An Analysis of Multi-Sided Platform Research Over the Past Three Decades: Framework and Discussion

Working Paper Draft: July 15, 2019

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ABSTRACT

Over the past thirty years, numerous scholars in economics and various management fields have studied a phenomenon that we now refer to as "platforms" or "multi-sided platforms." In this review article, we summarize, organize, and analyze statistically the literature around key concepts such as multi-sided markets, network effects or network externalities, platform openness, multi-homing, and winner-take-all market dynamics. We find that it is most useful to organize the research into seven streams (strategy, architecture, governance, business model and customer relations, multi-platform bundles, ecosystem participants, and technological innovation) and three separate but overlapping levels of analysis (business, corporate, and ecosystem). We present this framework and analysis and then conclude with a summary of our findings and identification of trends for future platform-related research.

KEYWORDS
Multi-sided platform; Research review; Literature bibliometric

1. INTRODUCTION

Platform companies are among the most valuable firms in the world ranked by market value, led by Microsoft, Amazon, Apple, Alphabet-Google, and Facebook in the United States and Alibaba and Tencent in China. In total, the top seven platforms represented a market value as large as $5 trillion in 2018. Also, we estimate that between 60 and 70 percent of the 200 or so current and former "unicorns" – privately held startups with valuations of a $1 billion or more – primarily rely on platform business models (Cusumano, Gawer & Yoffie, 2019). Not surprisingly, various researchers have attempted to explain the rise and dominance of platform businesses. Figure 1 shows the growth in published articles from the initial time when the term "platform" first appeared in the academic literature in 1989.

Insert Figure 1 About Here

Despite the growing volume of research, there is still no consistent definition of what constitutes a platform or a platform business. The term continues to be used loosely and in different contexts. For example, early researchers highlighted the value of product development platforms as part of a product portfolio, making it easier and cheaper to build new products (e.g., Meyer & Utterback, 1993). There are also references to platforms as an information and knowledge collection system within an organization (e.g., Kogut & Zander, 1992). Another early reference using the term platform was as a technology foundation (such as the personal computer with an easily accessible operating system for applications development) around which third-party firms could contribute their own innovations and make the platforms increasingly valuable (Cusumano, 1995, Gawer & Cusumano, 2002).

In recent years, the most dominant use of the term refers to a multi-sided platform (MSP), which applies to Microsoft, Amazon, Apple, Alphabet-Google, and many other businesses. Still, care is required even when adopting this term MSP. For example, Amazon, for most of its history, has derived most of its revenues as an online store, rather than as a marketplace for buying and selling goods, or as an innovation platform for web services and applications (Hagiu, 2014). This has changed in recent years but it shows that many platform business also contain traditional product or service businesses. A large number of studies also are limited to specific research questions and cases, and lack generalizable conclusions. Therefore, the aim of the present research review is, first, to provide more clarity in summarizing how the literature has defined what is a platform business; and second, to summarize what we have learned and what we still need to study in the future.

The remainder of this article is organized as follows. First, we review all the platform related literature and propose some definitions based on the literature. Then we review the theoretical backgrounds to concepts such as multi-sided market, network effects, and platform ecosystems, identifying three distinguishing characteristics that describe a multi-sided platform. Next, based on a bibliometric analysis, we review the main research findings on multi-sided platforms. We organize the literature into seven streams (strategy, architecture, governance, business model and customer relations, multi-platform bundles, ecosystem participants, and technological innovation) and three levels of analysis (business, corporate, and ecosystem). We add some commentary and discussions of future research trends for each level of analysis.

2. DEFINITIONS: PLATFORMS AND MULTI-SIDED PLATFORMS

The first academic papers in management or economics using the term "platform" in the title were published in 1989-1991 (e.g., Congleton, 1989, Rybakov, 1990, Avishai, 1991). These authors used the term platform to refer to a base for an interaction between different units of an organization or even a society more broadly. Subsequently, authors used the term with more specific applications, though still with various definitions and sometimes in very different contexts. More recently, Cusumano, Gawer and Yoffie (2019) define the term "platform" as "a foundation that connects individuals and organizations for a common purpose or to share a common resource." To clarify further usage of the term and related concepts, this paper also distinguishes between "management" and "non-management" contexts, based on a literature review and content analysis. Each context also has its own subcategories. Table 1 shows the platform definition tree under the management context.

Insert Table 1 About here

In a non-management context, popular uses include political competition platforms, which are ideas or policies that bring people together for a common political goal (e.g., Rybakov, 1990; Congleton, 1989; Gomberg, Marhuenda, & Ortuno-Ortin, 2004; Avishai, 1991). The political party platform depends on the composition of the primary election. Physical platforms described in the literature include offshore oil platforms (e.g., Ely & Meyerson, 2010; Gribkovskaia, Laporte, & Shlopak, 2008; Hansen, Pedrosa, & Ribeiro, 1992) and transportation platforms, which are designated area that bring people together to access a shared mode of transportation (e.g., Munoz et al., 2018). Researchers also use the term platform as a common way of thinking or communicating, such as shared values or a common language and research paradigm (e.g., Chen & Miller, 2012). Other researchers use the term platform to refer to a common approach to achieve a shared goal. For instance, Ghoshal, Arnzen, & Brownfield (1992) refer to executive education as a mechanism to bridge industry practice and business schools.

Our main concern in this paper is with the management context. Here, we can divide the use and definitions of the term platform into three levels: functional platforms, inter-organizational platforms, and industry or multi-sided market platforms. For example, Gawer (2014) and Gawer & Cusumano (2014) classify functional and industry platforms as internal (company-specific) and external (industry- or ecosystem-related), respectively.

For the functional or internal-company platform, considerable work has been done on product platforms or product development platforms (e.g., Meyer & Utterback, 1993; Cusumano & Nobeoka, 1998); Jiao, Zhang, & Pokharel, 2006; Simpson, 2004; Muffatto & Roveda, 2002). For example, McGrath (1995) defines a product platform as a collection of common elements, especially the underlying core technology, implemented across a range of products. Product platform in general refers to a set of common components, modules or parts from which a stream of derivative products can be efficiently developed and launched (Muffatto & Roveda, 2002; Meyer & Lehnerd, 1997). To be more specific, researchers have discussed three types of product platforms: the modular platform, the scalable platform, and the generational platform (Zamirowski & Otto, 1999; Martin & Ishii, 2002). The benefits of product platforms have been demonstrated

by various scholars in considerable detail for automobiles and other industries (Meyer, Tertzakian, & Utterback,1995; Meyer & Lehnerd, 1997; Cusumano & Nobeoka, 1998; Simpson, 2004). For example, researchers conclude that the product platform is flexible, responsible, time-saving, cost-saving, and product upgrading. Researchers have also noted the weaknesses of product platforms (Muffatto & Roveda, 2002), such as the potential inefficiency of a large modular product architecture.

Knowledge-sharing or information-sharing platforms are another type of functional platform. Various scholars argue that, with the development of advanced information technologies, the knowledge-sharing platform is an important organizational mechanism to enhance the ability of systematic acquisition, storage, and dissemination of organizational knowledge (Huber, 1991), as well as the combinative capacity of an organization (Kogut & Zander, 1992). Much work has investigated the firm's ability and motivations to integrate the dispersed pockets of expertise and institute an organizational repository of knowledge (Iyer, et al., 2015; Vuori & Okkonen, 2012), which can be vital for firms to survive (Purvis, Sambamurthy, & Zmud, 2001).

Among inter-organizational platforms, one particular construct is the supply-chain platform, which is an inter organization link that can carry out the platform functions of group actors. As stakeholders, they gather and collaborate for a specific purpose, such as for manufacturing, marketing, or research and development (Gawer, 2014; Corradini & De Propris, 2017; Narayanan, Colwell, & Douglas, 2007). Amasaka (2012) discusses the supply chain platform as a new form of partnership. Researchers have also investigated the role of export and import platforms in the foreign direct investment context (e.g., Ekholm, Forslid, & Markusen, 2007). Yet another form of inter-organizational platform are service or physical locations used for social or management functions, usually hosted by a nonprofit organization. The European biotechnology platforms (Cooke et al., 2010) and communication platforms in nonprofit services (Azhar, 2018) are some examples of this type. These inter-organization platforms involve external actors, as well as the focal actor. It is unusual, however, for these types of internal or inter-organization platforms to generate network effects, in contrast to platforms organized at the industry or ecosystem level.

For the analysis of industry platforms, we have focused on the multi-sided platform (MSP) as discussed in articles such as Rochet & Tirole, 2003; Eisenmann, Parker, & Van Alstyne, 2006a; Gawer, 2014; Gawer & Cusumano, 2014; Parker, Van Alstyne, & Choudary, 2016a; and Zhu & Iansiti, 2012). There has been a great deal of multi-sided platform research since the early 2000s (e.g., Rochet & Tirole, 2003, 2006; Armstrong, 2006; Schmalensee, 2002; Wright, 2004; Rysman, 2004; Caillaud & Jullien, 2003; Sun & Tse, 2007). Hagiu and Wright (2015) present a particularly clear definition and argue that an MSP enables direct interactions between two or more distinct sides and each side is affiliated with the platform. There is also a third party that creates and operates the network between the sides (Hagiu, 2014).

Cusumano, Gawer, and Yoffie (2019) divide all industry platforms into two types: *innovation platforms* ("common technological building blocks that the platform owner and ecosystem partners can share in order to create "complementary" products and services") and *transaction platforms* ("largely intermediaries or online marketplaces that make it possible for millions of people or organizations to share information or to access or buy and sell a variety of goods and services"). In a sample of 43 publicly listed platforms among the Forbes Global 2000 firms, they also showed that, at least the platforms that made this list, had similar revenues to non-

platform firms in the same industries but they achieved these sales with about half the number of employees. The platforms also had much higher operating profits, growth rates, and market values.

The remainder of this paper excludes the functional and inter-organization platform studies and focuses on industry-level (business and corporate) as well as ecosystem-level platform research. The key concept is "multi-sided-ness" (Gawer & Cusumano, 2014; Parker, Van Alstyne, & Choudary, 2016a; Rochet & Tirole, 2003; Zhu & Iansiti, 2012; Hagiu & Wright, 2015). This term refers to platforms and their "broader network of producers, suppliers, users, business partners, and other stakeholders" (Cusumano, Gawer, & Yoffie, 2019). The definition or description of multi-sided platforms in Table 1 follows this basic definition.

3. THEORETICAL BACKGROUND

Researchers have conducted a number of multi-sided platform studies from different perspectives, including industrial organization economics, strategy, and technology management (McIntyre & Srinivasan, 2017). However, two main theoretical models seem to have influenced the literature: the concept of a multi-sided market based on industrial organization economics; and the concept of network externalities or network effects (the terms are largely used interchangeably in the literature, even though some scholars make distinctions). A bibliometric analysis based on keyword clusters and the most cited references supports the observation that multi-sidedness and network effects or network externalities act as the dominant theoretical constructs. (Please refer to the supplemental materials attached to this paper.)

Multi-sided Markets

The multi-sided (or two-sided) market is the foundational theory for multi-sided platform research based on industrial organization economics (e.g., Spence,1975; Armstrong, 2006; Caillaud & Jullien, 2003; Evans, 2003; Evans & Schmalensee, 2007; Hagiu, 2006; Rochet & Tirole, 2003, 2006). Even though the definition of a multi-sided market remains controversial, according to previous research, there are several main features of the definition (Hagiu, 2006; Weyl, 2010).

First, is the idea of a multi-product platform firm where each of the market sides represent different types of customers and the firm provides distinct products or services for the multiple sides, potentially with different prices. Second, is the idea of network effects or network externalities: The platform participants experience increasing benefits with each additional participant on the different market sides. Third, there is bilateral or multi-lateral market power: The platform has power on all sides of the market (monopolistic or oligopolistic), such as for pricing, as it enables direct interaction between two or more market sides. The two-sided market is a particular and basic form of the multi-sided market, which is generally used as a foundation for analysis.

The general unit of analysis for a multi-sided market varies from the platform firm to the platform participants (Sun & Tsu, 2009). The role of the platform firm also varies, sometimes serving as a price regulator, a licensing authority, or a competition authority (Rochet & Tirole, 2003).

A few key assumptions usually frame the analysis of multi-sided markets (Wely, 2010). First, actor valuations are exogenous to any direct interactions between actors from other sides. Second, network effects are both cross-side (indirect) and same-side (direct). Third, actors from

each side interact either with all or a random subset of actors from another side. Fourth, actors from each side are of equal value to actors from another side. Among these assumptions, there are still some controversial issues in the research. For example, Rochet and Tirole (2006)'s RT model shifts the second assumption to consider only cross-side network effects when analyzing the pricing strategy.

Network Effects (Network Externalities)

The other key theoretical construct, network effects, relate to network economics and the broader concept of network externalities, which have been extensively studied by academic economists since the mid-1980s (e.g., Katz & Shapiro, 1985, 1986; Farrell & Saloner, 1985, 1986). Note that perhaps the first paper on network externalities influencing demand was by an AT&T economist, Jeffrey Rohlfs, in 1974 (Rohlfs, 1974). In multi-sided platform markets, economists generally view the platform as a "conduit" that facilitates exchange between different market sides or actors (Evans, 2003; Rochet & Tirole, 2006; Rysman, 2009). Network effects have been regarded as the "most critical distinguishing" feature of an industry-level platform (Gawer & Cusumano, 2014). Consequently, they also have been widely studied by management researchers (Parker & Van Alstyne, 2005; Eisenmann, Parker, and Val Alstyne, 2006; Afuah, 2013; Chen & Xie, 2007; Shankar & Bayus, 2003; Suarez, 2005; McIntyre & Subramaniam, 2009).

There is considerable overlap and confusion between the concepts of a network externality and a network effect, as well as increasing returns to scale. We can think of network externalities as the fundamental idea that a factor external or one separate from the functioning of a particular product or service, such as the number of users of a telephone, fax machine, or the Internet, or of a modern messaging service or social media application, impact the value or benefits a user experiences. The impact can be positive (as with a rising number of users) or negative (as with a declining number). Standards and compatibility, which might be associated with the customer networks of particular firms, are also important concepts in the analysis of network externalities and reasons for success and failure in these types of markets, such as communications and computers (for example, Katz & Shapiro, 1985; 1986, 1992; Liebowitz & Margolis, 1994). As used in the management and innovation field, network effects has become the more commonly used term among platform researchers, who usually emphasize the notion of a positive feedback loop where "the value one user experiences potentially increases as more people or organizations use the same product or service, and as more 'complementary' or related innovations appear." (Cusumano, Gawer, & Yoffie, 2019, p. 9).

In a network, customers or nodes are independent actors interacting with each other (Eisenmann, 2006). According to the interaction approach, as noted earlier, the network effects can be divided into two categories, i.e., direct or same-side (or one-sided), such as when the value to a customer increases with the number of other customers on the same side (or of the same type); and indirect or cross-side, such as when the value to users on one side of a platform, such as for ride sharing or room sharing, increases with the number of participants on another side (Hagiu, 2014; Gawer & Cusumano, 2014), such as the number of drivers with rides to offer or people with rooms to rent.

Researchers generally use network size to measure the strength of network effects. The argument is that, the more users a network has, the more valuable that network will be to each user. Zipf's law (Briscoe, Odlyzko, & Tilly, 2006) is one particular approach. However, researchers,

such as Afuah (2013, p.257), argue that a "network's structure (feasibility of transactions, centrality of members, structural holes, network ties, the number of roles each member plays) and its conduction (opportunistic behavior, reputation signaling, perceptions of trust) also have significant impacts on a network's value to users and to network providers." Empirically, based on the market structure, various researchers (McIntyre & Subramaniam, 2009; Fuentelsaz, Garrido and Maicas, 2015) calculate number based on number of participating firms and users to measure the network effects. Other researchers have cited Metcalf's Law, which measures the number of nodes in a network, as a way to approximate the value of a network effect (for example, Parker, G. Van Alstyne, M., & Choudary, 2016b; Cusumano, Gawer, & Yoffie, 2019).

In conclusion, both concepts – that of a multi-sided market and network externalities or network effects – have created the foundation for recent platform research, even though how to measure network effects remains problematic. The following sections of this paper on multi-sided platform characteristics and the main research content are all rooted on these concepts. As we will see, however, the refinement or lack of refinement of these two theoretical constructs has both contributed to and limited multi-sided platform research.

4. MAIN CHARACTERISTICS OF MULTI-SIDED PLATFORMS

Various authors discuss the characteristics of multi-sided platforms. In addition to strength of network effects, the literature suggests that three other characteristics are of particular significance to understanding platform performance: the degree of platform openness, multi-homing among competing platforms, and winner-take-all (or-most) market dynamics.

Degree of Openness

Various authors note that the optimal level of openness – for example how easy or costly it is for third-party firms or outside individuals to access a platform's features and functions, such as through application programming interfaces in the case of software platforms – is one of the most critical decisions for platform design and maintenance (Gawer & Cusumano, 2002; West, 2003; Gawer & Henderson, 2007; Eisenmann, Parker & Van Alstyne, 2009; Boudreau, 2010; Parker & Van Alstyne, 2018). Gawer and Cusumano (2014) and Gawer (2014) have argued that a critical difference between company-internal platforms and industry-external platforms is openness of the platform to outside parties for complementary innovations. They also maintain that only industry or external platforms generate indirect or cross-side network effects, which are important for growth dynamics.

Eisenmann, Parker and Van Alstyne, in several papers, have argued that there are several reasons why openness is important for industry platforms: 1) the level of participation (Eisenmann et al. 2009), such as encouragement or restriction of activities, and different roles of platform participants; and 2) the governance model choice, such as the ability to bundle developer innovations and the vertical integration decision. Moreover, "opening a platform can spur growth by harnessing network effects, reducing end-user fears of lock-in, and stimulating down- stream production. At the same time, opening a platform typically reduces user switching costs, increases forking and competition, and reduces the sponsor's ability to capture rents" (Parker & Van Alstyne, 2018, p. 3028).

