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A SOCIO-TECHNICAL VIEW OF PLATFORM ECOSYSTEMS: Systematic Review and Research Agenda

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Abstract

Business models are becoming more inclined towards platforms, which allow inclusion of diverse participants to promote leveraged growth and modularity of offerings. Despite being closely linked, several aspects of platforms are often studied exclusively from their ecosystems, lacking integrative insights on the topic of platform ecosystems. Most studies are tunnel focussed on the technical aspects, failing to account for the social factors that play a critical role within platform firms. In addressing this gap, the study aims to review research on both social and technical aspects of platform ecosystems to account for the complex interdependencies stemming from platform-oriented actor interactions. The study extends beyond a typical literature review approach to also include a theoretically grounded, yet practically relevant framework of socio-technical systems to offer a holistic review of literature on how platform ecosystems function and sustain in competitive environments.

Keywords - Platforms; platform ecosystems; socio-technical systems

1. Introduction

The locus of competition in business has moved over time, from competition between vertically integrated firms to disaggregated supply chains. Globalisation and digitalisation have stimulated an evolution towards platforms that facilitates resource-sharing between loosely connected firms. The term, platform is used to describe frameworks across a variety of settings – from economics, innovation, technology to new product development (Hsieh & Wu, 2019). By definition, *platforms* are products, services or technologies similar in some ways that offer an architecture for other firms to use as an interface in developing their own complementary components (Cusumano & Gawer, 2002; Gawer & Cusumano, 2014; Han, Martinez, & Neely, 2018; Kim et al., 2016; Krishnan & Gupta, 2001; Meyer & Lehnerd, 1997; Muffatto & Roveda, 2002). In January 2020, seven firms accounted for more than $6 trillion of market value (Cusumano, Yoffie, & Gawer, 2020); what these firms (Apple, Microsoft, Alphabet, Amazon, Facebook, Alibaba and Tencent) have in common is that their value propositions are built on digital platforms.

Such platforms support ecosystems, which are complex networks of interdependent firms that collectively benefit from network effects based on co-operation and competition between such firms (Beltagui, Rosli, & Candi, 2020; Bogers, Sims, & West, 2019). Put both together, and by definition, a *platform ecosystem* (PE) is an assemblage of a platform, its actors and the offerings developed on that platform (Costa et al., 2020; Eloranta & Turunen, 2016; Goldbach, Benlian, & Buxmann, 2018; Tiwana, 2015a). They facilitate co-creation between consumers and service providers in multi-sided markets (Ceccagnoli, Forman, Huang, & Wu, 2012; Costa et al., 2020; Kamboj et al., 2018; Kuppelwieser, Simpson, & Chiummo, 2013). For example, booking.com and TripAdvisor coordinate inputs from accommodation providers and travellers (Borges-Tiago, Arruda, Tiago, & Rita, 2021; Filieri et al., 2020; Nisar et al., 2019; Tamilmani et al., 2020), while car-sharing platforms such as Uber and BlaBlaCar connect drivers with passengers. The platform approach, however, is not necessarily restricted to B2C digital services. For example, Klöckner, a steel maker has developed a platform, XOM, as an open marketplace for industrial metals[1].

PEs represent an inversion (Parker, Van Alstyne, & Jiang, 2017) of traditional business models, whereby firms replace internal operational control with orchestration of external sources of value. Research finds platform firms to be twice as profitable that grow twice as fast in comparison to non-platform firms (Cusumano et al., 2020). This is largely because they achieve comparable revenues with lower costs and staff requirements. Yet, they are also at a risk of failure due to difficulties of pricing and market entry timing. For example, General Electric's attempt to transform from an industrial firm into a digital one through its Predix platform (Winnig, 2016) was a big bet that ultimately did not pay off.

Research on both platforms and ecosystems has steadily grown over recent years (McIntyre & Srinivasan, 2017). Researchers in economics largely focus on network effects that enhance platform value (Koh & Fichman, 2014; Song, Xue, Rai, & Zhang, 2018; Tanriverdi & Chi-Hyon, 2008). Technology management scholars explore how a technological architecture

[1] http://reports.weforum.org/digital-transformation/klockner/

attracts ecosystem actors (Chae, 2019; Den Hartigh, Ortt, Van De Kaa, & Stolwijk, 2016; McIntyre & Srinivasan, 2017; Meyer & Lehnerd, 1997). Operations management scholars focus on understanding how platforms match demand to supply from independent service providers in the sharing economy (Parente, Geleilate, & Rong, 2018). Some researchers also examine how operations within a firm adapt to platforms (Cenamor, Sjödin, & Parida, 2017).

