQ: How do external APIs drive the dynamic growth of a digital ecosystem?

This study utilizes a multi-step approach. First, this study analyzes the growth of the digital ecosystem over time by constructing a network of products and measuring their network topology. This enables us to identify functionally similar product groups based on their uses of APIs over time. Second, this study captures API features to examine how API user changes influence the structure of the ecosystem. By investigating the relationship between the two networks over time, we aim to identify the network and non-network properties of APIs that drive the evolution of a digital ecosystem. Third, this study adopts a survival model to statistically understand the effect of APIs on the growth of a digital ecosystem. Through this approach, this study aims to provide valuable insights into the growth pattern of the digital ecosystem.

Data for this study come from the WordPress ecosystem, the world's largest blog ecosystem. WordPress offers a wide range of functions through numerous products (i.e., plug-ins). Developers utilize the various APIs WordPress offers as well as other platform systems such as Google or Facebook to create new plug-ins. The analysis in the study encompasses the source data from all plug-ins from the inception of WordPress until December 2014.

The structure of this paper is organized as follows. This paper begins by reviewing the existing literature on digital ecosystems. Next, we delve into the network dynamics that are driven by the introduction of new APIs. Then, we describe the empirical model and the results of our analysis. Finally, we discuss the theoretical and methodological implications of this study.

Ⅱ. Literature Review

2.1 Nature of APIs in a Digital Ecosystem

A digital ecosystem is established to enhance a platform's overall functionality by leveraging developers' expertise (Tiwana, 2018). It is built upon a platform consisting of design resources, such as APIs, that can seamlessly integrate and facilitate the development of new products (Burford et al., 2021). To ensure system consistency and maintain high quality standards, developers must follow design rules when creating and offering products that utilize APIs in a digital ecosystem (Cenamor and Frishammar, 2021; Jacobides et al., 2018). By following these rules, a digital ecosystem can provide a wide range of products that efficiently enhance the platform's functionality beyond what the platform owner can achieve alone (Ganco et al., 2020).

Understanding the generative nature of APIs is crucial for comprehending the growing product variety in a digital ecosystem. This generative nature enables spontaneous and uncoordinated changes in structure and behavior beyond intended design expectations (Zittrain, 2006). The core functionality of APIs is openly accessible, allowing developers to utilize them in innovative ways that foster greater design flexibility and creativity within the ecosystem (Boudreau and Lakhani, 2015; Ondrus et al., 2015). Additionally, the generative nature relies on a continually evolving and diverse set of APIs provided by a wide range of API providers and utilized by developers (Yoo et al., 2010). Thus, the generative nature of APIs does not restrict developers to a narrow set of product designs but rather enables the use of a wide range of APIs to create products that exceed original functional expectations, leading to an ever-expanding array of design possibilities and fostering innovation within the ecosystem. As a result, the generative nature of APIs leads to dynamic, emergent, and unbounded functional features of products within a digital ecosystem.

The generative nature of APIs shapes the structural pattern of growth in a digital ecosystem (Ganco et al., 2020; Henfridsson et al., 2018). Successful digital ecosystems, such as Apple's iOS and Google's Android, rely heavily on innovative ideas from diverse developers who create new products based on their interests. As a digital ecosystem grows, a wider variety of products may emerge, further enriching the platform and providing users with an extensive selection of options (Parker et al., 2017). The use of APIs by developers is not random but can be seen as a deliberate search process over the landscape of a digital ecosystem (Ethiraj and Levinthal, 2004). Consequently, the growth of digital ecosystems results from developers' intentional selection of new and existing APIs. A structural pattern emerges from products that are connected based on the continual use of similar APIs. Therefore, this study conceptualizes digital ecosystems as having an emergent structural pattern, with boundaries shaped by the increasing number of products built by various APIs.

2.2 Application of Evolutionary Network Biology to Digital Ecosystems

This study employs the evolutionary network biology perspective to identify the key drivers of dynamic growth in digital ecosystems. By applying the evolutionary biology network perspective to the domain of digital ecosystems and mapping out the feature of diverse API uses, this study seeks to gain insights into structural patterns and relationships that are difficult to capture through other approaches.

The evolutionary network biology perspective investigates how genetic changes influence the structure and function of complex biological networks composed of multiple cell types (Kauffman, 1993). The cell types perform different functions, which are primarily produced through non-linear and selective interactions among genes (Kitano, 2002). In addition, some combinations of genes are consistently used across a diverse set of cell functions, and these recurring patterns form clusters of functionally similar cells (Hawrylycz et al., 2012; Rajarajan et al., 2018). Gene interactions provide the structural backbone of both intra- and intercellular networks, ultimately resulting in the complexity of biological systems (Wagner et al., 2007). In a digital ecosystem, the network structure of products using APIs parallels biological networks. As genetic changes influence biological functions through gene interactions, APIs enable diverse products to integrate and interact interchangeably, forming complex digital ecosystems (Yoo et al., 2010). API combinations are consistently utilized to implement functions that provide a structural backbone, enhancing the complexity and functionality of the digital ecosystem (Um et al., 2023). To understand the underlying dynamics in a digital ecosystem, we adopt the two evolutionary biology perspectives.