Openness also involves a potential trade-off between platform growth and appropriation of rents or levels of innovation (West, 2003). Parker, Van Alstyne and Jiang (2016) conducted a study on the optimal openness for developers in a platform ecosystem. Previous research (such as Boudreau, 2010) found an inverted U-shaped curve for the optimal level of openness. In addition, other researchers (Valloppillil & Cohen, 1998; Parker & Van Alstyne, 2005; Parker & Van Alstyne, 2018) have argued for a continuum model for the level of platform openness versus levels of innovation.

Multi-Homing

Multi homing refers to "the choice of an agent in a user network to use more than one platform" (Landsman & Stremersch, 2011). A comparative concept is single-homing, which refers to the choice of an agent in a user network to use only one platform. The concept of multi-homing is widely discussed in the platform literature and mostly in the consumer context, where multiple platforms (such as for social media or messaging) are usually available for consumers to choose (Bresnahan, Orsini, & Yin, 2015, Corts & Lederman 2009; Cennamo, Ozalp, & Kretschmer, 2018). Some platforms (e.g., innovation platforms as defined by Cusumano, Gawer and Yoffie, 2019) start as products and try to attract as many users as possible and keep users from using other similar platforms, in order to maximize network benefits for their platforms (Choi, 2010; Cennamo, Ozalp, & Kretschmer, 2018). The multi-homing analysis relates closely to the number of platform participants or degree of their activity, as well as multihoming by complementors (Cennamo, Ozalp, & Kretschmer, 2018).

The literature analysis suggests that economists have studied platform multi-homing mainly from two theoretical perspectives. The first stream of research looks at the equilibrium outcome when a multi-homing option is provided to users, without the (potential) existence of exclusive contracts (Armstrong, 2006; Caillaud & Jullien, 2003; Choi, 2010; Choi, Jullien, & Lefouili, 2017; Doganoglu & Wright, 2006; Rochet & Tirole, 2003, 2006). Another stream looks at the equilibrium outcome when a platform owner offers an option of an exclusive contact (Armstrong & Wright 2007; Balto, 1999; Doganoglu & Wright 2010). This context contains a multi-homing option or varies with the specific setting of a platform's competitive strength or stage in the lifecycle.

Empirical research on multi-homing has focused on what influences a platform participant to multi-home or a platform owner to allow or encourage multi-homing. In some cases, multi-homing can be beneficial for the platform owner (Armstrong & Wright, 2007; Bresnahan, Orsini, & Yin, 2015; Corts & Lederman, 2009, Lee, 2013; Rochet & Tirole, 2003). Specifically, multi-homing can increase the size of a market, even though there are potentially high technical and commercial costs to multihoming from the points of view of both users and complementors (Zhu & Iansiti, 2012). One reason is that multi-homing can result in more complementary products if multiple platforms can share the same complements (McIntyre & Srinivasan, 2017; Parker & Van Alstyne, 2005). As seen in the video-game software industry, multi-homing can sometimes reinforce the leading position of incumbent platforms by making it more difficult for competitors to enter a market with distinct complements (Lee, 2013).

In general, the research suggests that consumer multi-homing can induce more platform competition, which is beneficial for complementors wishing to avoid a price discount (Rochet & Tirole, 2003). At the same time, consumer single-homing can induce platforms to charge higher

prices for complements, especially when complementors are multi-homing (Armstrong, 2006). Broadly speaking, regardless of which side multi-homes, we can associate multi-homing with higher levels of platform competition as well as more interactions between platform owners and complementors (Cennamo, Ozalp, & Kretschmer, 2018; Armstrong 2006; Armstrong & Wright, 2007; Caillaud & Jullien, 2003; Hermalin & Katz, 2006; Rochet & Tirole, 2006).

There are also the negative effects of multi-homing. For example, Landsman and Stremersch (2011) find that multi-homing can reduce the differentiation between competing platforms and hurt the sales of a particular platform, especially if the same complements are available for multiple platforms. Exactly how these dynamics may play out varies with other factors. For example, the platform age and market share may moderate a multi-homing strategy and related results (Landsman & Stremersch, 2011). Specifically, for a newer platform with a smaller market share, platform-level multi homing has a prominent negative effect on platform sales. The effects will likely fade as a platform matures and gains market share.

The literature also discusses several decision-making factors for the multi-homing decision. First, multi-homing depends on a number of market parameters, including the degree of elasticity on both market sides (Jeitschko & Tremblay, 2018) and cross-side externalities (Cennamo, Ozalp, & Kretschmer, 2018). Second, cost is another popular factor. Specifically, Hagiu (2014) argues that switching costs reduces the likelihood of a multi-homing choice. The higher level of the cost to multi-home, the less multi-homing we are likely to see (Cennamo, Ozalp & Kretschmer, 2018; Corts & Lederman, 2009). Corts and Lederman (2009) also argue that, when the non-platform-specific fixed costs increase, there is a higher possibility of multi-homing. Third, user characteristics matter. Shapiro and Varian (1999) provide evidence that the higher the differentiation of the user network, the more likely there will be multi-homing, even taking other factors, such as hardware, into consideration.

Winner Take All or Most (WTAoM) Dynamics

Eisenmann, Parker, and Van Alstyne (2006), Parker, Val Alstyne, and Choudary (2016a), as well as Cusumano, Gawer, and Yoffie (2019), have all cited similar factors driving a WTAoM outcome for a particular platform: (1) the strength of network effects (direct or indirect); (2) the degree of multi-homing among competing platforms; (3) the potential for differentiation or niche competition; and (4) either economies of scale or other entry barriers. The main logic for their arguments is based on the strength and ongoing strength of network effects. This means that a platform owner should expand its installed base of users as rapidly as possible in order to attract more complements as well as new users. Such a get-big-fast strategy is likely to result in self-reinforcing positive feedback loops and induce a winner-take-all-or-most outcome, even with inferior platform quality (McIntyre & Subramaniam, 2009; Zhu & Iansiti, 2012; Cennamo & Santalo, 2013).

In short, researchers argue that market outcomes generally depend on the size of the installed base for a particular platform and the intensity of platform competition (Huotari et al., 2017). Researchers also argue that tipping—where all user and developers select the same platform—is an equilibrium state in these markets (Hossain, Minor, & Morgan, 2011; Schilling, 2002).

As for a platform leadership strategy, it seems obvious that platform-leader wannabes should try to enter a market early, develop and grow their installed base, attract more and more complementors or supply-side platform participants (such as suppliers of rooms to rent or cars to

drive), and then try to dominate the market, possibly through lower prices or broader market coverage (Gawer & Cusumano 2002, 2008; Huotari et al., 2017; Cusumano, Gawer, & Yoffie, 2019).

However, some researchers point out that not all markets follow these drivers; sometimes other characteristics or local factors dominate (Huotari et al., 2017). For example, Google has about 90 percent of Internet search and Facebook about 70 percent of social networking in all markets around the world except where they have encountered government resistance or restrictions. Cennamo and Santalo (2013) also find that a similar winner-take-all approach may not be universally successful since platform competition can be shaped by strategic trade-offs specific to each market. In addition, to achieve a winner-take-all-or-most outcome, the market must first be one that can be served by a single platform (Eisenmann, Parker, & Van Alstyne, 2006). Again, going back to the initial factors cited earlier, a WTAoM outcome usually requires that multi-homing costs are high for the user side or at least the most important side of the platform; network effects need to be positive and strong; and neither market side should have a strong preference for a specific type of platform product or service.

5. RESEARCH CONTENT FRAMEWORK AND LEVELS OF ANALYSIS

After clarifying some definitions and probing some of the theoretical pillars of multi-sided platforms, we used a bibliometric analysis and review of the literature to identify more specific themes and arguments in multi-sided platform research. The following sections discuss these findings in terms of seven research streams or topic areas and three levels of analysis. More details of the analysis are in the supplementary materials (appendix).

Seven Research Streams

We can identify at least seven streams of research in the platform literature, as follows.

(1) *Strategy:* The main content focuses on strategic positioning of the platform and competition. We can also include research on multi-sided market pricing and discrimination theory and analysis since pricing is part of strategy. In addition, even though most earlier research was conducted from the industrial economics perspective, some articles conduct pricing research from a management perspective. Overall, the strategy stream focuses on how a multi-sided platform can make optimal choices to achieve competitive advantage and then create a successful business.

(2) *Platform Architecture:* This stream focuses on how a multi-sided platform can organize its fundamental features to support platform functions and perform well in the market. Most research is based on technological components. The main keywords in this stream contain architecture, modularity, metrics and layers, which the literature review indicates are typical characteristics of platform architecture.

(3) *Governance:* Multi-sided platform governance refers to policies and mechanisms through which a platform owner or operator exerts influence over participants on both sides and coordinates operations in the ecosystem (Tiwana, Konsynski, & Bush, 2010; Wareham, Fox, & Cano Giner, 2014). In this research, the main keywords are governance, control and access.

(4) *Business Model and Consumer Relations*: This stream contains, first, the keyword business model and value, which discusses how a platform owner or operator can create value

using the multi-sided market strategy, compared with traditional markets. Second, this steam contains keywords such as customer/user/consumer, as well as behavior, trust, reputation and service. This type of research mainly focuses on how the platform owner deals with customer relations, such as through building trust and reputation.

(5) *Multi-platform Bundle Management and Strategy*: This stream is best represented by Eisenmann, Parker, and Van Alstyne (2006, p. 95), which argues that "Large companies operating in adjacent markets have the ability to offer a multiplatform bundle." Eisenmann, Parker and Van Alstyne (2006 and 2011) also discuss the related concept of platform envelopment. In this stream, the main content keywords we selected are entry, adoption, bundle, and envelopment.

(6) *Ecosystem Participants*: We can regard the environment around a multi-sided platform as an ecosystem with a specific structure of economic relationships among interdependent actors (Adner, 2017; Jacobides, Cennamo, & Gawer, 2018; Adner & Kapoor, 2010; Boudreau, 2012; Wareham, Fox, & Cano Giner, 2014). Research from this stream focuses on the interaction of participants as well as the central orchestrator (Iansiti & Levien, 2004; Moore, 1993; Altman & Tushman, 2017). The keywords in this stream contain, for example, ecosystem, industry, open, and partner.

(7) *Technological Innovation*: The platform-based ecosystem research is dominated by the quest to enhance technology-based innovation. Several researchers argue that the platform can induce innovations, even disruptive innovations (Ozalp, Cennamo, & Gawer, 2018). Some researchers believe that one purpose of a building platform is to drive industry-level innovation (Gawer & Cusumano, 2002; Perrons, 2009). This stream is represented by keywords such as technology, innovation, and evolution.

Three Levels of Analysis

The content analysis and literature review suggest that researchers come at the topic of multi-sided platforms from three levels of analysis: business, corporate, and ecosystem.

Business level refers to how a specific multi-sided platform can function as a separate business and gain success and share in a specific market. We can find this research in several research streams, particularly strategy, architecture, governance, and business model and customer relations.

Corporate level refers to broader issues, such as how a large company might enter a new market or adopt one or more new platforms. Usually this level of analysis focuses on companies that already have one or more multi-sided platforms. Researchers look at whether the firm should enter into a new field or adopt another multi-sided platform. For example, to improve corporate performance, Uber developed a new platform named Uber Eat to deliver restaurant food and take advantage of the Uber driver network and technology for route planning. Maximizing corporate benefit from platform investments is the basic logic for decision making. The corresponding research streams focused on this level of analysis are multiplatform bundle management and strategy.

Ecosystem level refers to how platforms relate to participants, from users to complementors. Research at this level looks at how the platform owner and its multiple sides interact with each other, and then how the whole ecosystem and industry perform, not simply how the platform owner performs. The main research content streams in this level cover ecosystem participants as well as technological innovation.

Of course, there are overlaps in the research, both in terms of content streams and levels of analysis. For example, it is not always clear how to distinguish the business level from the ecosystem level, especially when a multi-sided platform itself is related to several parts of an industry. However, there remain some distinguishing features or emphases for each level. For example, in the business level, even though researchers may discuss the interaction between multiple sides, their focus is usually on platform performance as a business. The main concern in this level of analysis is the platform's economic success, rather than the functioning of the ecosystem as a whole, although the two perspectives are closely related. At the ecosystem level, even though researchers may discuss interactions among ecosystem participants and the role of the platform owner, their focus is usually on the ecosystem or industry, such as how to promote technological innovation or how to maximize value creation among a broad set of actors.

We can also see differences in the strategy research between the business and corporate levels of analysis. In the corporate level, "entry or adoption" issues refer to how a large or diversified corporation may enter into a new field or adopt a new platform. By contrast, at the business level, the focus is less on entry and more on "competition" – how a business can gain an advantage or how a small entrant might compete with a large incumbent using a platform strategy. The large firms in the corporate level of analysis usually already own one or more multi-sided platforms, which they use as the foundation for multiplatform bundles. The content for the business level mainly looks at the sources of competitive advantage, especially compared with traditional single-sided markets.

Taken together, the three levels of analysis and the seven research streams suggest that managers should have different priorities at different stages of platform development. In the beginning of a multi-sided platform entry, business-level issues should have priority. As an example of recent thinking on this question, Cusumano, Gawer, and Yoffie (2019) summarize the managerial decisions into four steps: (1) Choose your market sides. (2) Figure out how to solve the chicken-or-egg problem and start building momentum in usage of the platform. (3) Determine the business model – figure out which side the platform owner can charge, and how much. (4) Establish rules for platform governance to determine who can do what on the platform.

In addition to these steps, platform owners need to consider the technology and organizational architecture to support multi-sided platform development and growth. Once they have achieved some success, network effects should kick in and contribute to expansion of platform usage and potentially lead to a winner-take-all-or-most outcome, under the right circumstances. Other issues that may later come into play after a business success include multiplatform bundles and platform envelopment at the corporate level, and other measures to maintain or expand a healthy ecosystem.

Table 2 integrates the main research streams and levels of analysis, based on a content analysis of keywords. The next section of this paper goes into more detail, using this framework.

Insert Table 2 About here

6. DETAILED ANALYSIS OF RESEACH BY STREAM AND LEVEL

The following section elaborates on the multi-sided platform research using the several streams and subcategories as well as the three levels of analysis. Tables 3, 4, and 5 highlight more specific research topics, with representative articles and theoretical arguments or empirical findings.

Insert Table 3, 4, and 5 About here

6.1 Business Level

Strategy

The literature suggests that multi-sided platform strategy differs from traditional strategy in several ways. The multiple sides of a platform introduce complexity, as does the need to deal with network externalities (network effects) as well as multi-homing. Platform strategists need to figure out how to grow and leverage an installed base of users or platform participants to gain competitive advantage, taking into account decisions such as when to enter a platform market, which platform features to offer, and what level of quality to offer (e.g., Eisenmann, 2006; Eisenmann, Parker & Van Alstyne, 2006; Hagiu, 2014; Schilling, 2002; Sheremata, 2004; Sun & Tsu, 2009; Zhu & Iansiti, 2012). Eloranta et al. (2016) also argue that platforms can be used to pursue strategic opportunities in particular types of industries or business functions. Various authors also emphasize the need for a strategy to solve the "chicken-or-egg" problem and provide open or easy access to the platform for users and complementors, decisions all shaped by multi-sided market characteristics.

Competition. Competition among platforms generally involve three main actors: the platform leaders, the platform wannabes, and the platform complementors (Gawer & Cusumano 2002). However, there are different ways to achieve competitive advantage. Several studies focus on the multi-sided platform network or ecosystem. For example, Sun and Tse (2009) show that cross-group network effects can turn the participants of a two-sided network into critical resources. Thus, the resource heterogeneity of the platform (i.e., varying initial network sizes) can be a source of sustained competitive advantage for two-sided networks and has significant impact on long-term competition dynamics. Eloranta et al. (2016) find that platforms can extend a physical product's capacity to produce new usage scenarios, facilitate interfirm information flows, enable collective benefits, and create awareness of new value potential.

Other researchers focus on dynamic competencies and argue that competencies change, according to the platform features. For example, Zeng and Glaister (2016) argue that characteristics of internet platform companies (IPCs) and the Chinese context challenge prevailing assumptions about competitive advantage. They find that dynamic capabilities of the firm, such as flexibility and experimentation, and active agency from external linkages, rather than firm-specific resources, are more important for the IPCs to maintain competitive advantage. Other scholars emphasize the role of technology in competitive advantage. For example, Yang and Jiang (2006) highlight engineering skills as well as market understanding and operations and maintenance skills as competencies needed to achieve competitive advantage in a platform market.

Several researchers challenge the tendency of platform markets to result in a winner-take-all outcome due to the need for various factors to make this happen and the likelihood that firms will

pursue different tradeoffs (Cennamo & Santalo, 2013; Eisenmann, Parker, & Van Alstyne, 2006; Gawer & Cusumano, 2008; West, 2003). For example, West (2003) empirically argues that a hybrid strategy combining open software with some control and differentiation may increase the likelihood of platform success. By contrast, Gawer and Cusumano (2002, 2008) list four levers of platform leadership as strategic tools: firm scope (what complements the platform leader will make itself), technology design (degree of openness and modularity), relations with complementors (what measures are taken to enhance the ecosystem), and the internal organization (how to structure the platform firm that makes some complements to minimize conflicts with complementors).