Overall, such research largely focuses on platforms, and also on ecosystems, but in silos. However, a platform is intertwined with its network, i.e. the ecosystem. While the platform perspective on its own reveals underlying strategies and best practices, it is not sufficient to comprehend the various trajectories that influence the level of innovation within a network. Existing studies are mostly interested in the technical side of a platform. Their focus is more on investigating the platform architecture, and understanding the role of its core components, complements and other tangible resources (De Reuver, Sørensen, & Basole, 2018; Rolland, Mathiassen, & Rai, 2018; Tiwana, Konsynski, & Bush, 2010), and not much on the social side of the platforms. Potentially, thousands of actors interact within a PE, sharing expertise and integrating knowledge, making the platform phenomenon as much of a social challenge, as it is a technical challenge. Neglecting the social aspects risks misunderstanding the wide-ranging complex actor interdependencies that determine the growth of a platform. Therefore, in addressing this gap, the present study argues that it is essential to move beyond exclusive strands of platforms and ecosystems to holistically account for PEs. A PE view will expand the scope of investigation to account for key counterparts of a platform, i.e. third party developers, innovators, end users, and other network actors in conjunction with the technical aspects.

The aim of this paper is thus to develop an understanding of PEs through a systematic review of the literature leading to a research agenda for informing future research on the topic. Dimensions of socio-technical (S-T) systems are employed here for guiding the review; S-T theory builds on the idea that the design and performance of an organisation can be understood only when the social and technical aspects are considered in conjunction, and treated as interdependent elements of a complex system (Hughes, Clegg, Bolton, & Machon, 2017). In contributing to the theory on PEs, this study advances understanding on the topic by conceptualising PEs as S-T systems to offer a structured review that encompasses aspects of actors, tasks, and structural dimensions in addition to the technical features of a PE. In contributing to practice, this study informs practitioners about platform dynamics, competition and management, whilst extending the PE vocabulary to the opportunities and challenges faced by interdependent firms in co-creating value in a networked setting. This is aimed at helping businesses understand both the actor dynamics of a PE, and the potential for collaborative innovation associated with participating in a network-oriented PE.

The next section provides a background on PEs and the S-T systems theory. The method used to conduct the literature review is then explained; findings from the review are mapped against the S-T dimensions, and the discussion that follows is directed at establishing a holistic research agenda. The paper is drawn to a close by listing the managerial and theoretical implications in operations management. The produced research agenda suggests that research on PEs is unequally spread across the social and technical dimensions; most research is concentrated on

the technical aspects, such as modularity, and lesser attention is given to the social aspects, such as platform control.

2. Background

2.1 The concept of platforms and platform ecosystems

There is a progressive shift in research with the formalization of fundamental assumptions on platforms in the fields of economics, industrial innovation, and management research (De Reuver et al., 2018; Annabelle Gawer & Cusumano, 2014; Thomas, Autio, & Gann, 2014). More authors are recognizing the influential role of platforms in the success of technological giants, such as Google, Apple, Intel, and Microsoft (M. A. Cusumano & Gawer, 2002; Meyer & Lehnerd, 1997; Perks, Kowalkowski, Witell, & Gustafsson, 2017).

In explaining platforms, most researchers (Brown, Fishenden, Thompson, & Venters, 2017; Den Hartigh et al., 2016; Ville Eloranta, Orkoneva, Hakanen, & Turunen, 2016; Oh, Koh, & Raghunathan, 2015) adopt the following definition – a *platform* can be a product, service or technology that external innovators, typically arranged in an *ecosystem* use as a foundation to innovate and develop complementary products, services, or technologies (Annabelle Gawer & Cusumano, 2014). Many researchers (Constantinides, Henfridsson, & Parker, 2018; Facin, De Vasconcelos Gomes, De Mesquita Spinola, & Salerno, 2016) also refer to another definition that suggests that a platform's architecture is a blueprint that depicts the partitioning of a PE into: a platform, and its complementary set of modules (Tiwana et al., 2010). Furthermore, key characteristics of platforms and their ecosystems are collated in Table 1.