First, this study adopts the macroscopic aspect of the evolutionary network biology perspective utilized by a hierarchical network structure to gain insight into the growth of a digital ecosystem (Ravasz et al., 2002). The hierarchical clustering approach effectively captures how different genes work together in complex generative processes, such as cell differentiation and morphogenesis (Bakken et al., 2021; Labont? et al., 2017). By analyzing the underlying dynamic, combinatorial, and generative patterns of genetic interactions using a hierarchical clustering network, we can gain insights into how common genotypes give rise to different phenotypes. This approach focuses on the typology of recurring patterns in a network (Zhang and Horvath, 2005). Notably, the topological overlap represents the hierarchical structure of a network and allows for the identification of clusters of frequently co-occurring gene interactions (Ravasz et al., 2002; Strogatz, 2001), which is beneficial for understanding the structure of large and complex networks and exploring the presence of recurring patterns of gene interactions in cells (Bakken et al., 2021; Hawrylycz et al., 2012; Rajarajan et al., 2018). Hence, by focusing on topological overlaps, existing studies have explained various complex biological networks, such as brain cells, without focusing on the role of individual genes. The topological overlaps explain how different cells can perform diverse functions within an organism, despite sharing the same instructions. Overall, the hierarchical clustering network provides a powerful tool for uncovering the complex interactions and patterns of gene regulation that drive the behavior and evolution of biological systems.

Second, this study takes the microscopic perspective of the evolutionary network biology perspective to examine the effect of external APIs on the growth of a digital ecosystem (Wagner and Altenberg, 1996). Specifically, this study focuses on the mechanisms of migration and mutation, which contribute to the continuous introduction of APIs and the functional variation of products, thereby increasing product variety (Baldwin and Clark, 2000). Migration refers to the interbreeding of API variations from external sources that leads to the selection of functional varieties of products. Introducing a diverse set of external APIs promotes increasing the number of products within and across clusters in an ecosystem. Mutation refers to the continuous changes within a cluster as new APIs migrate into it and generate functionally diverse products, leading to the emergence of new product types, or clusters (Lynch et al., 2006). Introducing new APIs enables the creation of products through the deletion, duplication, or substitution of subsets of existing API combinations (Fortuna et al., 2011). Therefore, the migration of new APIs can lead to the mutation of product functions and their clusters, ultimately promoting the product variety of a digital ecosystem.

2.3 The Impact of API Migration on the Structure of a Digital Ecosystem

This paper conceptualizes a digital ecosystem with a hierarchical network structure, based on the evolutionary network biology perspective. The ecosystem consists of two layers: the first comprises products, while the second consists of design resources, namely APIs (Um et al., 2023). For example, in a travel app ecosystem, various travel apps (products) form the first layer. The second layer consists of APIs such as Google Maps, weather information, and real-time traffic information. These APIs are used to create travel apps, which are then organized into hierarchical clusters based on their similar patterns of API uses. For example, apps that use Google Maps API for displaying maps and directions might form a cluster. As the ecosystem grows, new clusters emerge in the product layer, such as a new cluster of apps that integrate additional API functions such as augmented reality (AR) navigation or travel itineraries. This functional diversification and growth reflect the product variety of the ecosystem, representing how the use of new APIs can lead to the creation of new app varieties in a digital ecosystem.

Product variety, referring to the clusters of products sharing similar functional features (Boudreau, 2012), is facilitated by a diverse range of APIs, each with diverse extents of functional uniqueness and usefulness in products (Xue et al., 2019). APIs can be classified as internal or external based on whether they are created by the platform owner or external providers, respectively (Tiwana, 2015). For example, in a travel app ecosystem, internal APIs provided by the platform owner include APIs for system administration interfaces and basic product creation functions, such as user authentication or payment processing. Internal APIs are mainly used to integrate the travel apps ensuring seamless operation with the platform. On the other hand, external APIs, such as Google Maps API and social media integration APIs, originate from outside the ecosystem but offer valuable functions for travel app development. The Google Maps API, for example, is widely connected with other APIs such as social media APIs, due to its extensive use in displaying maps and facilitating connections with other social media apps (Xue et al., 2019). However, external APIs do not form the entire ecosystem's functional foundation. Instead, they enhance product variety within the clusters when combined with other external APIs or internal APIs, leading to within-cluster differentiation (Um et al., 2023). The combination of various external APIs is crucial to increase the app's functionality, enhancing the overall product variety within the ecosystem.