Researchers also discuss differences in the competitive environment for different kinds of platforms. For example, Economides and Katsamakas (2006) compare the industry structures based on a proprietary platform (such as Windows) with those based on an open source platform (such as Linux), and analyze the structure of competition and industry implications in terms of pricing, sales, profitability, and social welfare. Lee (2014) looks at contextual issues involving the broader economy, arguing that the value of a platform depends on the adoption decisions of a small number of firms. The study analyzes the type of strategic competition among platforms necessary to get oligopolistic behavior and cites the possibility of coordination failure, congestion effects, or firm multi-homing. As a results, multiple platforms can co-exist in equilibrium despite being inefficient.

Entry decision. At the business level, the entry decision mainly asks two questions: (1) How late can a firm enter a platform market and still effectively compete with incumbents? And (2) how can an incumbent platform retain its market advantage when faced with new entrants and their complementors?

For the first question, researchers find that the traditional logic for market entry, such as order or timing of entry, resources and capabilities, and predictions of post-entry performance, are different and difficult to explain for platform markets due to factors such as indirect network effects, variations in platform quality, and different types of consumer expectations (Zhu & Iansiti, 2012). For example, Zhu and Iansiti (2012) use the case of Xbox into the video game industry, arguing that the entrance success was decided by the strength of indirect network effects and on consumer discounts for future applications. Blondel and Edouard (2015) find that the open innovation process and business ecosystem support matter for a company that wants to enter into a platform-dominated market. Their basic assumption is that there will be a winner-take-all outcome due to the direct and indirect network effects. Sheremata (2004) argues that small entrants can challenge larger companies in the networked markets successfully via radical innovation. Eisenmann, Parker, & Van Alstyne, (2011) suggest that small entrants can succeed when employing proper platform envelopment strategies, even when the incumbent's network effects are strong.

For the second question, recent studies argue that the incumbent platform may lose its first-mover advantage when a late entrant overwhelms it by more effective competition. Schilling (2002) points out that this can happen when a platform does not have sufficient complements, compared to later entrants. Zhu and Liu (2018) analyze the entry decisions of Amazon into the product spaces of its complementors (such as through Amazon Marketplace) and find that the platform owner prefers to enter into more successful product spaces but not if too much market-specific sales efforts are required.

Pricing. As a new business form, multi-sided platforms disrupt some traditional economic theories. For example, economists have explored how the platform can act as a "conduit" to stimulate network effects (Caillaud & Jullien, 2003; Parker & Van Alstyne, 2005; Armstrong, 2006; Economides & Katsamakas, 2006, Eisenmann, Parker & Van Alstyne, 2006; Rochet & Tirole, 2006; Weyl, 2010; Zhu & Iansiti, 2012). Since a multi-sided market brings together several actors, such as users and complementors, traditional single-sided economic models of supply and demand no longer apply, and this anomaly has made pricing decisions an important stream of multi-sided platform research. For example, Clements and Ohashi (2005) argue that pricing not only plays an important role in the beginning of a product life cycle, but also can be significant in latter stages as well for a software platform.

Industrial organization scholars have come to dominate the platform pricing literature (Clements & Ohashi, 2005; Evans, Hagiu, & Schmalensee, 2006; Parker & Van Alstyne, 2005; Rochet & Tirole, 2003, 2006; Rysman 2009). Platform owners for two-sided networks can draw revenue from both sides but the research generally suggests that platforms should subsidize the one side most likely to attract another side (Caillaud & Julian, 2003; Evans, 2003; Rochet & Tirole, 2006, etc.).

Several scholars also have conducted detailed research on the antecedents of pricing structure and allocation. Investigating the platforms in multiple industries from the 1990s to the early 2000s, Rochet and Tirole (2003) argue that platform governance, differentiation, end-user multi-homing costs, network externalities, and platform compatibility all influence pricing decisions. In particular, based on user heterogeneity, Rochet and Tirole (2003, 2004, 2006) developed a popular model (RT) for two-sided markets and propose several factors to take into consideration when making pricing decisions: 1) the demand elasticities of both sides (see also Armstrong, 2006 as well as Rochet & Tirole, 2003); 2) relative market power; 3) consumer surplus created on the other side; 4) competition and multi-homing; and 5) bundling. Eisenmann, et al. (2006) list several points to deal with pricing strategy, including ability to capture cross-side network effects, user sensitivity to price and quality, output costs, same-side network effects, and brand value to users. Hagiu (2014) also lists several pricing principles for business executives related to price sensitivity, consumer benefit, and the value transaction.

Architecture

Generally, platform architecture plays a significant role in technological innovation (Baldwin & Clark, 2000; Baldwin & Woodard, 2009; Cennamo, Ozalp, & Kretschmer, 2018; Gawer, 2014; et al.,) as well as value creation and capture (Tee & Gawer, 2009). Although there is a relatively large number of studies on platform architecture, the basic research looks at common themes (Whitney, et al., 2004; Tiwana, Konsynski, & Bush, 2010; Cennamo, Ozalp, & Kretschmer, 2018; Baldwin & Woodard, 2009). Whitney et al., (2004) define architecture broadly as including several factors, such as functions, the physical components needed to perform those functions, the detailed arrangement and interfaces between the components, and a description of how the system will operate through time and under different conditions. Based on previous research, Tiwana, Konsynski and Bush (2010, p. 676) define the platform architecture as a "conceptual blueprint that describes how the ecosystem is partitioned into a relatively stable platform and a complementary set of modules that are encouraged to vary, and the design rules binding on both." Other researchers emphasize the technical functions (Cennamo, Ozalp, & Kretschmer, 2018) and define the platform

architecture as the set of technological capabilities and the way a platform's technological components function and connect to platform complements (Baldwin & Woodard, 2009, Tiwana, 2015).

The most cited definition for platform architecture is based on Baldwin and Woodard (2009), which argues that architecture is the relationship between platforms and the systems in which they are embedded. They state that the fundamental features of a platform architecture are "certain components [that] remain fixed over the life of the platform, while others are allowed to vary in cross-section or change over time" (p.23).

Modularization. Researchers argue that modularization is an important way for platforms to organize their architectures since subsystems affect evolvability (Tiwana, 2015; Tiwana, Konsynski, & Bush, 2010). Modules refer to components within a complex system that either stay connected with low variations or are relatively weakly connected with potentially more connections and higher potential system variety (Baldwin & Clark, 2000; Baldwin & Woodard, 2009; McIntyre & Srinivasan, 2017). Modular architectures are characterized by standardized interfaces between components (Yoo, Henfridsson, & Lyytinen, 2010). Architectures also offer different degrees of modularity. Tiwana, Konsynski and Bush (2010) refer to modularity as the degree to which changes within a subsystem do not create a ripple effect in the behavior of other parts of the ecosystem. As argued by Baldwin and Woodard (2009), low modularity can result in wide-ranging, unpredictable ramifications of any change in the ecosystem.

A modular architecture is a way for platforms to add more functions as well as attract complementors, who can use the modular design to add their own products and services to the platform (Gawer & Cusumano, 2008). A tightly integrated or integral design makes outside innovation more difficult. Modularity is also a way for platforms to cope with ecosystem change and evolution (Aerts et al., 2004; Tiwana, 2015). Tiwana (2015, p.268) offers the concept of extension modularity as "the degree to which an extension is loosely coupled and interacts through standardized interfaces with the platform." Other research lists the benefits of modular platform architectures to the extent that they decrease the coordination and transaction costs across module boundaries (Baldwin, 2008). Thus, modularity could free up the cognitive resources of complement developers to focus on more challenging problems (Tiwana, 2008), and encourage greater specialization, which can drive development of differentiated capabilities among ecosystem participants. However, modularity may also enable imitation and progressively erode the distinctiveness of modules and ecosystems (Pil & Cohen, 2006), narrow the scope of learning by platform owners, and cause the loss of specific synergies (Schilling, 2002).

Evolvability. A key property for the platform architecture is evolvability, which in this case means the ability of a platform architecture to adapt to unanticipated changes in the external environment. Because a platform architecture is a complex system that contains stable core components and more flexible peripheral components, reuse of stable core components can reduce the cost of adaptation or creating new variety for the system as a whole. Peripheral components can also play significant role to cope with changes in the external environment, enabling platform systems to evolve (Baldwin & Woodard, 2009).

Other scholars besides Baldwin and Woodard also highlight the importance of evolvability. As Aulkemeier et al., (2016) argue, the initial reason for the platform architecture is to build core capabilities and then create a partner ecosystem around the platform. Therefore, when adapting to unanticipated change in the external environment, it is the ability to evolve that makes a platform

architecture flexible and beneficial in the present and potentially in the future. Tiwana, Konsynski, & Bush, (2010) also state that the platform architecture should be able to evolve along with the ecosystem in which it is embedded.

Architecture representation. Baldwin and Woodard (2009) develop three approaches to represent the platform architecture, including network graphs, design metrics, and layer maps. Specifically, in the network graphs, the platform firm is regarded as a node, while the relationship between them is link. This kind of design is useful to illustrate a simple hub-and-spoke structure. For the design structure matrices, if the platform incorporates interfaces that complementors must use to access the system, the complements depend on the platform. Layer maps can be used where components act or compete across platforms. Within a layered architecture, components can be vertically arranged in separate layers, while the layers determine who competes in the market. Other researchers have conducted studies on the platform layer maps, such as Yoo, Henfridsson, & Lyytinen (2010), who conceive a platform as a layered architecture of digital technology.

Organizing logic. Two design rules are required for platform architectures: stability and versatility (Baldwin & Woodard, 2009; Tiwana, Konsynski, & Bush, 2010). Aulkemeier et al., (2016) designed a pluggable service platform architecture for e-commerce platforms, which contains the functions of platform provider and the service providers, taking the stakeholders into consideration. Kaliontzoglou et al. (2005) proposed an architecture for a secure e-government platform online, which addresses needs to balance interoperability, security and user friendliness.

Governance

Due to the multiple market sides and related features, existing research on platform governance has focused on policies and mechanisms through which a multi-sided platform operator can exert influence over participants on both sides and coordinate operations in the ecosystem (Tiwana, Konsynski, & Bush, 2010; Wareham, Fox, & Cano Giner, 2014).

In terms of content under this stream, Hagiu (2014) summarizes the issues through two questions: access to the platform (who is allowed to join) and interaction on the platform (what are participants allowed to do). Tiwana, Konsynski, and Bush (2010) can be regarded as a more detailed illustration of the interaction process, which addresses Hagiu's second question. They propose 1) decision rights partitioning, 2) control, and 3) proprietary versus shared ownership. The first refers to how decision-making authority is divided between the platform owner and module developers, which is related to platform features and functionality, the design, concept implementation, user interfaces, and control over the ecosystem's internal interfaces.

Baldwin and Woodard (2009) argue that the platform owner should not control all the decision rights. Other authors note that control in this context refers to "the formal and informal mechanisms implemented by a platform owner to encourage desirable behaviors by module developers, and vice versa" (Tiwana, Konsynski, & Bush, 2010, p. 680), and includes output control and process control. As for governance attributes and ownership, similar with Eisenmann et al. (2006), it refers to whether a platform sponsor shares or solely owns the platform.

Governance is also seen as a problem of designing effective ecosystem-wide mechanisms (Gulati, Puranam, & Tushman, 2012). Based on previous research, Song et al. (2018) summarize the three categories of platform governance mechanisms: pricing (Rochet & Tirole, 2006; Tiwana, 2014); mechanisms used to coordinate and control platform participants; and platform's self-development (Cusumano & Gawer, 2002). They also use the duration of app review processes and

platform update frequency as two examples of empirical mechanisms for platform governance. The former reflects how the platform controls complementors' behavior (Maurer & Tiwana, 2012), while the latter reflects how the platform can improve its own design and architecture by self-development (Tiwana, 2014).

Current research emphasizes balance according to several principles: loose or tight control, level of decentralization, close or distant governance. We can say that, first, all the governance content questions deal with the tradeoff of how loose or tight the rules are (Hagiu, 2014), with several concerns taken into consideration, such as antitrust. Hagiu (2014) believes the tradeoff is the choice of quantity versus quality, as well as distance. The tighter the governance rules, the higher the quality of the platform. From the network effects perspective, not only the number of members and their interactions, but also the quality of the members matters.

Centralization has been a classic topic for IT governance and this applies to platforms as well (Schwarz & Hirschheim, 2003). The degree of centralization and decentralization is also discussed when it comes to the decision-rights partitioning problem (Tiwana, Konsynski, & Bush, 2010). Tiwana, Konsynski and Bush (2010) describe this problem as centered around the level of authority and responsibility for each decision between the platform firm and its related sides. As for how close or faraway the governance relationship is, various scholars (Baldwin & Clark, 2000; Parker & Van Alstyne, 2005; Wareham et al. 2014) believe that an "arm's length" approach is best to promote standardization and to orchestrate the activities of a large ecosystem of complementors. An arm's length approach can also reduce governance costs. However, some researchers believe this type of governance may limit the ability of the platform to respond to changing local needs, which may constrain value creation (Huber, Kude, & Dibbern, 2017). They suggest a dyadic governance mechanism to balance the tension between co-created value and governance cost.

The influences of platform governance vary from platform network effects to ecosystem performance (Boudreau & Hagiu, 2009; Hagiu, 2014; Song et al., 2018), financial returns (Boudreau, 2012), management efficiency (Schwarz & Hirschheim, 2003), market success (Hagiu, 2014), and safety (de Reuver et al., 2011). Several scholars argue that governance can clearly affect the value of the platform ecosystem and customer value proposition (Hagiu, 2014; Boudreau & Hagiu, 2009). Song et al. (2018) reveals that, in a software platform, the longer it takes for the app review (one approach to platform governance), the weaker the cross-side network effects. Their observations are based on other research (for e.g., Ghazawneh & Henfridsson, 2013). Other scholars emphasize the difficulty of building and managing a platform, in terms of security, billing and customer data management (de Reuver, et al., 2011).

On the financial side, Boudreau (2012) argues that the multi-sided platform owner restricts entry of developers so that those who are licensed are able to make a sufficient return on their investments. On the management side, if a platform is able to implement a good governance strategy, then it should be more efficient as well as more successful as a platform organization (Schwarz & Hirschheim, 2003). Hagiu, (2014) also argues that proper platform governance is a way to avoid potential market failures. These failures include the following: 1) Insufficient information and transparency in the platform and market, which may lead to a lemons market failure, considering the quality of goods and services. 2) Too much competition within one particular side of the multi-sided platform, which can reduce incentives to invest in new products and services. 3) Less investment and actions on potential positive spillover effects.

Business Model and Customer Relations

This section focuses on platform business models and customer relations mainly based on customer characteristics and behavior.

Platform Business Models. There has been a virtual explosion of business model research along with the flourishing of e-commerce businesses around the world (Zott, Amit, & Massa, 2011). We still lack a consistent definition and language to describe platform business models (Zott, Amit, & Massa, 2011), which various scholars argue is a special type of business model (Saebi & Foss, 2015; Täuscher & Abdelkafi, 2017; Täuscher & Laudien, 2018). However, there are some common features or core questions in the discussions of platform business models, and these vary depending on the value proposition, the revenue model, the market opportunity, and the competitive environment. Most authors deal with similar concepts (Fehrer, Woratschek, & Brodie, 2018; Muzellec, Ronteau, & Lambkin, 2015), based on the seminal work on value chains by Porter (1980, 1985) and the value creation, capture, and delivery model of Teece (2010).

For value creation, in the context of a platform business model, the core question shifts from value creation to value co-creation among the platform participants (Fehrer, Woratschek, & Brodie, 2018; Haile & Altmann, 2016). The main arguments are based on the characteristics of a multi-sided platform, which is regarded as an open business model, with various degrees of openness (Saebi & Foss, 2015). All the actors are viewed as endogenous to the platform and they act in conjunction with the platform owner, rather than just existing at the boundaries of a core firm (Nenonen & Storbacka, 2010). This novel form of actor-to-actor interaction challenges the traditional logic that only one firm controls an entire interaction system (Wieland, Hartmann, & Vargo, 2017).

Moreover, value creation is no longer from the supply and demand market structure, but from the open interaction among platform participants (Belleflamme & Jacqmin, 2016; Fehrer, Woratschek, & Brodie, 2018). The business model thinking evolved from the line to the network, i.e., from Porter's (1980, 1985) firm-centered value chain logic, to the network integration and collaboration logic (Fehrer, Woratschek, & Brodie, 2018). The costs and revenues are connected with both sides, rather than from left to right, compared with the traditional value chain system (Eisenmann, Parker, & Van Alstyne, 2006). This value co-creation model shapes platform boundaries and interactions within the dynamic value system (Ehret, Kashyap, & Wirtz, 2013; Fehrer, Woratschek, & Brodie, 2018).

Along with value co-creation, value capture differs in a platform environment because of the broader set of value actors and the more complex value co-creation process. Various authors (Fehrer, Woratschek, & Brodie, 2018; Amit & Zott, 2015) discuss internalizing "positive externalities generated by each actor's value proposition" (Fehrer, Woratschek, & Brodie, 2018, p. 555). As claimed by Amit and Zott (2015), value capture can also be regarded as the economic viability of a multi-sided platform business model. Some researchers propose that different technological infrastructures influence value capture (Akaka, Vargo, & Lusch, 2013), such as governance rules (Fehrer, Woratschek, & Brodie, 2018) and collaboration practices (Berglund & Sandstrom, 2013). These theoretical arguments also discuss the advantages of platform value capture in terms of reducing transaction costs, increasing network externalities, and leveraging complementarities (Fehrer, Woratschek, & Brodie, 2018).

Following the general value drivers described by Zott, Amit and Massa (2011) on business models, Chandna and Salimath (2018) investigate the roles of different value drivers on firm

performance in peer-to-peer platforms. Empirical results show that a synergistic combination of four value drivers, including information processing capability, product portfolio complexity, innovative practices and network membership, rather than any one independent driver, is critical to firm performance and user satisfaction.