Insert - Table 1. Characteristics of platforms and platform ecosystems - Here

A PE, in addition to the platform, accounts for the actors and the offerings. These actors are the platform leader (the business that owns the platform), the external innovators, and the end users. Since external innovators use resources provided by the platform leader to innovate and develop offerings that are complementary to the platform leader's original offerings, they are called *complementors*. As a result, the offerings that complementors develop are called *complements*. For instance, in a Fire TV platform, Amazon is the platform leader, and the complementors (app developers) use the fire TV stick to innovate and develop a multitude of apps that are offered to the end users via standardised television sets (interface), all of which together constitute a PE (Fig. 1.). In addition, some academics also consider - technical and software artefacts, other tangible and intangible resources, and stakeholders, such as content providers and advertisers a part of the PE (Perks et al., 2017; Qiu, Gopal, & Hann, 2017).

Insert - Fig. 1. Platform ecosystem for Amazon Fire-TV stick - Here

In summary, PEs bring together different actors to build value within a system by appropriating exchanges between multiple interdependent groups using a dynamic framework (Rong et al., 2018). Actors utilize networking capabilities not only to further their own interests, but also to promote the overall PE, alongside making the strategic choice of competing either between or within the PE (Li, 2009). Such actors have a tendency of developing notable degree of interdependence over time (Nieuwenhuis, Ehrenhard, & Prause, 2018), which facilitates

interconnectedness and shared fate, enabling operation, innovation and stability across industries (M. Ceccagnoli, C. Forman, P. Huang, & D. J. Wu, 2012; Iansiti & Levien, 2004).

The concepts of platforms and ecosystems have been the subject of academic debate for over two decades (M. A. Cusumano & Gawer, 2002; Annabelle Gawer & Cusumano, 2014; Han et al., 2018; Krishnan & Gupta, 2001; Meyer & Lehnerd, 1997; Muffatto & Roveda, 2002). As mentioned earlier, most research focuses on technical architecture and components (De Reuver et al., 2018; Rolland et al., 2018; Tiwana et al., 2010). While technical aspects are important, the inherent social dimension of a PE cannot be overlooked. PEs facilitate a multitude of actor interactions. Consider, for example, the number of users and complementors interacting on platforms provided by companies such as Microsoft or Amazon. A PE view encompasses various relational and functional dynamics that can account for multiple actor perspectives in developing a more holistic understanding.

Managing a PE means ensuring adequate revenue sharing (Gong, Liu, Liu, & Ren, 2020) for incentivising external stakeholders to participate in that PE. For external stakeholders, the challenge is complying with the standards set by the platform whilst developing the needs of their own business, which may even mean using rival platforms (Nambisan and Baron, 2013). The power balance between parties is far less clear than in traditional buyer-supplier relationships, as platforms create ecosystems not supply chains. Ecosystem as a structure perspective proposes that a single value proposition is created through the interaction of multiple firms (Adner, 2016). This is representative of a PE, wherein the platform alone delivers no value unless coupled with the complements (Michael A Cusumano, 2010; Oh et al., 2015). The platform relies on network effects, i.e., more the number of actors participating in a platform, more valuable the platform will be for all participating actors.

2.2 Platform ecosystems as socio-technical systems

In biological sciences, ecosystems describe the complex interdependent systems that can be observed in nature (Iansiti & Levien, 2004). Organisational contexts may be similarly complex, as they consist of many people, processes and flows, with dynamic interactions, diversity and unpredictable variability (Soliman, Saurin, & Anzanello, 2018). The concept of S-T systems was developed to capture the complex interactions between humans, machines, and organisational environments, (Emery & Trist, 1960), which is complex in the context of PEs, as they facilitate interactions between multiple organisations. S-T frameworks inform research using varied methods including ethnography and participatory design, and are largely focused on understanding the human interaction inherent in manufacturing and other technical contexts (Baxter & Sommerville, 2011; Mumford, 2006).