This study aims to investigate how external APIs affect changes in product variety by examining the product network. In the product network, each node represents a product, and an edge represents a connection between two products that share the same API(s). Products are grouped into clusters based on their similar uses of APIs, forming the hierarchical structure of a digital ecosystem (Burford et al., 2021; Ravasz et al., 2002). Hence, product variety is facilitated by the change of hierarchical structure, ultimately contributing to the growth of a digital ecosystem. When external APIs gain functional popularity among multiple products, they can change the hierarchical network structure and cause a cluster to split as the way products share APIs changes. When new external APIs are migrated into a digital ecosystem, their connections with other existing APIs grow differently. Some APIs frequently connect with a small number of APIs, while others interact with multiple APIs less frequently, resulting in a functional mutation of products. A functionally useful API can create diverse new connections with other APIs in various ways, changing the hierarchical structure based on the extent of different uses. Such changes can be a critical factor that triggers a structural change in the hierarchical structure of the product network, such as the emergence of a new cluster or variations in an existing product cluster. Therefore, understanding the impact of external APIs on the hierarchical structure of a digital ecosystem can provide valuable insights into how ecosystems evolve and how product variety can be promoted through the effective use of APIs.

In a digital ecosystem, the migration of external APIs can continuously mutate existing product functions, leading to ongoing product variety (Yoo et al., 2012). Hence, as the number of APIs increases, their connections can change the cluster structures in two distinct ways. First, if the connections of external APIs follow the existing pattern of API uses in a cluster, it results in within-cluster differentiation (Um et al., 2023). For instance, consider a travel app that uses the Google Maps API to offer functions such as displaying maps, directions, and nearby points of interest such as restaurant. When new external APIs are integrated, such as those for real-time traffic information or street view images, these enhance the existing functions of the travel app. Thus, the use of new APIs leads to within-cluster differentiation, where a new travel app now offers more refined and advanced mapping features, which improve the user experience and expand the functionalities of the existing product type.

Second, if the uses of external APIs represent a new pattern of API uses in products, it suggests the introduction of new functional types of products, or clusters, into the ecosystem (Um et al., 2023). For example, the combination of various APIs creates a real-estate application that goes beyond simple property listings to offer a comprehensive information for potential buyers. If the product type is successful and continues to grow, it can lead to the emergence of a new cluster within the digital ecosystem, characterized by multi-dimensional real estate information. Thus, the migration of external APIs, like those from Google Maps, from outside a digital ecosystem has significant implications for the evolution of digital ecosystems (Yoo et al., 2012). It can lead to create new product varieties and enhancing existing product functions. It can also lead to the emergence of new clusters of products, resulting in the emergence of new clusters. Therefore, understanding the impact of external APIs on the product variety dynamics can provide insights into how ecosystems evolve and how product variety can be fostered through the effective use of APIs.

Ⅲ. Hypotheses

External APIs are essential in digital ecosystems as they facilitate unexpected and innovative product creation (Yoo et al., 2010). Since the role of external APIs in ecosystems is flexible, they can be combined with various other APIs based on their functionality, leading to innovative API usage patterns (Um et al., 2023). For example, the Google Maps API is widely used in applications beyond its original mapping functions, such as combining with social media APIs to provide location-based social interactions within travel apps. The various combinations highlight the dynamic potential of external APIs.

External APIs represent a wide range of uses depending on their functional usefulness, ultimately changing the existing network structure (Um et al., 2023). In this section, we explore the functional usefulness of external APIs that impact changes in product design patterns, focusing on their connectivity and frequency of use with other APIs, to determine their functional importance in the digital ecosystem. APIs are connected with others, as developers utilize them to create products (Xue et al., 2019). As the functional usefulness of APIs increases, they become more connected with other APIs; therefore, connectivity refers to the number of APIs connected with a focal API (Newman, 2012). For example, the Google Maps API's high connectivity allows it to easily establish new connections with previously unconnected APIs, unlike APIs with fewer uses due to functional limitations. This high connectivity enables significant impacts on the use of other APIs, leading to the functional mutation of existing products and the creation of new product types. External APIs are essential in digital ecosystems for fostering innovative and open-ended product developments. Thus, connectivity affects their role in driving changes in API connection patterns, contributing to greater product variety. Therefore, we propose the following hypothesis:

> ***H1**: External APIs with high connectivity with other APIs are more likely to affect the increase of product variety in a digital ecosystem.*

External APIs are connected at varying frequencies, with some being more frequently used than others. Use frequency of APIs represents the number of frequent connections between APIs in products, representing the weights between two products in the product network (Newman, 2012). External APIs with high use frequency can diversify product types, reshaping the current connection pattern. External APIs that are frequently connected with others are likely to create their unique design pattern widely used in products within a cluster of products. For example, the Google Maps API, when frequently used in travel apps, can be combined with other high-frequency APIs such as weather forecasting APIs and booking APIs. This combination creates a unique design pattern widely used in travel apps, offering integrated services like location-based weather updates and booking capabilities directly on the map. As the extent of use frequency increases, APIs with high use frequencies are likely to form a distinctive design pattern and divide an existing single product type into multiple types, increasing the functional mutation of products in the existing cluster. Hence, external APIs with high use frequency are likely to generate functionally distinct products that form their own product types. These external APIs exhibit high use frequency within each cluster, indicating their increased influence on the structural changes of a digital ecosystem. Therefore, we propose our second hypothesis as follows:

> ***H2***: *External APIs with high use frequency with other APIs are more likely to affect the product variety in a digital ecosystem.*

This study also examines the two non-network features of external APIs in the following two hypotheses. External APIs offered by other platform providers offer a more comprehensive range of functionalities than internal APIs provided by a focal platform provider. When developing products, developers may need help accessing a broad range of useful information within a short period. However, after external APIs have been introduced to a digital ecosystem for a while, developers can observe how others are using these APIs and mimic their design, particularly if products using these APIs become popular among users (Haefliger et al., 2008). For example, consider the case of Google Maps API, which was introduced early in many digital ecosystems. Over time, developers have integrated Google Maps with various other APIs, such as weather APIs and booking APIs, to enhance their applications. The success and popularity of these uses have led to a widespread adoption of the Google Maps API in similar applications. Thus, older external APIs such as Google Maps, which have been exposed to a broader range of developers, represent increased use and combination due to their established utility and familiarity. Therefore, if new APIs do not offer unique functionality, older external APIs are more likely to be included in the APIs for newly created products (Ethiraj and Levinthal, 2004). This is because their greater exposure among developers increases their likelihood of being integrated into the existing ecosystem and utilized in the development of new products, particularly if other developers have demonstrated their functional usefulness. Thus, the age of an external API has a positive impact on its use and likelihood of being incorporated into newly emerged clusters within a digital ecosystem. Therefore, we propose our third hypothesis as follows:

> ***H3**: Older external APIs are more likely to affect the product variety in a digital ecosystem.*

There are no specific functional boundaries in a digital ecosystem, and external APIs from various platforms can contribute to the growth of a digital ecosystem (Yoo et al., 2010). However, the source of these APIs plays a crucial role in their uses. Some external APIs are offered by large and reputable firms, such as Google and Yahoo, while others come from smaller providers. Due to their prominent reputation and easy accessibility, developers are more likely to learn about and adopt APIs from these large firms, integrating them into the ecosystem and using them with other APIs. For example, Google's suite of APIs, including Google Maps, Google Calendar, and Google Drive, are widely adopted due to the company's reputation and the extensive documentation and support provided. These APIs are frequently integrated into various applications, contributing to the growth and complexity of the digital ecosystem. In contrast, APIs from smaller providers, such as a niche weather API service, may offer valuable functionalities but struggle to gain recognition and widespread adoption. In addition, the number of APIs in a digital ecosystem is growing exponentially, and online communities have limited time to share information about them. Consequently, even highly functionally useful APIs from smaller providers may have limited opportunities to contribute to the emergence of clusters within a digital ecosystem if they are not offered by large-scale providers that generate multiple APIs. Therefore, the size of the provider significantly influences the adoption and integration of external APIs in products within a digital ecosystem, particularly in the formation of new clusters. Therefore, we propose our fourth hypothesis as follows:

> ***H4**: External APIs offered by firms that produce a large number of APIs are more likely to affect the product variety in a digital ecosystem.*

Ⅳ. Analytical Approach

This paper presents two analytical approaches to investigate the structural growth of a digital ecosystem. First, a hierarchical clustering network approach is employed to measure changes in the product network as new external APIs are introduced. This method enables the identification of patterns of API uses in changing product variety and tracking changes in cluster structures over time and the examination of how external APIs interact with other APIs during product development. Second, the impact of external API migration on structural evolution is analyzed using a survival model. This approach assesses the likelihood of the functional mutation of products (i.e., within-cluster differentiation) by extracting API information from the API network and analyzing the connection patterns of APIs. Through this approach, we can identify which external APIs are more likely to become part of newly emerged clusters and how they contribute to changes in the underlying structure of the digital ecosystem.

Overall, the combination of these two analytical approaches provides a comprehensive understanding of the structural growth of a digital ecosystem. The findings of this study have significant implications for businesses operating in digital environments, as they highlight the importance of monitoring API uses and migration patterns to identify opportunities for innovation and growth.

4.1 Measuring the Structure of the Product Network

In defining the digital ecosystem, we consider it a single component network where each product is represented as a node and the similarity in functions between any two products forms an edge. These similarities arise from shared API uses. As the number of products increases, they are clustered based on similarities in API usage. While additional products are implemented, additional clusters emerge, each characterized by the patterns of shared API uses. The growth necessitates the further categorization of larger product groups into smaller sub-clusters to maintain a clear network structure. These smaller categories, nested within larger ones, are the sub-clusters. Importantly, in our context, functional variety is defined as product variety-the greater the number of sub-clusters in a functional category, the higher the product variety.