Other studies discuss the possible platform business model structure and corresponding choice decision. For example, Täuscher and Laudien (2018) investigate digital platform business models via a cluster analysis approach. Rigorously based on Teece's value creation, value delivery, and value capture, they use platform attributes to examine detailed elements and suggest six platform business models for efficient product transactions, digital product communities, product aficionados, on-demand offline services, online services, and peer-to-peer offline services. Muzellec, Ronteau and Lambkin (2015) also studied the choice of platform business models with an analysis of five early stage Internet ventures and found that, "In two-sided Internet platforms, the monetization of the business model is B2B oriented" (p. 3).

Customer relations, characteristics, and behaviors. A relatively small stream of research has examined customer relations and management from a customer characteristics and behavior point of view. Some studies show that user personalities (Adamopoulos, Ghose & Todri, 2018) and user preferences (Gal-Or, Gal-Or & Penmetsa, 2018; Chakravarty, Kumar & Grewal, 2014) influence multi-sided platform-related outcomes. For example, Adamopoulos, Ghose and Todri (2018) investigate the impact of user personality traits on user behavior in social media platforms. They find that the similarity of the user characteristics plays a positive role on users' platform purchase behavior. Also, the agreeable, conscientious, and open social media users are more effective disseminators of social media platform purchases.

Gal-Or, Gal-Or and Penmetsa (2018) studied user's privacy concerns for the influence of platform competition. Their results show that the intensity of competition between the platforms matters for the extent of differentiation in platform advertising targeting levels. When users care less about loss of privacy, the competition for users may decline. The higher the targeting of differentiation, the higher the profits. Chakravarty, Kumar and Grewal (2014) empirically show that both total customer orientation and customer orientation asymmetry affect platform performance.

User positions also influence multi-sided platform outcomes (Ye & Kankanhalli, 2018; Chakravarty, Kumar & Grewal, 2014). Specifically, Ye and Kankanhalli (2018) use the mobile phone platforms to investigate users' positions with regard to innovation. Their results show that the direct influence of the lead users, the toolkit support, design autonomy, and the interaction of these antecedents play roles on the platform user innovation outcomes. Chakravarty, Kumar and Grewal (2014) also find that, apart from customer orientation, customer concentration also affects the platform performance, including the buyer-sider concentration and the seller-sider concentration.

Researchers not only focus on the influences of customers on the platform, but the influence of interactions and vice-versa. Celata, Hendrickson and Sanna (2017) argue that trust, reciprocity and belonging in peer-to-peer platforms is beneficial for mobilizing a sense of platform community. Eliciting customers' active participation in self-regulation is, therefore, crucial. Im et al. (2016) studied the relationship between the deal-seeking/brand-seeking keywords and consumer search behaviors and buying propensities. The research reveals that search queries containing deal-seeking keywords are related with higher click-through rates and conversion rates than search

queries without such keywords. Chakravarty, Kumar and Grewal (2014)'s work not only describes the influence of customer orientation on platform performance, but also shows that platform exchange attributes (including the dynamic versus static price discovery process, two- versus one-sided buyer–seller matching process and proportion of transaction-driven fees) moderate the relationship.

6.2 Corporate Level

This level of analysis is inspired by the phenomena of multiplatform bundles (such as at Amazon, Google, or Apple) and platform envelopment, along with the requirements of a successful multi-sided platform. The corporate issues center on the market entry decisions as well as how to use corporate resources to promote network effects once a firm has established more than one platform.

Platform Bundling and Envelopment

Multiplatform Bundles. Bundling originally refers to a business strategy where the purchase of one product leads to potential demand for another product (Chao & Derdenger, 2013). It follows that large companies which operate platforms in adjacent markets have the ability to offer a "multiplatform bundle" (Eisenmann, Parker & Van Alstyne, 2006, p. 95). The decision to offer a multiplatform bundle is at the corporate level, reflecting a desire to take advantage of user overlap or shared content (Eisenmann, Parker & Van Alstyne, 2006).

According to Eisenmann, Parker and Van Alstyne (2011), the benefits to bundling vary according to the type of platform envelopment. For example, when there is user overlap, a multiplatform bundle can create opportunities for tying at an attractive price, especially when a platform envelops complementors or an unrelated functional market. The multiplatform bundle also enjoys price discrimination benefits when moving into a functionally unrelated market. Multiplatform bundles can provide economics of scope when encountering weak substitutes. Bundling in a multi-sided market can also foreclose a complement producer's access to users and then provide the platform company with access to more profits from the complement market (Carlton & Waldman, 2002; Nalebuff, 2004).

One special topic at this level of analysis is antitrust. Usually, antitrust in public policy is concerned mostly with the business level (Rysman, 2009). However, at the corporate level, multiplatform bundling can trigger what has been called the "antitrust paradox" (Khan, 2017). This refers to the case where a multi-platform company (e.g., Amazon) may have low market shares in specific businesses but can still provide a threat to competitors due to the way it ties together customer data from multiple platforms and provides subsidies or discounts in multiple, seemingly unrelated markets.

Platform Envelopment. Eisenmann, Parker and Van Alstyne (2011) define a new strategy, platform envelopment, whereby a platform provider takes advantage of similar components and overlapping user bases to move into an adjacent platform market with a new multiplatform bundle. They also identified three types of platform envelopment based on the relationship between two platforms: envelopment of complements, of weak substitutes, and of unrelated functions. Different factors also seem to impact success. For envelopment of complements, Eisenmann, Parker and Van Alstyne argue that user overlap seems particularly significant; the higher the overlap, the

greater the likelihood of success. As for envelopment of weak substitutes, economies of scope seem to be more important. As for envelopment of unrelated functions, both larger user overlap and large economies of scope should correlate with success. Eisenmann, Parker, & Van Alstyne (2006) also deal with how a company faced with the threat of platform envelopment can cope with this threat and the multiplatform bundle. They argue that a target firm can survive platform envelopment by either changing its business model, finding some bigger partners to gain support, or suing for antitrust violations.

Other scholars have also discussed platform envelopment and success factors (Müller, Kijl & Visnjic, 2018; Zhang & Duan, 2012). Specifically, Müller, Kijl &Visnjic (2018) researched Yahoo and Google. They argue that, if a corporation can add related functionality to its initial platform and then expand into distinct platforms, it can expect a positive performance, as in the case of Google. On the other hand, Yahoo expanded into functionally distinct platforms directly, with less positive results. Looking at large Chinese e-business platforms (Taobao, Baidu and Tencent), Zhang and Duan (2012) connect the mechanisms of envelopment to cross-side network effects, overlapping between platforms, and strategic locking behaviors based on learning effects.

Entry and Envelopment

Entry decisions and platform adoption at the corporate level also differ from the business level if the corporation already has a platform and is contemplating adding another. The entry decision for this level focuses on the decision whether or not to adopt a new multi-sided platform as well as other issues, such as how to maximize network effects.

Researchers have also looked at the influence of a multiplatform corporation's entry decision on competitors. For example, to retain its competitive advantage, using the case of Intel, Gawer and Henderson (2007) find that the large platform company should encourage widespread entry despite the fact that potential entrants (rationally) feared Intel's ability to "squeeze" them ex post. The organizational structure and processes as commitment mechanisms impact success.

Research at this corporate level is limited, making generalizations difficult. However, the managerial challenges of a multi-brand or multi-product corporation (Skold & Karlsson, 2007) can provide some analogies to the challenges of a multiplatform bundle and platform envelopment. This topic requires more study of traditional corporate strategy themes such as portfolio management, multi-business organizational structures, how business units and functional units interact, and product or service differentiation issues.

6.3 Ecosystem Level

Ecosystems can exist without a platform in the center. However, when looking at a multi-sided market, the multi-sided platform is regarded as itself to be a kind of ecosystem, with multiple participants contributing to user value (Kapoor, 2018). Not surprisingly, there is considerable research on the relationship between platforms and ecosystems (Gawer & Cusumano, 2002, 2014; Eisenmann, Parker, & Van Alstyne, 2009; Boudreau, 2010; Ozalp, Cennamo, & Gawer, 2018; Perrons, 2009; Parker, Van Alstyne & Jiang, 2017). Still, however, there remains a lack of consistent definitions and concepts. For example, we have the notion of a platform leader (Gawer & Cusumano, 2002), a keystone firm (Iansiti & Levien, 2004; Kang & Downing, 2015), an industry platform (Gawer & Cusumano, 2014; Cusumano, Gawer, & Yoffie, 2019), and platform based ecosystems (Zhu & Iansiti, 2012; Ozalp, Cennamo & Gawer, 2018; Iansiti & Levien, 2004;

Parker, Van Alstyne, & Jiang, 2017; Parker & Van Alstyne, 2014). Even though each concept has its own context and specific meaning, one required characteristic of an ecosystem is interaction between the external parties and the focal platform or organization (Altman & Tushman, 2017). The following table lists the main concepts of multi-sided platform ecosystem discussions. The following sections are organized by the two main themes in the research – ecosystem participants and ecosystem functions with regard to technological innovation.

Insert Table 6 About here

Participants

Researchers agree that the platform-based ecosystem shows a specific structure of economic relationships among interdependent actors (Adner, 2017; Jacobides, Cennamo, & Gawer, 2018; Adner & Kapoor, 2010; Boudreau, 2012; Wareham, Fox, & Cano Giner, 2014). Thus, who are the core participants of a platform-based ecosystem is a theme that has drawn lot of attention and has been one of the most important research streams for this level of analysis (Adomavicius et al. 2007, 2008; Eisenmann, Parker &Van Alstyne, 2009; Gawer & Henderson, 2007; Lee & Mendelson, 2008; Parker & Van Alstyne, 2008; West, 2003).

The main participants in a platform-based ecosystem are broadly regarded as the platform owner and complementors (Ozalp, Cennamo, & Gawer, 2018). Since the partner activity matters for platform-based ecosystem performance (Ceccagnoli et al., 2012), researchers focus on the interaction of participants as well as the central orchestrator of the ecosystem (Adner & Kapoor, 2010; Iansiti & Levien, 2004; Moore, 1993; Altman & Tushman, 2017).

The central orchestrator, i.e., the platform leader, plays a key role in the ecosystem (Evans, Hagiu, & Schmalensee, 2006; Altman & Tushman, 2017). The basic assumption for participants is that the platform owner and complementors have a reciprocal relationship: when the platform owner invests resources for the platform to attract complementors, in turn, the complementors would like to commit resources that complement the platform. Thus, the main research questions focus on how the platform owner can encourage third-party complementors to stimulate and contribute to the development and value of the ecosystem as a whole (Gawer & Cusumano, 2002; Cusumano & Gawer, 2002; Ceccagnoli et al., 2012; Eisenmann, Parker & Van Alstyne, 2009; McIntyre & Srinivasan, 2017; Parker & Van Alstyne, 2008; West, 2003). Recent research has explored potential approaches, including the promotion of indirect network effects and specific platform technologies (Eisenmann, Parker & Van Alstyne, 2009; Gawer & Cusumano 2002), by creating platforms of superior technical quality (Evans, Hagiu, & Schmalensee, 2006; Yoffie & Kwak, 2006), or by adopting an open innovation strategy (Eckhardt, Ciuchta & Carpenter, 2018).

As for complementors, due to the inherent mutual dependence within the system (Venkatraman & Lee, 2004), researchers believe that complementors can provide resources critical to platform ecosystem's success, such as value creation and commercialization (Ceccagnoli et al., 2012; Eckhardt, Ciuchta, & Carpenter, 2018; Vanhaverbeke, Chesbrough, & West, 2014; Parker, Van Alstyne & Jiang, 2017), platform growth (Boudreau & Jeppesen, 2015; Parker & Van Alstyne, 2018), and technological innovation (Gawer & Cusumano, 2002; Kapoor & Lee, 2013). There are several nuances identified in this research. For example Boudreau and Jeppesen (2015) specifically find that unpaid complementors respond to platform growth, but do not stimulate network effects. But most researcher find that complementors are beneficial for technological innovation within

the ecosystem (Evans, Hagiu, & Schmalensee, 2006; McIntyre & Srinivasan, 2017). Kapoor and Lee (2013) also argue that firm-complementor investments matter for shaping new technology benefits.

Fuentelsaz, Garrido and Maicas (2015) found evidence that the technological value of complementary assets for the platform owner and ecosystem varies due to contextual factors. Ecosystem conditions also influence complementors' performance. For example, Kapoor and Agarwal (2017) found that ecosystem complexity enhances motivation and thus leads to higher and sustained complementor performance.

Among complementors, third-party developers are especially important for online or software platforms. Andreessen (2007) even defines the platform-based ecosystem from the perspective of third-party developers. Some platform companies prefer to rely on external innovation compared to internal development (Parker, Van Alstyne & Jiang, 2017). A growing stream of researchers have looked at the role of third-party developers in the ecosystem (Kapoor & Agarwal, 2017; Qiu, Gopal & Hann, 2017; Makinen, & Kanniainen & Peltola, 2014; Parker & Van Alstyne, 2018). Parker & Van Alstyne (2018) also examine the optimal decisions or timing for third-party developer's intellectual property, concluding that the longer the innovation rights holding for developers, the higher their royalties. Makinen, & Kanniainen & Peltola (2014) argue that developers are of vital importance for new platform-based applications development, including planning, resource allocation, development costs, timing of commercial introduction, and end-product launches.

Technological Innovation

Technological innovation that can occur beyond the boundaries of the firm and beyond the scope of supplier contracts can be regarded as one specific benefit of an innovation platform and ecosystem (Gawer 2014; Cusumano, Gawer, & Yoffie, 2019). However, technology management scholars have argued that, due to network effects and multi-sided relationships, the modes of technology innovation shift from individual engineering designs to modular designs and distributed innovation, which can benefit from the work of multiple actors as well as network effects (Gawer & Cusumano, 2002, 2014; McIntyre & Srinivasan, 2017).

Most researchers agree that the platform can induce innovations, even disruptive innovation (Ozalp, Cennamo, & Gawer, 2018). Some researchers believe that a major purpose of building a platform is to drive innovation (Perrons, 2009). Several innovation researchers explore what is the optimal platform design, governance mechanisms, and ways to generate network effects (e.g., Boudreau, 2010; Baldwin & Woodard, 2009; Gawer & Cusumano, 2002, 2014; Gawer & Henderson, 2007; Tiwana, Konsynski, & Bush, 2010). For example, the concept of platform leaders and industry-level innovation platforms refers to technology firms which can mobilize a vibrant ecosystem to enhance the value of the core technological platform, and also contribute to ecosystem value (Gawer & Cusumano, 2002, 2014; Eisenmann, Parker, & Van Alstyne, 2009; Parker et al., 2016; Cusumano, Gawer, & Yoffie, 2019). In a highly innovative ecosystem, an embedded technological platform can encourage technology transactions and thus offer greater benefits for users in terms of better complements and services (Cennamo, 2018). Ozalp, Cennamo and Gawer, (2018) also provide evidence that next-generation platform technologies can shape the learning curve, trigger disruptive innovation, and then thrive in next-generation competition.

The main mechanisms of technology innovation for platform-based ecosystems lay firstly on external rather than internal mechanisms (Altman & Tushman, 2017; Gawer & Cusumano, 2014). This means that platforms interact with and derive value from entities outside their boundaries, mainly complementors (Parker, Van Alstyne, & Choudary, 2016a; Rochet & Tirole, 2003; Zhu & Iansiti, 2012). In this sense, the locus of value creation moves from inside to outside the firm (Parker, Van Alstyne, & Jiang, 2017).

Other mechanisms depend on network effects (Ceccagnoli et al., 2012; Eisenmann, Parker, & Van Alstyne, 2009; Gawer & Cusumano, 2002, 2014; Kenney & Pon, 2011). For example, participants on one side of a platform may benefit when more participants join the other side (Gawer & Cusumano, 2014; Katz & Shapiro, 1992; Zhu & Iansiti, 2012; Altman & Tushman, 2017). Generally, these network effects represent self-sustaining positive feedback loops (i.e., network effects), such as to encourage more complementary innovations from the developer side of a software platform. When the number or quality of platform adopters and complementors rise, we can expect an exponentially increasing rate in the value of the platform (McIntyre & Srinivasan, 2017). However, network effects also come with tradeoffs or limits. For example, Boudreau (2012) showed that the positive feedback loops do not perpetuate themselves ad infinitum; too many complementors at some point may discourage further investment for additional firms to join the ecosystem, which in turn reduces overall levels of innovation.

Another mechanism for technology innovation is platform openness. Various researchers argue that an open innovation strategy can contribute to platform owners taking on leading positions in their markets (Gawer & Cusumano, 2002; Iansiti & Levien, 2004; West, 2003; Eckhardt, Ciuchta, & Carpenter, 2018). Researchers also have studied the platform openness decision in terms of specific platform "sides" (Boudreau, 2010; Gawer & Cusumano, 2008; Parker & Van Alstyne, 2018; West, 2003). Specific factors related to openness are platform interfaces, access to information, cost of access, and interface governance, all of which can influence innovation (Baldwin & von Hippel, 2011; Boudreau, 2010; Eisenmann, Parker & Van Alstyne, 2008; Lee & Mendelson, 2008; West, 2003; Gawer, 2014). Researchers also suggest a tradeoff with platform openness. More open interfaces typically increase complementors' incentives to innovate (Boudreau, 2010; Eisenmann, Parker & Van Alstyne, 2009), while too much openness can lead to a loss of revenue and profit for those same complementors (Eisenmann, Parker & Van Alstyne, 2006, 2009).