In contrast to top-down views of management, S-T systems consider the emergent, bottom-up perspective of participants, autonomy and discretionary behaviour (Trist, 1981). Organisations are, thus, considered as systems composed of four essential interacting dimensions – technical aspects, tasks, actors, and structures; these dimensions are widely recognized for building the technical, organisational, strategic, and social cores of an organisation (Lyytinen & Newman,

2008). By applying this approach to PEs, each of these dimensions can be considered in relation to the platform and the ecosystem in which the platform operates.

The motivation behind applying the S-T perspective stems from the idea that failure to do so enhances the risk of a system not making expected contributions towards organisational goals (Baxter & Sommerville, 2011). A technical lens offers insights into how a system meets technical requirements, but fails to account for the intricate relationships between an organisation and the actors undertaking and supporting the varied business processes (Baxter & Sommerville, 2011; Goguen, 1999). For establishing a coherent understanding of how the social system (network actors) adjusts/realigns goals to support the technical aspects (technical changes and innovations within PEs), an S-T approach is seen fit. S-T systems are inherently dynamic and evolve via recursive shaping of technical infrastructure and social constructs, reflected in actions altering entities at the technical, task, structure and actor levels (Dremel, Herterich, Wulf, & Vom Brocke, 2018). In understanding PE from an S-T lens, the following descriptions for the four S-T dimensions have been established.

Technical aspects include all elements building an organisation's technical core, including the functional scope, hardware and software components, design methods, architecture and infrastructure, and the interaction between these elements (Lyytinen & Newman, 2008). Therefore, the *technical-level actions* are aimed at realization of platform value and developing the platform architecture, the components and the modules integral for a sustainable PE.

Task describes an organisation's raison d'être, and the manner in which an organisation evolves with the environment, in line with the goals and requirements of different stakeholders. Here, the focus is on aligning systems, goals and purposes with the enablers to ensure work gets done within the organisation (Lyytinen & Newman, 2008). Therefore, the *task-level actions* address the incentives for encouraging stakeholder participation in a PE, and the governance and orchestration criteria established to align actors' interests with the goals of a PE.

Actors include an organisation's members and the key stakeholders, who carry out or influence the work. These stakeholders are leaders, maintainers, developers, and users of the system (Lyytinen & Newman, 2008), and can set forward claims or benefit from system development. Therefore, the *actor-level actions* address the role of key stakeholders of a PE, i.e., the platform leaders, the complementors and the end users.

Structure covers systems of geographical dispersion, levels of centralization, decision-making, authority, and workflow, focussing on both - the normative dimension of role expectation, in general; and the behavioural dimension of patterns exhibited by PE actors in terms of sharing specifications, exercising authority, and operating within an established ecosystem (Lyytinen & Newman, 2008). Given the many structural challenges of a PE, such as allocation of resources and capabilities, interface sharing, and interrelationships between a platform leader and other stakeholders, *structure-level actions* address issues of boundary conditions, competitive strategies, technical standards and specifications for key value producers.

These S-T dimensions will serve as the foundation for evaluating the extant literature on PEs to enable an integrated and holistic examination. Mapping a structured review against these dimensions is expected to identify strengths and weaknesses in PE research, which will help in the development of a clear research agenda for future research on the topic.

3. Methodology

This review employs systematic literature review method (Tranfield, Denyer, & Smart, 2003), which represents transparent and replicable elicitation of core aspects across a particular field in literature, which can then be suitably synthesized and analysed based on a standard protocol. (Boell & Cecez-Kecmanovic, 2015). Fig. 2 shows the different phases for systematically reviewing the literature (Tranfield et al., 2003) – (a) *planning and scoping* for identifying the objectives and boundaries of a review; (b) *execution* involving rigorous data search for shortlisting relevant publications; and (c) *analysis* for studying the shortlisted publications in a detailed and transparent manner to systematically report the findings.

In *planning and scoping*, the preliminary search began with selecting appropriate timeframe, shortlisting keywords, and identifying data sources. Elsevier's Scopus database, the largest database of peer-reviewed literature, was scanned to access publications of relevance for this review. Specific keyword combinations for the search string included 'platform and ecosystem (or eco-system)', or 'platform and business model', or 'platform based (or platform-based) ecosystem (or eco-system)', or 'platform based (or platform-based) business model(s)', or 'platform (or platform-based) markets'. Both hyphenated and unhyphenated combinations, including singular and plural forms were added. This study focused on reviewing articles published over the last two decades (1999 - 2019). This search string returned 10,402 articles.