To capture the structural changes within this network structure, we employ a hierarchical clustering network approach (Zhang and Horvath, 2005). This approach uses a “top-down” or divisive method for hierarchical clustering. Following our network definition, each node represents a product, while each edge represents the weight of the number of APIs commonly shared between pairs of products. The approach begins by observing the entire ecosystem and progressively dividing it into more categories. The number of sub-clusters is calculated at a lower hierarchy level, maintaining a minimum similarity threshold between products. Hence, this method measures the similarity in API uses between products by counting the number of commonly shared APIs.

To calculate the weights of API usage in products, we constructed an adjacency matrix of products, which was then converted to a topological overlap measure (Ravasz et al., 2002). This measure converts the entries from the adjacency matrix into weighted similarity measures within the product network (Zhang and Horvath, 2005). The objective is to accurately capture the hierarchical clusters of products (i.e., product variety) and detect structural changes (i.e., functional mutation), such as splits and merges, as new products with different API usage patterns are continually created (Yip and Horvath, 2007). A higher number of extracted clusters indicates more functional categories, signifying greater differences in functionality between these categories. The number of sub-clusters serves as a valid and reliable measure of functional variety in many studies. Thus, this methodology enables us to statistically analyze the structural changes of clusters and gain a deeper understanding of the growth of a digital ecosystem.

4.2 A Survival Model to Estimate the Impact of API Migration on Mutation

The second approach in this study focuses on analyzing how external APIs impact the structural changes in clusters within a digital ecosystem. To achieve this, a survival model was adopted (Segal, 1988) that captures the effect of external APIs during periods of new events when new clusters are formed. The hazard function used in the survival model represents the rate at which events occur in each entity during a specified time period. The event in the hazard model is defined as the birth of new clusters rather than the death of clusters, which is the typical interpretation of hazard. Therefore, in this study, the hazard function is interpreted as the probability of the functional mutation of products (i.e., within-cluster differentiation) relative to the control group or time-invariant clusters. A Weibull hazard function is utilized for the panel data set to account for changes in the hazard ratio and its result represents parametric values. This approach will offer insights into the impact of external APIs on the structural dynamics of a digital ecosystem.

To understand how external APIs impact the differentiations within clusters in a digital ecosystem, this approach utilizes the external API as the unit of analysis. As external APIs are continually introduced and used to create new products, they may cause existing clusters to evolve or remain unchanged. Two types of predictors are utilized in this approach. First, the network properties of external APIs, such as their connectivity and use frequency, are considered. Connectivity measures the number of APIs connected to a focal API, while use frequency measures the number of times an

API is used with others in products. Second, non-network properties such as API age and the size of APIs offered by a provider are employed. API age is used to explore whether the length of time an API is present in a digital ecosystem affects the emergence of new clusters. The size of APIs offered by a provider is used to understand whether product variety is dependent on diverse API providers, as a lack of variety can limit the exploration of unique API functions. The data are analyzed using a survival model, which is specified as follows:

$$\log h_i(t) = \alpha(t-1) + \beta_1 x_{1ij}(t-1) + \beta_2 x_{2ij}(t-1),$$

where x_{1ij} indicates network property and x_{2ij} shows non-network property.

V. Empirical Study

5.1 Data Collection and Processing

This study uses data from WordPress to investigate the impact of external APIs on the structural changes in a digital ecosystem over time. The study focuses on the API information utilized in each plug-in, where an API represents a design resource and a plug-in represents a product. All available source code information was collected for a total of 23,895 plug-ins as of December 2014, resulting in a data set of over 100GB. A text-mining program was developed using Java to extract information about the APIs used in each plug-in. Using the time stamps recorded in each source code, this study created a longitudinal data set that provides detailed information about which APIs were used in each plug-in from January 2004 to December 2014.

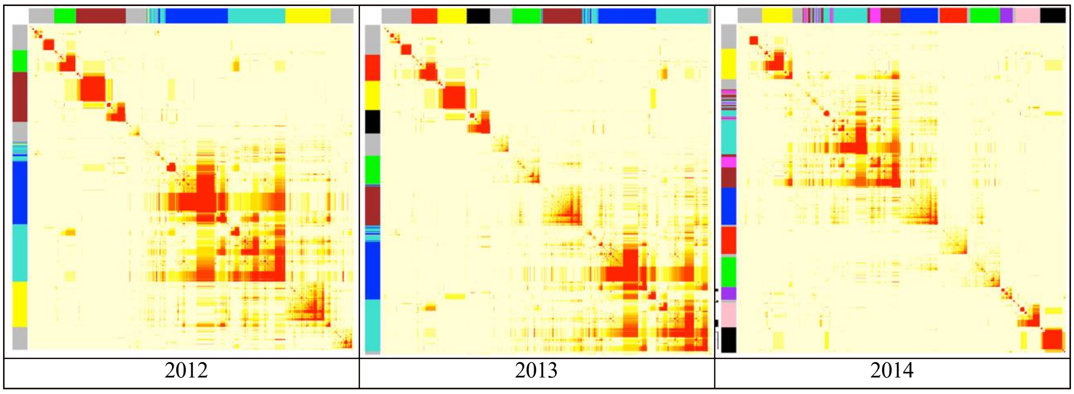
To obtain network information about plug-ins, data is constructed by the monthly tables of plug-in x API. The entries in the table are binary numbers (0 and 1) that indicate whether an API is used (marked as 1) or not (marked as 0) in a plug-in. To collect API information effectively, a text-mining program was developed to compare the source codes of all plug-ins in a list of more than 10,000 APIs obtained from www.programmableweb.com to capture the function call information used in each plug-in as of December 2014. The text-mining process revealed that in January 2004, 86 plug-ins used 44 APIs (40 internal APIs and 4 external APIs), while in December 2014, 23,985 plug-ins used 443 APIs (113 internal APIs and 330 external APIs offered by 265 companies). The detailed plug-in x API data were used to capture the structural changes in the evolution of the digital ecosystem over time.