Apart from these mechanisms, the platform owner in the ecosystem can adopt several innovation strategies to enhance the position of industry leadership (Gawer & Cusumano, 2002; Iansiti & Levien, 2004; West, 2003). Gawer and Cusumano (2002) studied the case of Intel and list four levers (noted earlier) that can drive industrywide innovation. The goal of platform leadership, in their sense, is for the platform owner to create an ecosystem where actors work together to make the whole more valuable than the sum of the parts.

7. DISCUSSION AND CONCLUSIONS

The following discussion is based on the seven main research streams and the three levels of analysis. Figure 2 illustrates the timeline trends of the three levels. Figure 3 details the seven main research streams and the trends for each level.

Broadly speaking, from the start of multi-sided platform research in the 1980s, the business level and the ecosystem level have dominated the research if we look at the number of publications year by year. To be more specific, we can see ecosystem-level publications in the very early years, while business-level research caught up from 1996, and then surpassed the number of ecosystem-level publications. Since then, both business- and ecosystem-level publications have increased at a similar rate. In 2018, for example, we count at the business level 80 articles and at the ecosystem level 62 articles (based on the WoS dataset). In comparison, corporate-level research appears starting in the late 1990s but is less common. In 2018, we counted only 9 articles published at the corporate level of analysis.

Insert Figure 2 and 3 About here

We can make several comments regarding the research for each level of analysis, based on the statistical data.

7.1 Business-Level Platform Research

Statistical data and historical trends

The strategy stream dominates the business-level research, from the very beginning of this topic through to recent years. Strategy research has focused on the multiple sides of platform markets, compared with the traditional single-sided market view, and how to achieve competitive advantage with service and pricing strategies seen as differing for each side. At the same time, industrial economics has been the main research discipline behind the analysis of multi-sided markets as well as multi-sided platform dynamics.

Business model and customer relations also play a significant role in business-level platform research. Even though it was not started as early as the strategy stream, it caught up in the early 2000s, and also saw a relative quick increase in publications quantity. Business model content mainly discusses value creation from the value network perspective rather than the traditional value chain. Customer relations deals more with the issues of trust and platform reputation management, discussing questions such as user characteristics and behavior.

Recent years witnessed the appearance and development of both the architecture and governance streams of research. The architecture content is mainly based on looking at technological designs that can support other functions, which resemble information systems and computer science research. Governance publications also appear to be growing in recent years.

Commentary review and potential future trends

The business level research typically represents the basic theories and characteristics of multi-sided market and network externalities associated with a single multi-sided platform. The main research content in this level has evolved as follows, from (1) the evaluation of a multi-sided platform, compared with a traditional single-sided business, to (2) the choice of which side to enter, to (3) how to develop each side, and then to (4) governance of each side.

In the first period, the main research focus was on the competitive advantages of the multi-sided platform, mainly with regard to the sources of competition. In the second period, researchers paid more attention to which side to enter, which mainly deals with the chicken-or-egg problem. In the third period, researchers focused on how to build up the user and complementor bases. The above three periods and questions mainly discuss competitive advantage and pricing strategy. The appearance and development of multi-sided governance research naturally follows the earlier research and growth of platforms in the economy and real issues that have surfaced, including factors that may induce failure in certain multi-sided platforms. For example, both Uber and Didi are ride-sharing platforms that came close to a financial catastrophe due to the failure to protect riders from a few unqualified and ill-intentioned drivers. Given the broader discussion of governance issues with other platforms, including social media leaders such as Facebook, we expect governance research to increase in the immediate future.

Platforms as a new business model and source of value creation should also remain an important subject of research in the future. Many startups are now creating multi-sided platforms, and so platform studies have become a key part of entrepreneurship research. Academically, the research suggests that, although value creation for the multi-sided platform may require a shift in thinking from the value chain to the value network, we need more detail on mechanisms and outcomes, especially for startups with little market power. Strategy also may need to change for firms that are successful and grow, from a focus on conquering multiple sides of a platform to governing multiple sides.

Customer relations are also more complex with multi-sided platforms compared to conventional businesses. For the platform owner, both users and complementors resemble traditional customers or may replace suppliers. The platform owner needs to juggle several potentially difficult relationships: between users and complementors, among users, and among complementors. Not only are the relations important among different actors, but also the type of relationship also matters, including trust, reputation, and the rules for how platform and ecosystem participants interact. These issues all are strongly connected with network effects. For example, too many rules, such as constraints on who can join a platform, can depress networks. How to combine governance challenges with effective customer relations is itself a complex topic. In this stream, due to the practical needs and the development of information systems and big data technology, we expect empirical, data-driven research on these issues to increase in the future.

Architecture research is an old topic that has taken on new significance with multi-sided platforms. A lot of architecture studies rely on earlier work in computer science and information systems, as well as on product platforms. However, multi-sided platform architectures are different. For example, the architecture in a product platform is controlled and used mostly within a firm and its suppliers and controlled by contracts. By contrast, the architecture for a multi-sided platform extends across an ecosystem and is not controlled in the same way. Also, the product platform architecture generally aims to increase product innovation, whereas the multi-sided platform architecture aims to support multiple functions. In the future, we expect the architecture stream research to focus more on complex but practical system requirements, but this subject may not be a priority for management and business researchers. Multi-sided platform architecture is likely to be a more popular topic among computer science and information system researchers.

7.2 Corporate-Level Platform Research

Statistical data and historical trend

As we noted above, platform research at the corporate level has remained a small but important percentage of publications during past three decades. In this level, content keywords such as entry and adoption are most popular. Keywords such as multiplatform bundle and platform envelopment are harder to find, even though these concepts are essential for the theoretical foundations of this research.

Commentary review and potential future trends

Research at the corporate level mainly focuses on how one large corporation (usually with one or more platforms) can maximize network effects. Typical issues include winner-takes-all-or-most characteristics (see e.g., Schilling, 2002; Eisenmann, Parker, & Van Alstyne, 2006, Huotari et al., 2017). Representative research at this level are papers published by Eisenmann, Parker, & Van Alstyne (2006, 2011), who raised the concept of multiplatform bundles and platform envelopment. However, there is not a lot of available data for these phenomena and the topic is not well developed.

Other representative research in this level looks at entry and adoption as well as diversification for large corporations with more than one platform. As for empirical research, it is common for studies to discuss the competition between the platform owner and platform complementors. For example, Zhu and Liu (2018) analyze the competition between Amazon and its sellers (complementors). Wen and Zhu (2017) explore platform-owner entry into the mobile app market. We expect to see more research where platform owners expand or diversify, such as Uber into Uber Eats, or Amazon into financial services, auctions, book publishing, groceries, and other related and unrelated businesses that may rely on a common customer base or online marketing channel.

Other research questions at the corporate level remain to be answered. For example: How can multiplatform companies maximize network effects of the separate business platforms and then enjoy additional cross-platform benefits? What factors should be take into consideration when making an entry decision into a new market, especially when there is a dominant industry platform? What is the optimal architecture design for a multi-platform corporation in terms of sharing user data, infrastructure, and information technology? How should firms balance the make or buy decision for certain kinds of products or service? Once a firm establishes a new capability, what is the deciding factor for going to market or not?

A potential breakthrough for research in this level may be in the clarification and accurate measurement of network effects across multiple platforms. The academic research on network externalities or network effects appears even earlier than studies of multi-sided platforms, for example, from economists such as Katz & Shapiro (1985, 1986) and Farrell & Saloner, (1985, 1986). These researchers established the conceptual foundations for later management and strategy research, such as in the work of Parker and Van Alstyne (2005) on two-sided market network effects. Boudreau and Jeppesen (2015) used the number of new models generated for a given platform in a given month to test the network effects from 85 online multi-player platforms. Yet, still, it is hard to see clear definitions and measurement techniques for corporate performance with multiple platforms. In the near future, we expect to see more research on corporate performance, multi-platform network effect mechanisms, as well as multiplatform corporate decision making.

7.3 Ecosystem-Level Platform Research

Statistical data and historical trend

Research on multi-sided platforms at the ecosystem level has dominated the field since the early 1990s and remains one of the main topics for scholars. Early and recent research in this level generally relies on the basic assumption that the ecosystem can create larger benefits or value for users and the ecosystem as a whole if there are mechanisms for coordination and cooperation among the different actors (Gawer & Cusumano, 2002; Kapoor, 2018). Thus, the main issues for this level of research are the relationship and interaction among participants within the ecosystem, as well as how to maximize benefits for the ecosystem as a whole. Technological innovation at the ecosystem or industry level is a particularly common topic.

Commentary review and potential future trends

In terms of research content, firstly, studies of technological innovation at the ecosystem level have been largely theoretical and or case-based, and should become more empirical and broader in the future. We expect technological innovation to remain the central topic of research, though some scholars will explore other aspects and tradeoffs, such as in social welfare and labor contracts. Secondly, we expect more research on the mechanisms of technological innovation and other ecosystem-level benefits, apart from interactions among the participants of a multi-sided platform. Thirdly, we expect more intensive research on the actual interactions among the multiple participants, with more examples.

In terms of research methodology, we have seen mostly case studies and theoretical studies rather than large-scale empirical studies. Examples of cases include Gawer, Cusumano and their cu-author's (e.g., 2002, 2007, 2008, 2014), such as the focus on Intel and ecosystem-level technological innovation. There are some empirical studies, however. Adner and Kapoor (2010) examine the interactions and roles of participants, i.e., components and complements, for the value creation of ecosystem as a whole. But more typical of the multi-sided platform ecosystem setting is the work of Kapoor and Agarwal (2017). They examine the mechanisms used by developers to sustain superior performance in the ecosystem in the context of the mobile app development market. Usually, researchers prefer to simplify the setting in an ecosystem to examine the actions and performance of one or two participants. The reality appears more complex, not only in the number of the participants, but also in the interactions.

7.4 Final Comments

The range, volume and variety of multi-sided platform research have significantly advanced our understanding of what a platform is and how platforms impact business and corporate strategy, innovation, economic development, and a number of other issues of interest to managers, entrepreneurs, and policy makers. It is striking that so much of our knowledge about platforms comes from multiple disciplines, beginning with economics but extending to nearly all the management fields as well as computer science. Our purpose in conducting this review article has been to clarify what we know and suggest what we might study more in the future. Multi-sided platforms are a relatively new phenomena, and we still have much to learn.

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Table 1. The Platform Related Constructs under Management Context

Categories & Constructs	Definitions or Descriptions	Examples	Example Studies
Functional platform			
Product develop platform	A set of common components, modules or parts from which a stream of derivative products can be efficiently developed and launched	Product develop platform	Meyer & Utterback, 1993; Jiao et al., 2007; Simpson, 2004; Muffatto & Roveda, 2002, et al.
Information, knowledge, technology-sharing platform	An important organizational mechanism to enhance the ability of systematic acquisition, storage, and dissemination of organizational knowledge	Knowledge management platform system	Huber, 1990; Kogut & Zander, 1992; Vuori & Okkonen, 2015, et al.
Inter-organizational platform			
Supply chain platform	Supply chain platform is an inter organization link, which carries out the platform functions of group actors while depending on a framework that recognizes collaborating relation within all related shareholders.	Export platform, supply chain platform, industry and academic cooperation platform	Amasaka, 2012; Corradini, & De Propris, L, 2017; Narayanan, Colwell, & Douglas, 2007, et al.
Public service and public organization	Service or physical location for a better social and management function, usually hosted by nonprofit organization	European biotechnology platforms; Communication Platforms in Nonprofit Services	Cooke et al.(2010); Azhar (2018)
Industry platform			
Multi-sided platform (MSP)	1)A multi-product firm: each of the sides or the participates are the customers of the platform owner, which provides distinct services for multi sides of market, and the prices might be different. 2)The network effects; participants' benefits increase with the participates' extension of both this side and other sides. 3)Bilateral or multilateral market power: the platform owner has power on all sides of market (monopolistic or oligopolistic), such as pricing, as it enables the direct interaction between the market sides.	Facebook; Google Android; Amazon AWS; Uber; American Express	Gawer & Cusumano, 2014; Parker, Van Alstyne, & Choudary, 2016; Rochet & Tirole, 2003; Zhu & Iansiti, 2012; Hagiu, 2014, et al.

Table 2. Research Framework for Multi-Sided Platform Research Keywords, Streams and Levels

Representative keywords	Research stream	Level of analysis
"competition/compete/competitive", "pricing/price", "discriminate/discrimination", "strategy",	Strategy	Business level
"architecture", "modularity", "metrics", "layer"	Architecture	
"governance", "access", "control",	Governance	
"customer/consumer/user", "value", "behavior", "busin model", "trust/reputation", "service",	Business model and customer relations	
"entry/adopt", "bundle/envelopment",	Multiplatform bundle managem and strategy	Corporate level
"ecosystem", "industry", "open", "partner",	Ecosystem participants	Ecosystem level
"technology", "innovation", "evolution".	Technological innovation	

Table 3. Summary of Business Level Multi-Sided Platform Research Contents and Conclusions

Topics & Dimensions	Selected articles	Contributions/Conclusions
STRATEGY		
Competition		
Competitors	Cusumano & Gawer (2002)	List three kinds of competitors: the platform leaders (companies that drive industrywide innovation for an evolving system of separately developed pieces of technology), a wannabes (companies that want to be platform leaders) and complementors (companies that make ancillary products that expand the platform's market)
Competition advantages sources	Sun & Tse (2009)	Discover that cross-group network effects can turn the participants of a two-sided network into critical resources. Thus, resource heterogeneity of platformis a source of sustained competitive advantage
	Eloranta et al. (2016)	Find that platforms are perceived to extend the physical product's capacity to produce new usage scenarios, facilitate interfirm information flows and enable collective benefits, and create awareness of new value potentials
	Zeng & Glaister (2016)	Find that dynamic capabilities of the firm, such as flexibility and experimentation, and active agency from external links, rather than focusing on firm-specific resources can maintain sustainable competitive advantage
	Yang & Jiang (2006)	Highlight the engineering technology, as well as market understanding and operation and maintenance, as the platform competencies to win the competitive advantage
Competition situation	Economides & Katsamakas (2006)	Results show that competition situation varies between different kinds of platforms (proprietary platform (such as Windows) and open source platform (such as Linux)) and analyze the structure of competition and industry implications in terms of pricing, sales, profitability, and social welfare
	Lee (2014)	Find that multiple platforms can co-exist in equilibrium despite being inefficient, after considering conditions, such as coordination failure, congestion effects, or firm multi-homing are considered
Competition strategy	Gawer & Cusumano (2008)	Listed four levers of platform leadership as strategy tools: firm scope, technology design, relations with complementors, and the internal organization.
	West (2003)	Hybrid strategy that combines the open software advantage and remaining proper control and differentiation may increase the likelihood of platform success
	Cennamo & Santalo (2013)	Platform competition is shaped by important strategic trade-offs and that the winner-take-all approach will not be universally successful
	Eisenmann et al. (2006)	Give instruction for platforms to deal with the WTAoM, which used to be regarded as envelopment threaten
Entry		
Late entrant decision	Zhu & Iansiti (2012)	Entrance's success is decided on the strength of indirect network effects and on the consumers' discount factor for future applications

	Blondel & Edouard (2015)	Open innovation process and business ecosystem support matter for late entrant compete with platform incumbents
	Sheremata (2004)	Small entrants can challenge larger companies in the network markets successfully, via the profit of radical innovation
	Eisenmann, Parker & Van Alstyne (2011)	Small entrants can success by employing proper platform envelopment strategies, even the incumbent network effects are strong
Incumbent platform retaining	Schilling (2002)	A platform firm face a higher likelihood of lock-out when it has poor availability of complements
Entry and response	Zhu and Liu (2018)	Platform owner prefer to enter into more successful complementor's product space, while complementors intend to reduce innovation in corresponding space.
Pricing		
Pricing structure	Clements & Ohashi (2005); Caillaud & Julian (2003); Evans (2003); Rochet & Tirole (2006)	Generally suggests that an optimal pricing strategy is subsidizing from one side to another side to attract actors to join, by using a deep discount
Antecedents of pricing allocation	Rochet & Tirole (2003)	The platform governance, differentiation, multi-homing end-user costs, network externalities and platform compatibility play roles for the pricing allocation
	Hagiu (2014)	Several pricing principles for business executive, concerning the price sensitivity, benefit and value transaction
	Eisenmann, Parker & Van Alstyne (2006)	Points to deal with the pricing strategy, including ability to capture cross-side network effects, user sensitivity to price and quality, output costs, same-side network effects and user's brand value
ARCHITECTURE		
Platform architecture definition		
Definition	Whitney et al. (2004)	Architecture more broadly as several factors, including a list of functions, the physical components needed to perform the functions, the detailed arrangement and interfaces between the components and a description of how the system will operate through time and under different conditions
	Tiwana, Konsynski, & Bush, (2010)	Define it as a "conceptual blueprint that describes how the ecosystem is partitioned into a relatively stable platform and a complementary set of modules that are encouraged to vary, and the design rules binding on both."
	Cennamo et al. (2018)	Define it as the technological capabilities of a platform, and the way platform technological components function and connect to platform complements
	Baldwin & Woodard (2009)	Believe the architecture is the relationship between platforms and the systems in which they are embedded. They argued that the fundamental features of a platform architecture is "certain components remain fixed over the life of the platform, while others are allowed to vary in cross-section or change over time"