Insert - Fig. 2. Systematic literature review - Here

For *execution*, to achieve a manageable number of publications, the subject areas were limited to three fields closely related to the topic - business and management, social sciences, and decision sciences, and to articles published in the English language. This returned 2,149 articles altogether. With the aim of reviewing high quality journal articles (Levy & Ellis, 2006), the *Academic Journal Guide 2018* issued by the Chartered Association of Business School (ABS) was used as reference to identify ABS4* (Exceptional), ABS4 (top rated), and ABS3 (highly regarded) rated journals. This resulted in 290 shortlisted articles from 56 ABS4*, ABS4, and ABS3 journals. The rationale behind this was to ensure extraction of high quality articles using an extensively accepted and recognized criteria in the field of business and management (Matthews & Marzec, 2012; Thomé, Scavarda, & Scavarda, 2016).

With *analysis*, a review of 290 journal publications by 'title' and 'keywords' was conducted; those indicating clear focus on platforms were shortlisted. Reviewing the abstracts of such papers brought down the list to 70 journal publications from 36 journals altogether. The following sections will focus on elaborating some of the emergent findings from these 70 publications across the four S-T dimensions.

4. Findings

4.1 Technical aspects of a platform ecosystem

The technical dimension captures literature relevant to all elements that build the technical core of a PE, including the components and modules. Academics commonly identify modularity and complexity as the two inherent characteristics that enable interactions between such core components and interchangeable modules of a PE.

4.1.1 Platform modularity

Research considers modules synonymous with applications designed and developed by third party developers (Benlian, Hilkert, & Hess, 2015) as the complementary add-on subsystems (Ghazawneh & Henfridsson, 2015; Goldbach et al., 2018). The platform remains unchanged, but the modules are changed in cross-section to produce different outputs (Zhong & Sun, 2020). The primary role of complementary modules is to enhance the core functionality of a platform, where each module is delivering an intended technological function in the overall system (Singaraju, Nguyen, Niininen, & Sullivan-Mort, 2016; Tiwana, 2015a). For example, Google Chrome is a search engine, but its extensions act as modules to offer extended functionalities of a calendar, dictionary, storage drive, etc. In other words, when such modules connect to a platform, they add new functionalities and features to the system (V. Eloranta & Turunen, 2016; Qiu et al., 2017; Tiwana et al., 2010). Therefore, modularity is the key to introducing flexibility in any system (Cenamor et al., 2017). Modular architectures allow the exchange, reuse, and adaptation of modules to enable varied functionalities, which not only reduces technological complexity of products (Facin et al., 2016), but also helps in managing platform complexity (Cennamo, Ozalp, & Kretschmer, 2018; Rolland et al., 2018).

Research summarizes these understandings to suggest that platforms possess a small, but stable set of core components that cannot be changed, and a larger set of peripheral components that can be substituted or modified, as required (Meyer & Lehnerd, 1997; Rolland et al., 2018). Consider a video game platform; here, the game console and operating system are the core components, using which the complementors build video games, i.e. the peripheral components (Toppenberg, Henningsson, & Eaton, 2016). A platform, therefore, acts as a foundation on which all these components interoperate and evolve to offer extended functionalities (M. Ceccagnoli et al., 2012; Ondrus, Gannamaneni, & Lyytinen, 2015; Tiwana, 2015b).

4.1.2 Platform complexity

Given that platforms operate via a modular architecture composed of a core and a periphery (Annabelle Gawer & Cusumano, 2014; Nucciarelli et al., 2017), the many interdependent modules interact with their complements resulting in complexities within a PE (Cennamo et al., 2018). For instance, if these interfaces between modules are loosely coupled, they generate increased outputs at different layers of the platform architecture, but on the downside, also increase the risks of fragmentation, inefficiency, and overcrowding (Wareham et al., 2014). On the other hand, tightly coupled interfaces ensure product lock-in by securing market position, but limit flexibility and risk stifling innovation that would restrict platform evolvability

(Wareham et al., 2014). In summary, if more modules interact with the complements, then there exists higher interdependence between such modules, resulting in higher platform complexity (Cennamo et al., 2018). For example, on a smartphone platform, complexity is the measure of technological interdependencies experienced by a developer in developing an app for that platform.