After processing the plug-in x API matrices, this study constructed API x API monthly tables to extract API network information and explore the direct connections between APIs. APIs are considered connected if they are used in a plug-in at the same time, and the API network comprises source and target nodes along with their edge weights. The source node represents the starting point of the connection, while the target node indicates the endpoint between two APIs. Edge weight indicates the number of times source and target nodes are connected. By creating 443 monthly matrices, each comprising three elements (source node, target node, and edge weight), this study could capture changes in the API network from January 2004 to December 2014. The age of APIs was measured by the period during which they are introduced into the digital ecosystem.

Ⅵ. Results

6.1 Hierarchical Network Structure of Products

The results of the analysis of the functional mutation of product types are presented in Figure 1, where the X-axis and Y-axis depict the plug-ins observed at each time point. As time progresses, the size of each axis increases. The segmented clusters of plug-ins, which represent different combinatorial patterns of APIs, are shown using a color bar based on a hierarchical clustering technique (Langfelder et al., 2008). The diagonal region below the color bar displays squares of different densities, with red indicating high similarity and yellow indicating low similarity. Each square in the diagonal region represents plug-ins grouped together based on their common API pattern, with the size of each square indicating the number of plug-ins in the cluster. The size and shape of each square continuously evolve over time, reflecting the mutation of each cluster. The length of each segment in the color bar corresponds to the size of the cluster. Figure 1 illustrates the visualized structural changes of a digital ecosystem using the TOM approach from 2012 to 2014. The number of clusters increased from 6 in December 2012 to 8 in



<Figure 1> Structural dynamics of a digital ecosystem from 2012 to 2014

December 2013 and 11 in December 2014. Correspondingly, the number of external APIs also increased from 208 in 2012 to 253 in 2013 and 344 in 2014.

The number of newly emerged clusters increased from one in 2004 to eleven in 2014. This expansion highlights the growing product variety and the need for greater attention to be paid to cluster differentiation driven by the introduction of external APIs. Within-cluster differentiation in a cluster, or sub-cluster, also increased, as indicated in Table 1. The increase in the number of sub-clusters underscores the importance of careful analysis and understanding of each cluster's distinct functional mutation of product types. As of 2014, some of the most frequently used external APIs included Facebook Real-time Updates, Flickr, Google Maps APIs, Gravatar, Twitter, and YouTube, which have proven to be reliable and efficient tools for developers seeking to integrate with other APIs when creating plug-ins.

A statistical analysis was conducted to gain insight into the role of external APIs in the emergence of new clusters in the plug-in network. The dependent variable of this study was the emergence of new clusters at each time point, while the independent variables included both network and non-network properties of APIs. Network properties such as connectivity and use frequency were extracted through API information used in all plug-ins, while non-network properties such as the number of APIs offered by a provider and API age were extracted through the log file of plug-in source codes. To account for the time lag between API introduction and adoption by developers, different time points were used for the explanatory variables (time t-1) and the dependent variable (time t). The dependent variable was represented by binary values (0 and 1) indicating the presence or absence of new cluster emergence each month. Table 2 presents the descriptive statistics of the variables used in the analysis.

<Table 1> Number of clusters and APIs

Year	2004	2008	2011	2014
Number of Clusters	1	2	5	11
Number of within-cluster differentiation	2	12	43	102
Number of external APIs	4	38	163	344
Number of internal APIs	40	59	92	99

<Table 2> Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
1. Connectivity of external APIs	45,064	4.955	13.695	0	169
2. Use Frequency of external APIs	45,064	2.309	13.119	0	457
3. API age	45,064	15.624	115.988	0	132
4. Number of APIs a provider offering	45,064	3.922	8.664	0	33

The survival model utilized in this study enables the estimation of the likelihood of being in the core of a cluster during the occurrence of new clusters in a given time period. This likelihood is measured by a hazard ratio, which represents the relative probability of change occurring. In this study, the term "risk" does not have a negative connotation but instead refers to the possibility of change, primarily influenced by the introduction of external APIs.