Modularization		
Modularization architecture	Yoo, Henfridsson, & Lyytinen (2010)	Modular architecture is characterized by its standardized interfaces between components
	Schilling (2000)	Modularity is a general characteristic of a complex system
	Baldwin & Clark (2000); Baldwin & Woodard (2009); McIntyre & Srinivasan (2017)	Modules refer to some components within a complex system stay powerfully connected and with low variety, while others stay relatively weakly connected and with higher variety
	Tiwana, Konsynski, & Bush (2010)	Refer modularity as the degree to which changes within a subsystem do not create a ripple effect in the behavior of other parts of the ecosystem
	Baldwin & Woodard (2009)	Low modularity can result in wide-ranging, unpredictable ramifications of any change in the ecosystem
Modularity functions	Baldwin & Clark (2000); Baldwin & Woodard (2009); McIntyre & Srinivasan (2017); Gawer (2009); Yoo, Henfridsson, & Lyytinen (2010)	Facilitate innovation by breaking up a complex system into discrete elements interaction by its standardized interfaces between components
	Tiwana (2015)	Raise extension modularization, which can enhance the extension performance with the input control, by accelerating its evolution
	Baldwin (2008)	Decreases the coordination and transaction cost across the module boundary
Property		
Envolvability	Baldwin & Woodard (2009)	Conceptulize it as the ability of platform architecture to adapt to unanticipated changes in the external environment
Architecture representation		
Network graphs, design metrices & layer maps	Baldwin & Woodard (2009)	Listed three ways to presenting the platform architecture: network graphs, design metrices and layer maps
	Yoo, Henfridsson, & Lyytinen (2010)	Emerge a layered modular architecture, contribute to the conceptualization and strategic aganda for the digital industry
Organizing logic		
Stability and versatility	Baldwin & Woodard (2009) Tiwana, Konsynski, & Bush, (2010)	List two design rules, stability and versatility, as required according to the platform architecture discusstion

GOVERNANCE		
Governance content		
Access to the platform	Hagiu (2014)	Listed two major non-price governance rules: 1) access to the platform: who is allowed to join in (numbers on board)? and 2) interaction on the platform: what are they allowed to do?
Interaction on the platform	Tiwana (2015)	List three contents for the platform governance: 1) the decision rights partitioning, 2) control, and 3) proprietary versus shared ownership. Based on this, build a framework of platform co-evolution dynamic
Mechanism & policies		
Three categories of machanism	Song et al. (2018)	Summarize three categories of governance machanism and adopted app review and platform update frequency as two empirical mechanisms of platform governance, also examined the governance role on network effects
Principles		
Arm's length	Baldwin & Clark (2000); Parker & Van Alstyne (2005); Wareham et al. (2014)	Emphasizes the merits of standardization to orchestrate a large ecosystem of complementors in an arm's length way
Dyadic governance tension	Huber,Kude,& Dibbern (2017)	Adopt dyadic governance tension to balance the tension between cocreated value and governance cost
Loose or tight	Hagiu (2014)	Believed that the loose or tight is a tradeoff of quantity and quality, which also matters for the anti turst issue
Decentralization degree	Schwarz & Hirschheim (2003)	Discuss the level of centralization for IT governance from the IT function perpective
	Tiwana,, Konsynski, & Bush (2010)	Regard the decentralization as the level of authority and responsibility for each decision between the platform owner and complementors
Governance influence		
Network effects and ecosystem	Hagiu (2014); Boudreau & Hagiu (2009)	Governance can clearly affect the value of the platform ecosystem and customer proposition
	Song et al. (2018)	Empirically examined the influence of governance: the longer the time it takes for the app review, the cross-side network effects will be weakened
Financial return	Boudreau (2012)	Restricts entry of developers so that those who are licensed are able to make a sufficient return on their investments
Management efficiency	Schwarz & Hirschheim (2003)	A better management efficiency and more successful platform organization are expected.
Market success	Hagiu (2014)	Claims proper platform governance as a way to avoid potential market failure, as listed: 1) lemons market failure; 2) incentive products and services invest; 3) less investment and actions on potential positive spillover effects
Safety	de Reuver et al. (2011)	Emphasize the role of governance in terms of security, billing and customer data management issues

BUSINESS MODEL & CUSTOMER RELATIONS

Business model

Value cocreation, capture & deliver	Fehrer, Woratschek, & Brodie (2018)	Based on the characteristics of platform, argue for value cocreation for platform, rather than firm-centered value creation; theoretically propose a platform business model logic with the value co-creation and value capture
	Täuscher & Laudien (2018)	Listed key attributes of value creation, value capture, value deliver of platform business model
Value driver	Chandna & Salimath (2018)	Synergistic combination of four value drivers, including information processing capability, product portfolio complexity, innovative practices and network membership, rather than independent driver, is critical to firm performance and satisfaction
Structure & choice	Muzellec, Ronteau & Lambkin (2015)	Conduct an analysis of five early stage Internet ventures and reveals that “In two-sided Internet platforms, the monetization of the business model is "B2B oriented”
	Täuscher & Laudien (2018)	Reveals six clearly distinguishable types of marketplace business models and thus shows that there is no one-size-fits-all approach to creating, delivering, and capturing value
	Saebi & Foss (2015)	Regarded platform as one choice for open innovation strategy

Customer relations of characteristics & behavior

User personality	Adamopoulos, Ghose & Todri (2018)	Similarity of the users’ characteristics plays a positive role on users’ platform purchase behavior
User preference	Gal-Or, Gal-Or & Penmetsa (2018)	Study the user’s privacy concerns for the influence of platform competition. When users care less on the privacy loss, the competition for users may decline
	Chakravarty, Kumar & Grewal (2014)	Both the total customer orientation and customer orientation asymmetry affect the platform performance
User position	Ye & Kankanhalli (2018)	Both the direct influence of the lead userness, the toolkit support, design autonomy and the interaction of these antecedents play roles on the platform user innovation outcomes
	Chakravarty, Kumar & Grewal (2014)	Customer concentration also affects the platform performance, including the buyer-sider concentration and the seller-sider concentration
Interactions	Celata, Hendrickson & Sanna (2017)	Trust, reciprocity and belonging in peer-to-peer also have influence on platform
Influence of platform on users	Im et al. (2016)	Search queries containing deal-seeking keywords are related with higher click-through rates and conversion rates than search queries without such keywords

Table 4. Summary of Corporate Level Multi-Sided Platform Research Contents and Conclusions

Topics & Dimensions	Selected articles	Contributions/Conclusions
BUNDLE AND ENVELOPMENT		
Multiplatform Bundle		
Definition & benefit	Eisenmann, Parker & Van Alstyne (2006); (2011)	Ask the question and list three bundling benefits, which are various according to the platform envelopment
	Carlton & Waldman (2002)	Conclude that bundling in multi-sided market can foreclose a complement provider's access to users and then gain the profits of the whole complement market
	Chao & Derdenger (2013)	Use the original meaning of bundling, analyze the mixed bundling in two-sided market context and find that pricing structure deviates from two-sided market
Platform envelopment		
Definition	Eisenmann, Parker & Van Alstyne (2006); (2011)	Based on the benefits of the employing similar components and overlapping user bases, a platform provider can build a new multiplatform bundle, by combing its own functional platform and other parts of a platform
Mechanism	Eisenmann, Parker & Van Alstyne (2011)	Identify three types of platform envelopment, as well as the mechanisms for each to gain success.
	Müller, Kijl &Visnjic (2018)	Use case of Yahoo and Google, and find that if corporation can add related functionality to its initial platform and the expanded into distinct platforms, a positive performance is expected
	Zhang & Duan (2012)	Form the mechanisms of envelopment phenomenon as cross-network effect, overlapping between platforms, and the strategic locking behaviors based on learning effect
Strategy	Eisenmann, Parker & Van Alstyne (2006)	List three ways for focal firm to survive platform envelopment: changing business model, finding some bigger brother to gain support, or suing for antitrust.
ENTRY AND ENVELOPMENT		
Entry	Gawer and Henderson (2007)	Large platform company should encourage widespread entrance despite the fact that potential entrants (rationally) fear Intel's ability to "squeeze" them ex post.

Table 5. Summary of Ecosystem Level Multi-Sided Platform Research Contents and Conclusions

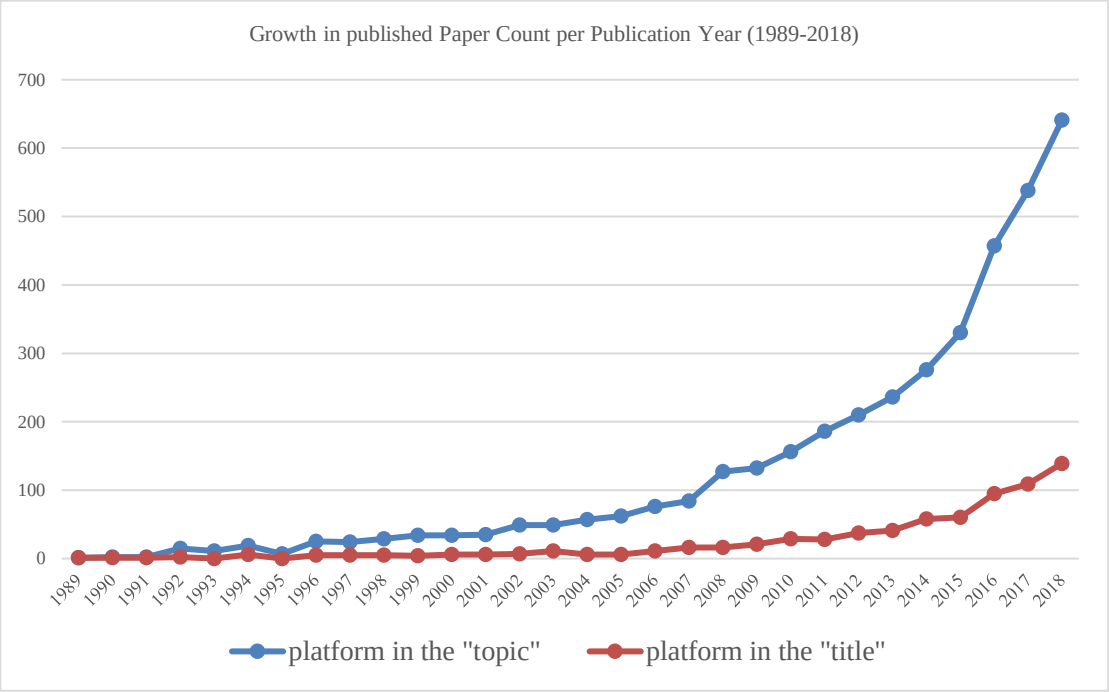
Topics & Dimensions	Selected articles	Contributions/Conclusions
PARTICIPANTS		
Participants		
Actors	Ozalp, Cennamo, & Gawer (2018)	The main participants in a platform based ecosystem include the terms of platform owner/focal firm, developers, users and suppliers
Assupmtion	Venkatraman & Lee (2004)	Basic assumption for participants is that the platform owner and complementors are reciprocal for each other: when platform owner invests resources for the platform to attract complementors, in turn, the complementors would like to commit resources that complement to the platform
Questions	McIntyre & Srinivasan (2017)	The main questions in this context focus on how the platform owner can encourage the third-party complementors to stimulate and make contribution to the development and value of the ecosystem as a whole
Platform owner		
Central orchestrator	Altman & Tushman (2017)	Believe that the platform owner, as central orchestrator, plays a core role in an ecosystem
Approach: technocal quality	Evans, Hagiu, & Schmalensee (2006)	Complementors can make contribution to the development and value of the ecosystem by creating platforms of superior technical quality
Approach: indirect network	Gawer & Cusumano (2002)	Complementors can make contribution to the development and value of the ecosystem by the indirect effect and platform technology
Approach: open innovation strategy	Eckhardt, Ciuchta & Carpenter (2018)	Complementors can make contribution to the development and value of the ecosystem by adopting open innovation strategy
Complementors		
Benefit: innovation	McIntyre & Srinivasan (2017)	Generally, the complementors are believed to be beneficial for technology innovation
	Kapoor & Lee (2013)	Firm-complementor investments matter for shaping new technology benefits
	Fuentelsaz, Garrido & Maicas (2014)	Technological value of complementary assets for the platform owner and ecosystem varies due to contextual factors
Benefit: value creation	Ceccagnoli et al. (2012)	Complementors can provide resources critical to platform ecosystem value creation
	Ander & Kapoor (2010)	Structure of technological interdependence influences value creation in ecosystem.
Benefit: platform growth	Boudreau & Jeppesen (2015)	Unpaid complementors do respond to platform growth, but do not stimulate network effects
Third-party developer	Parker, Van Alstyne & Jiang (2017)	The developers can invert the firm
	Parker & Van Alstyne (2018)	The longer the innovation rights holding for developers, the higher their royalties

	Makinen, Kanniainen & Peltola (2014)	Developer should plan things like resource allocation, development costs, timing of commercial, and end-product launches, for the benefit of new platform-based applications development
TECHNOLOGY INNOVATION		
Innovation		
Innovation	Gawer & Cusumano (2002)	Platform leaders in the industry level means technology firms who can rely on the vibrant ecosystem to enhance the value of the core technological platform
	Ozalp, Cennamo, & Gawer (2018)	The platform can induce disruptive innovation
	Parker et al. (2016)	Networked markets are transforming the economy by platform revolution
	Perrons (2009)	One purpose of building platform is to drive innovation
	Cennamo (2018)	In a highly innovative ecosystem, an embedded technological platform firm can evolve into technology transaction and thus offer greater benefits for the users for a better complements and service
Mechanism: external actors		
Interaction with external	Gawer & Cusumano (2014)	Focal platforms interact with and derive value from entities outside their boundaries
	Parker, Van Alstyne, & Jiang (2017)	The locus of value creation moves from inside to outside the firm
Mechanism: network effects		
Positive loops & trade-off	Ceccagnoli et al. (2012)	By encouraging complementary exploiting indirect network effects, platform technology owners can cocreate business value within platform ecosystem
	Gawer & Cusumano (2014)	Generally, these are positive feedback loops. Also notice trade-off for the network effects
	McIntyre & Srinivasan (2017)	Generally, these are positive feedback loops. When the platform adoption and complementors rise, an exponentially increasing rates are expected
	Boudreau (2012)	Trade-off for the network effects also remained. Evidenced that the positive feedback loop of the network does not perpetuate itself ad infinitum.
Mechanism: openness		
Issues of openness	McIntyre & Srinivasan (2017)	Degree of platform openness related issues should be paied attention to, such as the platform interface, the access to information, the access cost, and the interface governance, influences the innovation results
Degree & trade-off	Boudreau (2010)	Opening up interfaces typically increase complementors' incentives to innovate
	Eisenmann, Parker & Van Alstyne (2009)	Decisions to open a platform entail tradeoff s between adoption and appropriability.
Innovation strategy		
Four levers	Gawer & Cusumano (2002)	List the levers to drive industrywide innovation, including scope, product technology, relationship with external complementors, and internal organization, to create an ecosystem larger than the sum of its parts.

Table 6. The Main Concepts of Multi-Sided Platform in Ecosystem Level

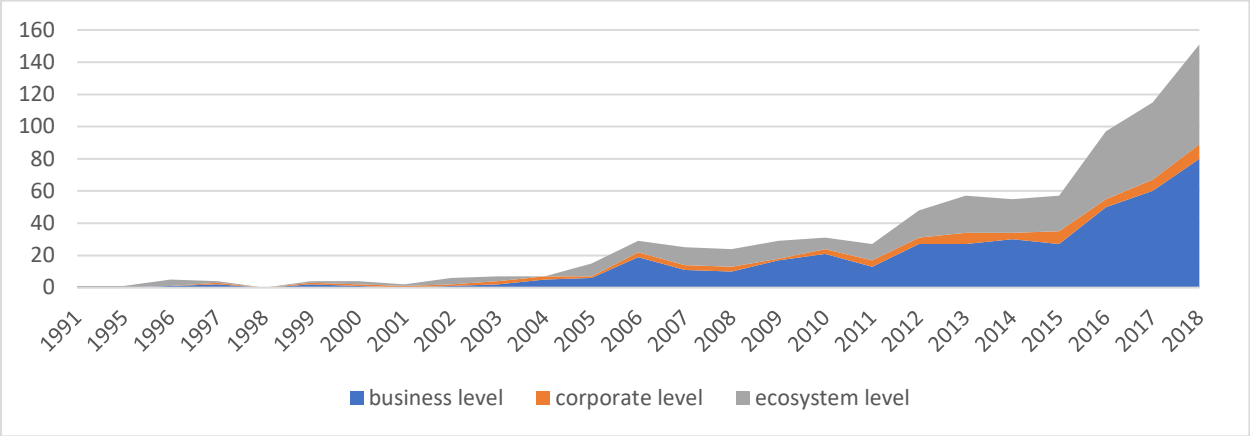
The concepts	Main definitions	Selected sources
Platform leaders	"Companies that drive industrywide innovation for an evolving system of separately developed pieces of technology." "The common objective sought by the companies we talks to: to drive innovation in their industry."	Cusumano & Gawer (2002, P.52); Gawer & Cusumano (2002, P. 6)
Keystone firm	A firm that drives industrywide innovation for an evolving system of separately developed components.	Iansiti & Levien (2004) Kang & Downing (2015)
External/industry platform	"As products, services, or technologies that act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services." "as foundations (virtual or physical) that bring together individuals and organizations so they can innovate or interact in ways not otherwise possible."	Gawer & Cusumano (2014. P. 417) Cusumano, Gawer, & Yoffie (2019. P.8)
(Multi-sided) platform ecosystem /platform based ecosystem	Population of developers, complementors and others, as partners co-create value with the platform owner by developing applications and solutions to be used on the platform.	Adner (2017); Jacobides et al. (2018); Cennamo & Santaló (2013); Zhu & Iansiti (2012); Ozalp, Cennamo & Gawer (2018); Cennamo & Santaló (2013); Iansiti & Levien (2004); Ceccagnoli et al. (2012); Parker, Van Alstyne, & Jiang (2017); Parker & Van Alstyne (2014)