Key Finding 1*: Both core and peripheral components are vital for maintaining the technical stability of a PE. While the core components are foundational for establishing standards, the peripheral components are elementary for enabling flexibility throughout the PE. Such flexibility is represented in the modularity, whereby different combinations of the same set of modules are used to develop a multitude of offerings for satisfying differing customer needs.*

4.2 Task aspects of a platform ecosystem

The task dimension captures relevant literature to show how PEs evolve with their environment. The focus is on governance and orchestration mechanisms and incentives that enable value capture for all stakeholders participating in a PE.

4.2.1 Platform governance

The most critical aspect of owning/leading a platform is that of platform governance (Wareham et al., 2014). In most instances, a platform leader is responsible for governance, whereby they exercise power over other PE actors (Karhu, Gustafsson, & Lyytinen, 2018; Tiwana, 2015a). Platform leaders do not necessarily claim leadership of all aspects of a platform, instead, their control of key interfaces and components is sufficient to maximize the overall value appropriation (Thomas et al., 2014). Platform leaders are, however, required to adequately handle issues of conflicting interests, and determine if the relationship between them and the complementors will be more collaborative or competitive (M. A. Cusumano & Gawer, 2002). Complexities of the modern-day business environments present a paradox, where a cooperating business (i.e. a complementor) can also be a competitor (Devece, Ribeiro-Soriano, & Palacios-Marqués, 2019). In either case, platform leaders must establish technical standards and specifications acceptable by the key value producers to ensure compatibility of the platform with the offerings developed on that platform. They are responsible for decisions concerning intellectual property and interfaces of the platform architecture, leadership, decision rights, pricing, and control mechanism (Constantinides et al., 2018; Karhu et al., 2018; Wessel, Thies, & Benlian, 2017).

4.2.2 Network orchestration and boundary conditions

Although the platform leader is mostly responsible for governance and orchestration of a PE, other stakeholders in the network are also engaged in changing and redirecting the platform over time (V. Eloranta & Turunen, 2016). Organisations are expanding their boundaries to harness external expertise and innovativeness on an extraordinarily large scale; for instance, this is indicated in the unprecedented rise in number of app developers across the Android and iOS platforms (Tiwana et al., 2010). Recent figures show Google's play store has over 3.3

million apps[2] resulting in more than 100 billion downloads each year (Karhu et al., 2018). Network orchestration thus becomes critically essential for the management of such extensive platforms. Parameters such as (a) organisational and component specialization, (b) co-specialization for ensuring complement designs conform to platform's core technology, and (c) coordination for hierarchical task execution, all require coherent orchestration for operating in PEs (Cennamo et al., 2018; Thomas et al., 2014).

Network orchestration essentially involves a standard and routine set of practices primarily orchestrated by the platform leader to influence the development of a value platform (Perks et al., 2017). Evidence in literature reinforces the fact that platform leaders are responsible for conceptualizing and implementing a suitable architecture capable of producing novel offerings, whilst efficiently coordinating with the network actors (Perks et al., 2017). In conceptualizing the architecture, boundary conditions are set to dictate the extent of openness a platform will extend to support its complementors; such *platform openness* criteria forms the basis of a platform architecture (De Reuver et al., 2018). This criteria is further split into *access openness* and *resource openness* to control the influence of platform governance on platform openness (Karhu et al., 2018). Resource openness applies to the software tools and regulations that act as an interface for bridging the platform leader and complementor relationships (Eaton, Elaluf-Calderwood, Sørensen, & Yoo, 2015). This implies the boundary conditions act both, as *regulators* - any change in these conditions will change platform value, and as *thresholds* – these conditions must be met for successful platform creation (Thomas et al., 2014).