Table 3 presents the survival analysis results, providing insight into the individual role of different predictors in the emergence of new clusters. The coefficients indicate the likelihood of external APIs becoming part of newly emerged clusters.

The connectivity of external APIs has a significant positive effect of 4.8% at the 0.01 level, implying that APIs with high connectivity are more likely to become part of cluster differentiation in the following month. This finding supports H1, indicating that an increased range of external APIs' connectivity is key to increase product variety in the digital ecosystem.

The use frequency of external APIs also has a positive effect, with a 0.6% increase at the 0.01 level, indicating that APIs that are frequently used in combination with others are more likely to be part of cluster differentiation. This supports H2 and implies that APIs with high frequency play a critical role in product variety.

In addition, the result for API age shows a 0.1% increase at the 0.01 level, supporting H3. This suggests that APIs that have been present in the digital ecosystem for a longer duration have a higher probability of interacting with diverse APIs, leading to increase product variety.

However, the analysis does not support H4 that external APIs offered by companies that produce a large number of APIs play a critical role in product variety. The negative coefficient at the 0.01 level indicates that an

<Table 3> Panel Weibull survival model

DV: Cluster Differentiation (t)	Model
Connectivity of external APIs (t-1)	0.048 (0.001)***
Use Frequency of external APIs (t-1)	0.006 (0.001)***
API age (t-1)	0.001(0.0001)***
Number of APIs provider offering (t-1)	- 0.013 (0.002)***
Constant	44.123(0.328)***
N	45,059
Number of group	344
Wald chi-square	3938.44

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

individual API's functional usefulness is more important than the reputation and size of the platform company that offers it. The number of APIs produced by a company represents opportunities to be relatively exposed and recognized by developers, but the analysis shows that APIs offered by smaller companies have an equal opportunity to increase the number of function calls if their API function is unique and useful for increasing product variety.

Ⅶ. Discussion

This study explores the impact of external APIs on the product variety of a digital ecosystem over time. As the number of APIs in a platform system continuously grows, it creates a dynamic and generative network structure that evolves from a single hierarchical structure to multi-layered hierarchies. Our approach adopts the evolutionary network biology perspective to examine the role of external APIs in this structural change. Our results complement those of previous studies on digital innovation and provide insight into how the landscape of a digital ecosystem can be transformed through the introduction of new external digital APIs and their connection patterns.

To achieve this goal, this study mainly uses a hierarchical clustering network analysis to predict structural changes related to the connection patterns among digital APIs. By examining network properties and each node's attributes, this study explores the influence of various factors on structural change. The theoretical approach expands current digital ecosystem studies and provides guidance for future researchers to study evolutionary networks. Overall, the findings reported in this paper contribute to the understanding of how digital ecosystems evolve and provide insights into how external APIs play a critical role in this process. By adopting an evolutionary network perspective, this study offers a new lens through which to examine the dynamic change of a digital ecosystem.

The results of this study provide empirical evidence on how to systematically study changes in the growth pattern of a digital ecosystem and how external technologies can lead to such structural change by becoming part of existing design resources. Unlike existing studies, this study assumes that change in the structure mainly comes from the increasing number of external APIs that create multiple hierarchical structures. The findings suggest that without appropriately enabling to use external design resources by the platform owner, the ecosystem may not grow as sustainably as it would with them. External APIs play a critical role in increasing product variety across multiple product types in the growth of a digital ecosystem. Specifically, the results of our analysis show that broad connections with others are key to driving change. Moreover, the size of API providers does not necessarily influence the usefulness of their products. These findings demonstrate that new platforms or API providers can gain market competitiveness against larger ones by providing functionally useful products. Once a product's technological features are acknowledged, new firms can create their own market.

The advent of digital technologies has disrupted traditional innovation patterns, giving rise to a generative nature that operates differently from what we've seen before. Specifically, digital ecosystems transform a platform owner's vertically integrated hierarchical structure into a horizontally coordinated, multi-layered system that is generated by developers and contributed to by multiple digital ecosystems. This new paradigm of innovation introduces novel, combinable patterns that cannot be anticipated. This study aimed to explore this dynamic mechanism by examining the role of newly introduced heterogeneous digital technologies in a system. The findings offer insight into the unique and unexplored evolutionary forces that drive innovation in a platform system.

Although this study provides unique theoretical and methodological contributions to many disciplines based on the evolutionary network biology perspective, it has some limitations. Given the nature of a single digital ecosystem, this study focuses on a limited number of API attributes to represent the generative nature of APIs in a network structure. However, the analytic approach of this paper captures the changes in the use frequency of each API, which lead to the evolution of network structure by investigating the dependency between network properties and API attributes.