Figure 1. Growth of Published Paper Count per Publication Year (1989-2018)



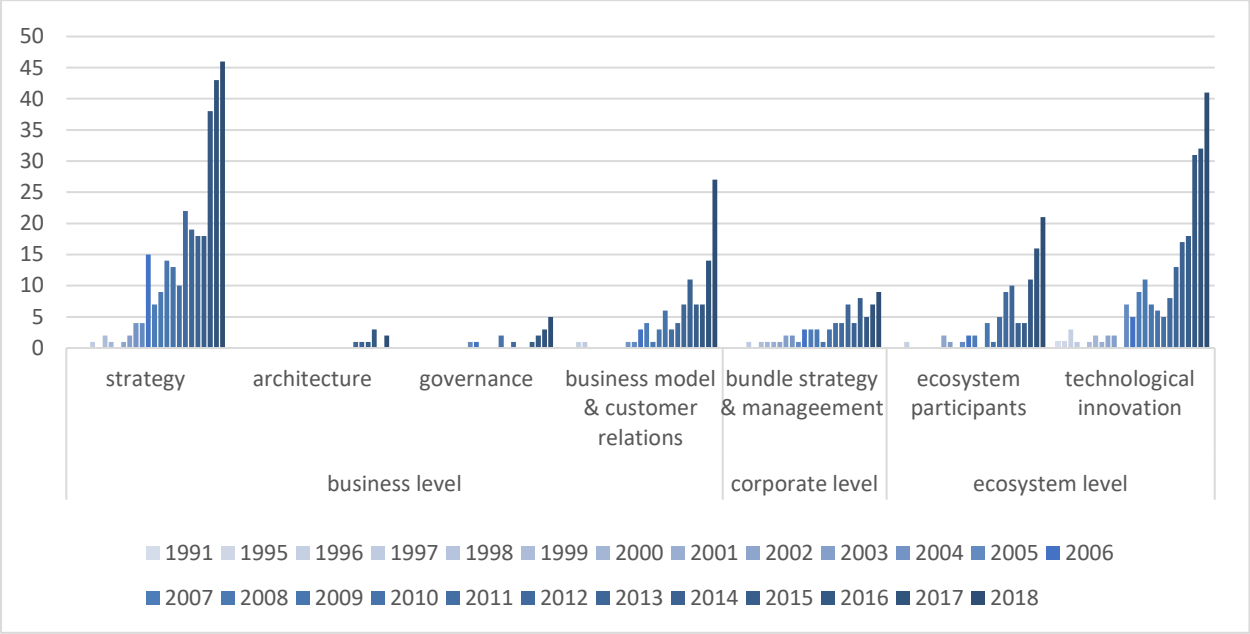
Notes: The literature search was conducted in Web of Science Core Collection. The Indexes for the Web of Science include: Social Sciences Citation Index (SSCI) --1956-present. The search uses “platform” as keywords in 3 subject fields (Management; Business; and Economy).

Figure 2. Growth and Percentage of Three Levels of Analysis on Multi-Sided Platform



Notes: The literature search was conducted in Web of Science dataset. For detail data description and data processing, please refer to supplementary material for this part.

Figure 3. Timeline View of Each Research Stream of Multi-Sided Platform (1991-2018)



Notes: The literature search was conducted in Web of Science dataset. For detail data description and data processing, please refer to supplementary material for this part.

Supplemental Materials on Multi-Sided Platform Research in 1991–2018: A Bibliometric Analysis

1. Research design

1.1 Methodology and bibliometric analysis visualization tools

These supplemental materials adopt the bibliometric to measure and analyze some indicators in the multi-sided platform literature on the basis of relative large database (Thelwall, 2008). This study uses this method to summarize the publication information from the aspects of authors, countries, disciplines and co-citation, co-authors and others. In addition, with the help of bibliometric, studies can summarize the keyword, research content, research question trends.

This study employs CiteSpace as a bibliometric method tool to visualize the research content and tendency. "CiteSpace is a freely available Java application for visualizing and analyzing trends and patterns in scientific literature. It is designed as a tool for progressive knowledge domain visualization. It focuses on finding critical points in the development of a field or a domain, especially intellectual turning points and pivotal points" (Chen, 2004). With this visualization tool, this study uses the citation and references to make analysis, and then to show the bibliometric network timeline development. CiteSpace version 5.3.R4 is applied in this analysis.

1.2. Research design process

This review is organized as the following sequence: 1) Article retrieval by several terms that closely related with multi-sided platform research, based on intensive literature review; 2) Data collection from Web of Science and article selection based on several criteria; 3) Data processing for research trend. Then it is followed by bibliometric analysis results: 4) descriptive and tendency information, including author's nationality as the main contributor, and the main discipline focus; 5) knowledge domains mapping; as well as 6) keyword co-occurrence network, which indicated current research themes and future research directions.

1.2.1. Article retrieval

After definition clarification and theoretical understanding of multi-sided platform, we conducted rigorous literature collection specific on this definition, to form a literature dataset for further literature analysis, rather than the widely "platform" search in title. To reduce selection bias, we conducted an intensive literature review, identifying several closely related keywords on this topic. Keywords on this topic contains "industry platform", "multi-sided market", "two-sided market", "multi-sided platform", "two-sided platform", "network effect", "platform ecosystem", "business ecosystem", "platform based market", and "network externality".

Second, we conducted an initial article search in Web of Science (WoS) Core Collection, by searching those keywords when one of them are appeared in article TOPIC. WoS is famous for its widespread use globally, as well as its multi-discipline availability nature (Zancanaro, Todesco, & Ramos, 2015). Thus, we choose WoS as the sole data source for analysis. Even though the WoS dataset is a famous article database, the book collection still is not enough. Thus, we search from the Social Sciences Citation Index (SSCI), which contains only articles from peer reviewed journal in WoS. Even through the article dataset in SSCI underestimates the overall knowledge of multi-sided platform, the published

articles can relatively represent the overall trends of this field, from the sampling perspective. Besides, the articles published in peer reviewed journals present a relatively higher quality of research in this field. We set the timespan from 1980 to 2018, excluded the correction from document types. A total set of 809 articles is built from Web of Science (updated in June. 11th, 2019).

1.2.2. Data collection and implementation of criteria for selected papers

We downloaded all the information of each articles; and then, we conducted rigorous literature review on title, keyword, and abstract, even whole paper, of all 809 articles one by one, deleting ones that are not focusing on this topic, even though they may contain these keywords in topic from some aspect. As for the selection criteria, we kept the ones that have clear definition and usage of multi-sided platform. We deleted some ones that contain network effects but on other objects rather than multi-sided platform. Taking social network for example, it is a main research content for network effects, but not all of them are related with multi-sided platform. For example, some articles study knowledge diffusion on social network, but nothing is related with multi-sided platform. Finally, a data set of 578 articles is created (timespan of this dataset is from 1991 to 2018), which is the basic dataset this study used for further detail analysis.

1.2.3. Data processing for research trend analysis

With CiteSpace as a bibliometric method tool, the following parts show the multi-sided platform research disciplines and main contributors. The node type choices conclude “cited authors”, “categories” and “cited reference”, while each slice is 1 year. We selected top 50 levels of most cited or occurred items from each slice. The threshold for the nodes in this map labeled is 5.0% of all nodes. Specific parameter setting information for each analysis will be illustrated in following parts when it is necessary.

2. Bibliometric results and discussion

Results are provided in terms of a) overall bibliometric data, including author’s nationality and an analysis of discipline focus and multi-discipline tendency; b) knowledge domains mapping, including an illustration of top cited articles and keyword clusters to figure out the main research theoretical basics; and c) keyword co-occurrence network, which indicates current research themes and future research directions.

2.1 Bibliometric trends

2.1.1 Main contributor: Author’s nationality

Node type in this part is “country” in CiteSpace. Table S1 lists author’s countries with top publication frequency based on WoS dataset, from 1991 to 2018. The USA dominates the research and contributes 204 articles within the 578 dataset. China catches up and contributes 76 articles, followed by England and South Korea. Beside of the article quantity, the centrality of articles evaluates the network and influence of each articles. According to this criteria, Netherlands, Italy and Germany occupy the highest centrality positions, while USA keeps a step far away.

2.1.2. Discipline focus and tendency

Numbers of multi-sided platform research have been generated in various disciplines. Based on the WoS dataset of 578 articles, within the particular disciplines, economics dominates the researcher trend (209), followed by management and business (153 and 114, respectively). In addition, computer science (87), operation research and management

science (63), information science and library science (60) also occupy a large number of the research pool.

Beyond the absolute quantity, from the timeline view, table and figure illustrate several insights on the trends and distributions of discipline focus for each year, as well as the main contributors in certain period, which can unveil the discipline change tendency on multi-sided platform research.

Main conclusions can be drawn from figure S1 and table S2. As we can see, the economics research not only occupies as the main contributor though the whole period, but also witnesses the start of multi-sided platform research, with the average blossom year of 1996. After that, there are two main streams on multi-sided platform research, one is management and business research stream, with the average publish year as 2002 and 2003. Followed in the year of 2006, the operation research and management science thrived.

Another stream we can draw is that the computer science also blossomed around the year of 2000, following the economics by the end of 20th century and accompanying the management and business in the early 21st century. In this stream, we can identify the increase of the information science and information system, engineering and industry around the year of 2010.

After the year of 2015, the two streams show some combination trend. Multi-discipline and discipline combination become the new trend, such as environmental science, public administration, science and technology, and transportation science, telecommunication. However, it is the economics, management business on multi-sided platform that remains as the main contributor and continue to increase, while other discipline streams, such as computer and information, have quicker increase rate, counting nearly half of the discipline distribution.

All in all, as we can see, it is the economics that witnesses the starting of multi-sided platform research field around 1990s, followed by two disciplinary branches: management and business branch, and computer science and information system. Another multi-discipline trend appears around 2010s, which combining the economics, management and computer science. Even though the diversification of multi-discipline appears, economics, management and business remain as the dominate disciplines.

2.2 Mapping knowledge domains

According to the basic view of scientometrics, academic articles represent the frontier in a field, while the cited references in academic articles provide a basis for cutting-edge knowledge (Chen, 2004). The following part analyzes the cited reference of the 578 articles of multi-sided platform research, aiming to generate a general knowledge map of the current multi-sided platform academic research literature.

2.2.1 Top cited articles within the WoS dataset

Table S3 shows the top cited articles within the WoS dataset, listing articles information, their cited frequency and centrality. These results are consistent with other aspects' results, regarding the discipline (i.e., economics, management and business), the author's nations (i.e., USA), as well as main knowledge (i.e., two-sided market and ecosystem) and keywords in the following parts. A brief review of these references for the WoS dataset shows that these literatures are mainly rooted on multi/two-sided market, as well as network effects and ecosystem. Based on these basic knowledge, we can draw that

detail research questions in this field may focus on strategy, competition, entry, pricing in business level, envelopment in corporate level, and technological innovation in ecosystem level. Detail illustration on these research questions will be discussed in following parts.

2.2.2 Top terms and cluster analysis

Apart from listing the top cited references, this study conducted cluster analysis on the cited references, to generate clusters, and then to map the knowledge domains for multi-sided platform research.

With the Citespace to conduct cluster analysis, the parameter setting include: 1. Time slice from 1991 to 2018 with 1 year per slice; 2. Term source=title/abstract/author/keywords/keywords plus; 3. Node type=cited reference; 4. Pruning= pathfinder/pruning the merged network; 5. Select criteria=top 50 most cited articles per slice. Keyword was used as the source to generate the final cluster and timeline function. Finally, 45 clusters are formed, with Modularity Q as 0.8497, which suggesting a higher level of internal knowledge aggregation degree of each cluster. The mean silhouette is 0.5464, indicating an appropriate consistency of articles within each cluster. Table S4 shows detail information for the top 6 clusters, named by the LSI (latent semantic indexing) and LLR (log likelihood ratio), including cluster ID, cluster size and mean year for each cluster.

Drawn both from the table S4 and figure S2, clusters of cited references identified the main knowledge of literature under analysis. Even though there show some differences between the term labelled by LSI and LLR, consistent conclusions can be drawn when taking some issues into consideration: 1) Though labelled by different method, the cluster remains the same, which means the knowledge beneath a specific cluster remains the same; 2) Clusters numbered 1#, 3#,4# and 5# present differences between the LSI and LLR. After carefully analysis, the cluster name labelled by LLR can be regarded as detail research questions based the LSI, i.e., the two-sided market. 3)Usually, the term will be labelled by different name, while the term “two-sided market” appears three time by the method of LSI. This phenomenon indicates the importance of “two-sided market”. Thus, totally, the combination of term labels by LSI and LLR shows us both the dominate knowledge of this literature, and the detail branches of dominant knowledge.

Figure S2 uses CiteSpace as a bibliometric method tool. It illustrates the multi-sided platform research knowledge map and time trend. The node type is “cited reference” and only the most 5% cited nodes of all the nodes are labelled. The bubble size means the citation frequency. The curve connected with two nodes means this reference cites or is cited from other reference, among the 5% top cited nodes. To visualize the analysis results, here we show the timeline view, and we label each cluster by the keyword cluster. The right column is the automatic cluster results, labelled by the LSI method. From the timeline view, we have an overview understanding of the knowledge map. This figure shows the most cited references in each cluster, which means they is leading each cluster. The citation work illustrates how the references expand their influences to other clusters from the citation network.

Together with figure S2 and table S4, based from the clustering, abstracting and labeling, the main knowledge of the multi-sided platform can be listed from three aspects. The first one is two-sided market, which is different from previous single side market. To

be specific, the earliest stream of two-sided market has an average publication year in 2004, mainly focusing on pricing theory and economics industry theory. Platform competition is another detail research topic in two-sided market knowledge. Average published in the year of 2009, these articles discuss the relationship between the multiple sides, considering the platform owner's variety influences on different parts. More recently in the average year of 2010, authors evaluate how the multi-sided platform can achieve value creation, which is based on the business model perspective.

The second basic knowledge is network effect or network externality, which is a basic mechanism and theory for two-sided market. The third basic knowledge is business ecosystem. Different from the supply chain, the multiple sides make the market be ecosystem. Examples can be drawn from this figure in each cluster.

All these three basic knowledge domains are integrated but not separated. Theories on multi-sided market, network externality/effect, and business ecosystem provide fundamental knowledge for comprehensive and accurate understanding of multi-sided platform research review.

2.3 Keyword co-occurrence as research content analysis

We conducted a keyword co-occurrence network analysis to figure out the popular research content and questions in the 578 selected published articles. Keywords are the node types for each paper, using the Pathfinder way do the pruning way, selecting the top 50 levels of most cited or occurred items and then showing cluster labels by mutual information. 204 Keywords and 368 links are generated in total. According to Chen, Ibekwe-SanJuan, & Hou (2010), modularity is an important metric that can indicate the general structural property of a network and signifies how reasonably a network can be detected and divided into independent blocks. Statistically, in this keyword co-occurrence network, the modularity was 0.6894, indicating a well-structured network (Newman, 2006). In addition, the silhouette refers to the evaluation of clustering validity, which can be used as criteria to select appropriate cluster number (Rousseeuw, 1987). In this keyword co-occurrence network analysis, the mean silhouette was 0.6874, suggesting a higher level of clustering validity.

Figure S3 and table S5 visualize and illustrate the keywords and links that happened more than 10 times. In detail, in figure S3, the node size refers to the co-occurrence frequency of the keywords, with the larger size means the more frequently occurrence. The links color displays the period of time when two nodes correlating with each other. The more bluer the link color, the earlier the correlations occurred. The more redder, the more recent the correlations occurred.

Table S3 illustrates the characteristics of the selected keywords from the dataset. To reduce the replication from the automatic computing, we manually combined the terms together, for a better understanding, terms, such as two-sided market, 2 sided market, two-sided-market and sided-market and terms of platform ecosystem and platform-ecosystem. We summed the frequency and averaged the centrality by frequency for each keyword.

In the first tier, "competition", "network externality", "innovation" and "two-sided market" have the highest frequency (more than 100 times), indicating these are of crucial importance for multi-sided platform research theoretically and empirically. Tier two contains the keywords that are more specific for some research content, including the

business and management issues, such as “market”, “model”, “performance”, “value creation”; strategy issues, such as “strategy”, “adoption”, “entry”; innovation and industry issues, such as “technology”, “evolution” and “ecosystem”; economics and industry issues, such as “pricing/price”. These are the basic impression of main research content from the keyword perspective. Further exploration analysis based on the keyword frequency is conducted for more rigorous content and tendency analysis in the following part.

3. Data processing for knowledge domain and top terms as keyword co-occurrence

After definition clarification and theoretical understanding of multi-sided platform, we conducted rigorous literature bibliometric analysis and intensive literature review, for a detail understanding of multi-sided platform research contents tendency and main research conclusion. The following parts elaborate detail data processing for research content analysis, based on keyword frequency and cluster analysis. Research results can be reached out in the main article in session 7.

Firstly, this study elaborates the research content streams and trends, based on previous bibliometric analysis of keyword frequency results. According to table S5, this study selected the most frequent keywords to label each of the article, in order to reveal the core research content. After detail review of the top listed keyword, we deleted some of the non-content keyword, including some theoretical related keywords, such as “multi-sided market”, “network externality/network effects”; some disciplinary labels, such as “economics” and “management”; some words are related with research objects, such as “media” and “information technology”; some keywords that are not so typically related with content, such as “market”, “impact”. Finally, 25 most representative keywords were chosen to form a keywords pool, to label the articles in WoS dataset: “competition/compete/competitive”, “pricing/price”, “discriminate/discrimination”, “strategy”, “architecture”, “modularity”, “metrics”, “governance”, “access”, “control”, “customer/consumer/user”, “value”, “behavior”, “business model”, “trust/reputation”, “service”, “entry/adopt”, “bundle/envelopment”, “ecosystem”, “industry”, “open”, “partner”, “technology”, “innovation”, and “evolution”.

Then, we reviewed each of the articles to check if it contains each of the 25 keywords. If the keywords of a certain article contain a certain words from the keyword pool that we selected, it is labeled as “1”, otherwise, it will be labelled as “0”. All of the 25 keywords were examined one by one for each article, thus, a metric of 578 articles * 25 keywords were formed. This metric is the basic dataset for following content analysis.

To note that, one keyword hardly explains the main content of each article. Thus, the 0/1 label of each keyword for each article can effectively avoid single label for each article, as most of the articles are focusing on several topics. This method can figure out the dilemma that one certain article belongs to multiple labels. Furthermore, after labeling all the articles from the WoS dataset, there is 398 articles contain one or more keywords according to the keyword pool, counting 68.86% of all the 578 articles from the WoS dataset. Those articles that are labelled as “0” from all the 25 keywords aspects, mostly contain “multi sided market”, “network externality/network effects” in their keyword. Thus, we believe that the total 25 keyword pool has a relevant robust representation for the whole research content.

Secondly, based on the research streams abstracted, this study conducted intensive literature review, detail illustrating the dominate research domains and conclusion.

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Thelwall, M. (2008). Bibliometrics to webometrics. Journal of Information Science, 34(4), 605–621.

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics*, *20*, 53-65.

Zancanaro, A., Todesco, J. L., & Ramos, F. (2015). A bibliometric mapping of open educational resources. *The International Review of Research in Open and Distributed Learning*, *16*(1), 1-23.

Table S1. Countries with top publication frequency of WoS dataset

Country	Frequency	Centrality
USA	204	0.36
PEOPLES R CHINA	76	0.17
ENGLAND	51	0.21
SOUTH KOREA	48	0
TAIWAN	39	0.11
FRANCE	39	0.26
GERMANY	28	0.74
NETHERLANDS	24	1.18
ITALY	16	0.83
CANADA	15	0.26
SINGAPORE	15	0.16
JAPAN	12	0.17
BELGIUM	11	0
AUSTRALIA	11	0.09

Table S2. Distribution of articles by discipline from 1991 to 2018

Category	Frequency	Average Year
ECONOMICS	209	1996
MANAGEMENT	153	2002
BUSINESS	114	2003
COMPUTER SCIENCE	87	2000
OPERATIONS RESEARCH & MANAGEMENT SCIENCE	63	2006
INFORMATION SCIENCE & LIBRARY SCIENCE	60	2002
COMPUTER SCIENCE & INFORMATION SYSTEMS	55	2002
ENGINEERING	50	2007
COMMUNICATION	23	2006
TELECOMMUNICATIONS	21	2006
PUBLIC ADMINISTRATION	20	2014
REGIONAL & URBAN PLANNING	19	2014
ENGINEERING & INDUSTRIAL	16	2009
ENVIRONMENTAL SCIENCES & ECOLOGY	16	2013
SCIENCE & TECHNOLOGY - OTHER TOPICS	13	2016
TRANSPORTATION	13	2016
ENVIRONMENTAL STUDIES	12	2013
COMPUTER SCIENCE & SOFTWARE ENGINEERING	10	2010
TRANSPORTATION SCIENCE & TECHNOLOGY	10	2016

Table S3. Top cited references, citation frequency & centrality in the WoS dataset.

Frequency	Centrality	Cited references
47	0.01	Armstrong, M. (2006). Competition in two-sided markets. *The RAND Journal of Economics*, *37*(3), 668-691.
38	0.02	Rochet, J. C., & Tirole, J. (2006). Two-sided markets: a progress report. *The RAND journal of economics*, *37*(3), 645-667.
34	0.05	Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic management journal*, *31*(3), 306-333.
29	0.02	Rysman, M. (2009). The economics of two-sided markets. *Journal of economic perspectives*, *23*(3), 125-43.
23	0	Weyl, E. G. (2010). A price theory of multi-sided platforms. *American Economic Review*, *100*(4), 1642-72.
23	0.08	Tiwana, A., Konsynski, B., & Bush, A. A. (2010). Research commentary—Platform evolution: Coevolution of platform architecture, governance, and environmental dynamics. Information systems research, 21(4), 675-687.
20	0.03	Zhu, F., & Iansiti, M. (2012). Entry into platform-based markets. *Strategic Management Journal*, *33*(1), 88-106.
19	0.11	Rochet, J. C., & Tirole, J. (2003). Platform competition in two-sided markets. *Journal of the european economic association*, *1*(4), 990-1029.
19	0.03	Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. *Journal of Product Innovation Management*, *31*(3), 417-433.
15	0.01	Boudreau, K. (2010). Open platform strategies and innovation: Granting access vs. devolving control. *Management science*, *56*(10), 1849-1872.
13	0.1	Eisenmann, T., Parker, G., & Van Alstyne, M. (2011). Platform envelopment. *Strategic Management Journal*, *32*(12), 1270-1285.
13	0.01	Gawer, A. (2014). Bridging differing perspectives on technological platforms: Toward an integrative framework. Research policy, 43(7), 1239-1249.
13	0.03	Caillaud, B., & Jullien, B. (2003). Chicken & egg: Competition among intermediation service providers. *RAND journal of Economics*, 309-328.
12	0.16	Boudreau, K. J. (2012). Let a thousand flowers bloom? An early look at large numbers of software app developers and patterns of innovation. *Organization Science*, *23*(5), 1409-1427.
11	0.01	Ceccagnoli, M., Forman, C., Huang, P., & Wu, D. J. (2012). Co-creation of value in a platform ecosystem: The case of enterprise software. *MIS Quarterly*,*36(1)*,*263-290.*
11	0.1	Lin, K. Y., & Lu, H. P. (2011). Why people use social networking sites: An empirical study integrating network externalities and motivation theory. *Computers in human behavior*, *27*(3), 1152-1161.
11	0.27	Hagiu, A. (2006). Pricing and commitment by two-sided platforms. *The RAND Journal of Economics*, *37*(3), 720-737.
11	0.07	Hagiu, A., & Spulber, D. (2013). First-party content and coordination in two-sided markets. *Management Science*, *59*(4), 933-949.
10	0.01	Rysman, M. (2004). Competition between networks: A study of the market for yellow pages. *The Review of Economic Studies*, *71*(2), 483-512.
10	0.21	Ghazawneh, A., & Henfridsson, O. (2013). Balancing platform control and external contribution in third-party development: the boundary resources model. *Information systems journal*, *23*(2), 173-192.

Table S4. Top terms with cluster size and mean publication year

Cluster ID	Size	Mean Year	Top Term (Latent Semantic Indexing)	Top Term (Log Likelihood Ratio)
0	38	2011	Business ecosystem	Business ecosystem
1	24	2008	Two-sided markets	platform competition
2	22	2007	Network effects	Network effects
3	20	2009	Two-sided markets	Variety effect
4	20	2004	Two-sided markets	Industry and pricing
5	20	2010	Two-sided markets	Value creation

Table S5. Top frequently occurring keywords.

Keyword	Freq	Keyword	Freq	Keyword	Freq	Keyword	Freq
Competition	178	industry	44	Service	20	price	12
network externality	118	platform	44	Information	19	framework	12
Innovation	103	performance	43	Product	19	quality	12
two-sided market	190	technology	37	Demand	18	diffusion	12
compatibility	73	economics	34	platform ecosystem	16	software	12
market	67	network	32	Management	16	evolution	11
model	61	adoption	27	Firm	15	advertising	10
network effect	61	entry	24	Dynamics	13	perspective	10
strategy	54	system	23	information technology	13	media	10
externality	53	internet	21	Ecosystem	13		
business ecosystem	45	value creation	20	Impact	13		

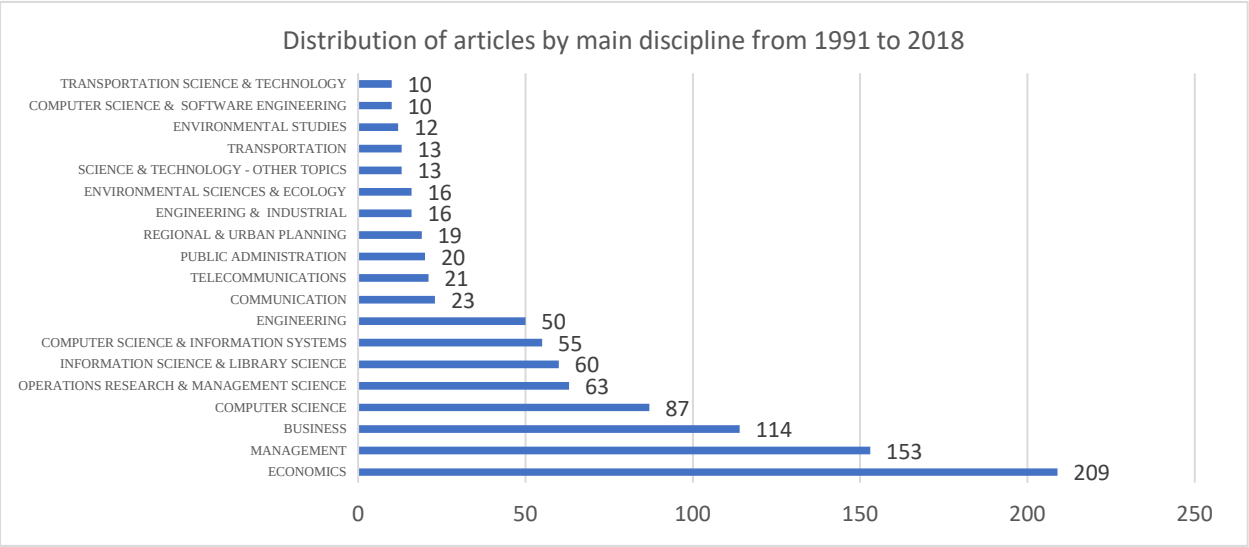

Figure S1a. Distribution of articles by discipline from 1991 to 2018 based on WoS dataset

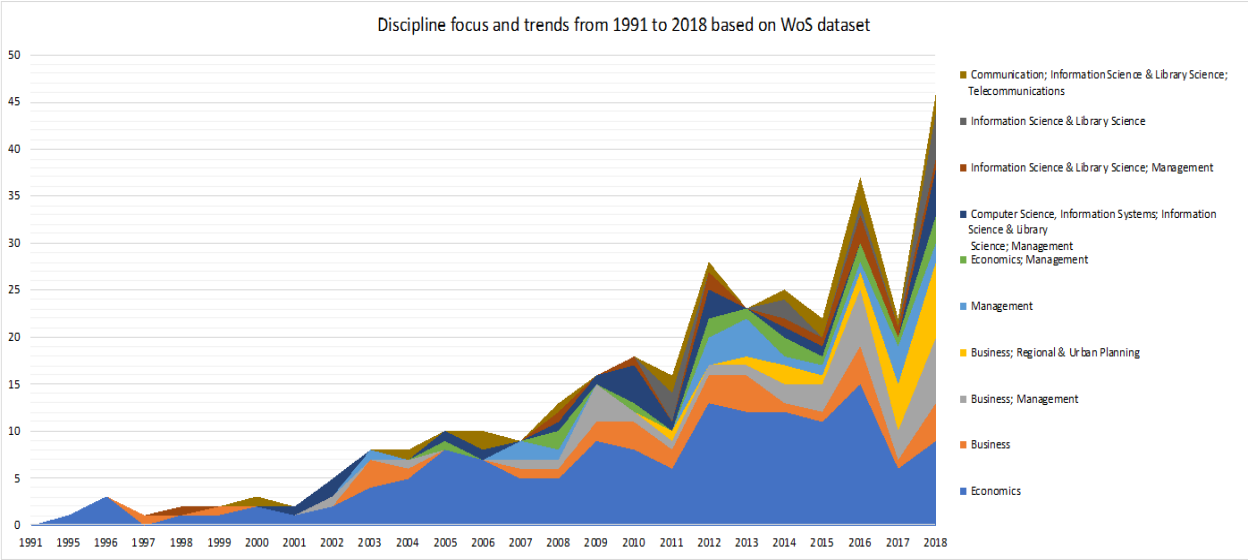

Figure S1b. Discipline focus and trends from 1991 to 2018 based on WoS dataset

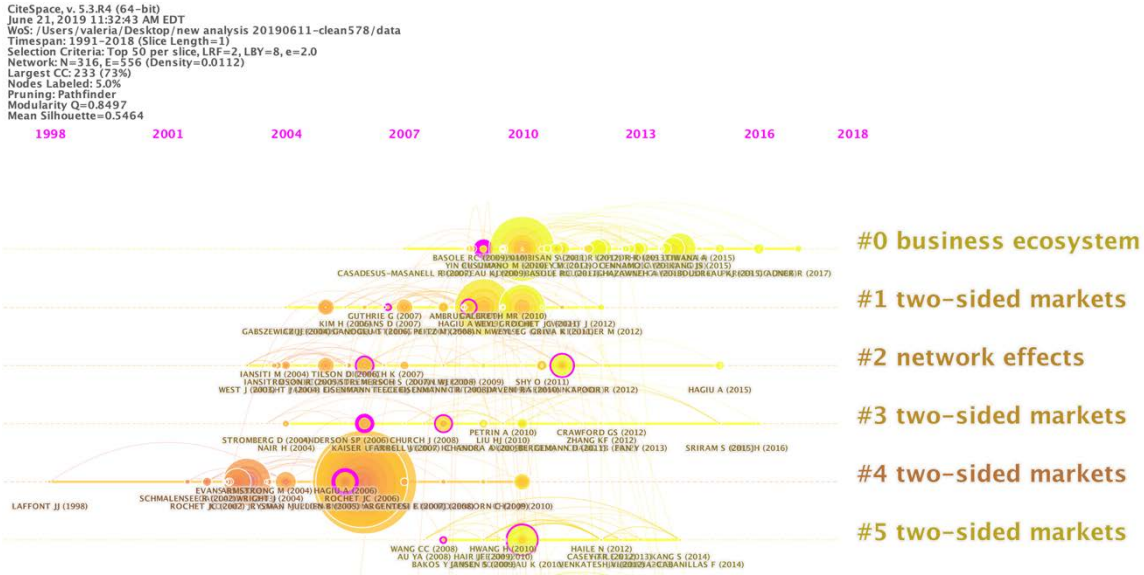

Figure S2. Timeline view for knowledge domains and representative articles for each cluster.

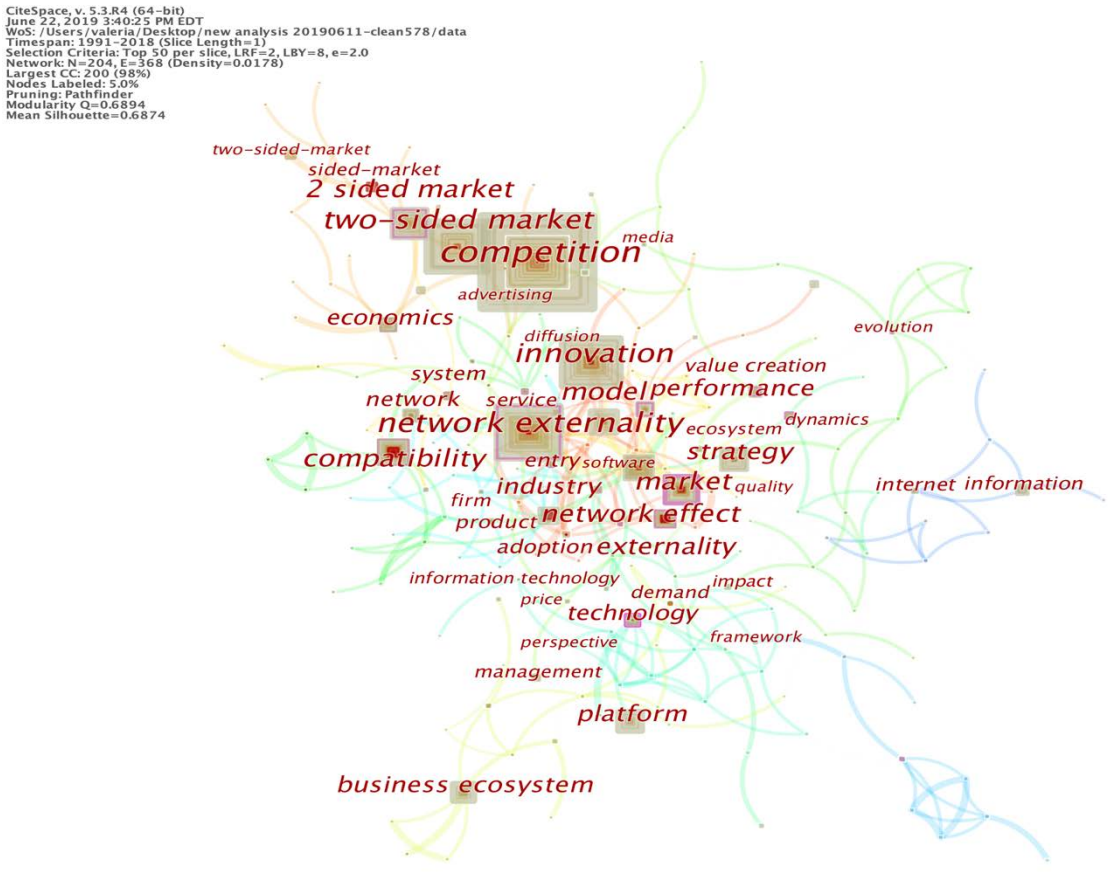

Figure S3. Visualization of the most frequently appearing keywords