This study provides new insight into the evolutionary aspect of a digital ecosystem using the generative feature of digital technology, describing the primary evolutionary forces and the basic mechanism of structural change in a systematic way. In addition, the cutting-edge computational technique used in this study provides empirical evidence for the theoretical argument. Therefore, this research presents a new way of exploring the role of external digital technologies in discontinuous innovation patterns in a digital ecosystem.

Ⅷ. Conclusion

Digital ecosystems are among the most dynamic and complex systems in the realm of innovation. These systems exhibit unbounded and unpredictable evolutionary patterns that differ from traditional innovation patterns that are based on a bounded and controlled environment. This study introduces a new perspective that allows for a better understanding of these evolutionary dynamics and the underlying mechanisms that drive them. This study provides a comprehensive analysis of the role of external APIs in driving the dynamic evolution of digital ecosystems by adopting an evolutionary network biology perspective.

As we found in our literature survey, a product is defined as a combination of functional components, such as code modules and APIs (Simon 1996; Fleming and Sorenson 2001, 2004). Following this principle, existing studies represent products as a combination of APIs, particularly when studying how web developers build their products using the combinatorial design principle (Yoo et al., 2012). Based on such product development conditions, scholars demonstrate that a large and less cohesive network can be divided into many small, densely connected sub-networks called modules, organized in a hierarchical manner. However, existing studies have a lack of detail and distinction between categories as the size of network increases.

We demonstrate that as the number of products increases, new functions are continuously integrated into the products, leading to the emergence of larger functional categories compared to previous time points. Also, we capture the formation of smaller sub-clusters within each larger category, representing the detailed growth and diversification within the ecosystem. In such dynamics, the uniqueness of this study lies in its approach to examining how external APIs, introduced from outside the ecosystem, significantly influence product variety and ecosystem growth. By focusing on the network properties of APIs, our research discovered the structural changes and the functional mutations of products within the ecosystem. Also, by examining the non-network properties of APIs, we found that APIs from a diverse range of providers, including smaller firms, enrich the ecosystem. Specifically, implementing diverse features in APIs makes it easier for developers to facilitate the continuous growth of digital ecosystems rather than solely depending on established partnerships and collaboration opportunities with large platform companies.

Our findings have practical implications for practitioners. Platform owners can strategically integrate and support the use of external APIs to enhance product variety and drive ecosystem growth. Encouraging the use of high-connectivity and frequently used APIs can lead to functionally popular product developments and increased user engagement. Platform owners can provide dedicated API marketplaces including communities where developers can easily find, evaluate, and adopt useful APIs in order to collaborate with other developers. Platform owners can provide comprehensive documentation and technical support to facilitate the use of external APIs so that developers ensure the efficient uses of such tools.

In addition, platform owners can facilitate the continuous use and integration of older APIs to leverage their functional familiarity and proven utility. Maintaining backward compatibility of older APIs encourages their continued use and integration. Highlighting successful products that have leveraged established APIs can demonstrate their long-term value and reliability. At the same time, platform owners need to prioritize the functional value of APIs over the size and reputation of the provider. This approach can help smaller firms gain a competitive edge by offering unique and valuable API functions that attract more developers and users. By evaluating the functional performance and utility of APIs, regardless of the provider's size, platform owners can ensure these APIs meet the ecosystem's needs. This strategy can increase the functional uniqueness of digital ecosystems that provides features and capabilities that competitors do not have. Therefore, by recognizing the potential of APIs from smaller providers, platform owners can diversify their ecosystem and prevent reliance on a few large providers. This strategy can lead to a more resilient and innovative ecosystem.

While this study provides significant insights, it is limited to a single digital ecosystem. Future research should explore multiple ecosystems to validate the findings and offer a more detailed understanding of the dynamic growth patterns in digital platform systems. Additionally, investigating other attributes of APIs and their impacts on different aspects of digital ecosystems can further expand our knowledge of digital innovation. Despite these limitations, this study sheds light on the critical role of external APIs in fostering dynamic growth and product variety in digital ecosystems. By adopting an evolutionary network perspective, we provide a novel framework for understanding how digital ecosystems evolve and how strategic use of APIs can drive innovation and competitiveness.

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<Abstract>

Uncovering the Role of External APIs in Driving Dynamic Ecosystem Growth

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Purpose

This study highlights the crucial role of external APIs in driving dynamic evolution within a digital ecosystem. Drawing on the concept of evolutionary network biology perspective, this study hypothesizes that APIs' (non)network properties can significantly impact a digital ecosystem's product variety.

Design/methodology/approach

This study analyzes plug-in source code data from WordPress.org between January 2004 and December 2014, using survival analysis to test this hypothesis.

Findings

The empirical results demonstrate that external APIs have a more significant impact on promoting ecosystem evolution over time than those offered by a focal platform system. This research enhances our understanding of ecosystem dynamics and emphasizes the critical role of the generative nature of APIs in fostering ecosystem growth.

Keyword: APIs, Dynamic Growth, Product Variety, Digital Ecosystem

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