4.2.3 Platform Incentives

Complementors mostly have self-driven motives for participating in a PE. The extent of compromise required on the complementors' part in aligning their interests with those of the platform leader for the collective good of the PE influences the complementors' decision for participating in a given PE. Essentially, complementors have to be convinced that there are ample long-term returns for their potential investments on a given platform (Wareham et al., 2014). Here, in order to encourage co-investment, platform leaders offer exciting platform incentives to potential complementors. By offering open access to dedicated resources (APIs etc.) and enabling complementors to conduct business on a platform, companies are looking at sparking innovation, whilst persuading complementors to use their platform to create value and invoke positive network effects (Karhu et al., 2018). This can be observed in the Google Maps functionality and related infrastructure, which is open for complementors to employ Google's functionalities to innovate and build applications to be hosted on Google earth that has nearly one billion users (Iyer & Davenport, 2008)

In this respect, research highlights the importance of determining how the demand for a platform can be significantly increased (M. A. Cusumano & Gawer, 2002). For instance, Intel's *rabbit strategy* focuses on assisting a promising complementor with significant incentives in such a visible manner that other potential complementors are tempted to immediately follow (M. A. Cusumano & Gawer, 2002). This strategy attracts the attention of complementors

[2] https://www.statista.com/statistics/266210/number-of-available-applications-in-the-google-play-store/

towards a new profitable market and conveys the platform leader's intention to not participate/compete in the complementors' market. A parallel approach that platform leaders use is of selective promotion, i.e. promotion of certain complementors to foster the success of individual complements (Joost Rietveld, Schilling, & Bellavitis, 2019). For instance, Apple shortlists apps to feature them on their App Store as 'editor's choice' or 'best apps' etc. to attract user attention specifically to those applications, in turn, maximising their sales. Such selective promotion is also useful in managing end users' perceptions of the overall quality and range of offerings available across a PE, and can be used to expand the range of offerings ultimately adopted by the end users (Joost Rietveld et al., 2019).

Another type of incentive applicable here is the perception of enhanced quality. Complementors and other stakeholders are often subject to certification processes by platform leaders before approving their participation in a PE. End users associate such certifications with high quality, thereby positively influencing sales for the independent stakeholders and complementors (M. Ceccagnoli et al., 2012).

Key finding 2: *Platform leaders facilitate governance and orchestration mechanisms to ensure a collaborative and advanced work environment is maintained across the PE. They establish boundaries to enable seamless execution of essential tasks, whilst ensuring those boundaries do not compromise the innovativeness or the resource capacity of the PE in any way. Platform leaders are also responsible for developing incentive mechanisms not only to attract competent complementors, but also to maintain lasting relationships with them in the interest of maximizing the overall value created and captured for all PE actors.*

4.3 Actor aspects of a platform ecosystem

The actor dimension captures literature relevant to the key stakeholders, i.e. the platform leaders, complementors, and the end users of a PE.

4.3.1 Platform leader

Platform leaders, also referred to as lead firms, are responsible for shaping the platform environment, and orchestrating the complex inter-organisational networks (Perks et al., 2017). The platform leader can either be a single firm or a small group of firms (Annabelle Gawer & Cusumano, 2002), who can influence, but not define, the trajectory of an innovation (A. Gawer & Phillips, 2013). They assume the role of an architect in building PEs, and are accountable for designing, managing, and continuously changing them, as the network intricacies evolve with time. (Helfat & Raubitschek, 2018). Evolvability is a key factor here, without which a platform leader will struggle to stay at the top of uncertain market trajectories and shifts, heterogeneous customer requirements, changes in roles of the many different network actors, innovation demands, fragmented technological evolution, and other factors (Wareham et al., 2014). For example, computing is no longer restricted to personal computers, but Microsoft remained tied down to their Windows OS, and failed to evolve with the changing consumer demands for smartphones and cloud computing, which together were disrupting and displacing their core business.

4.3.2 Complementors

Complementors, also referred to as complementary asset providers, are developers of complementary or ancillary offerings released in the interest of expanding a platform's market (M. A. Cusumano & Gawer, 2002). They are known to submit complements, for instance, *apps* for a platform, which is a primary type of shared resource available for distribution on the platform (Karhu et al., 2018). Complementors are mostly unpaid as they operate external to a price system, and are motivated by heterogeneous intentions, which affects their response to a platform's growth; for instance, complementors developing add-ons for Firefox receive no payments from the platform leader (Boudreau & Jeppesen, 2015). In committing their resources to innovation, research suggests complementors should focus on the products that the platform leader is not likely to offer to avoid being in the same competitive space as the platform leader (M. A. Cusumano & Gawer, 2002). The focus should be on products that can enhance the value of core products, whilst tracking and quickly responding to all core changes.

4.3.3 End Users

End users are the consumers of complements offered in a PE. Some authors also consider complementors to be a type of user, whereby, they proliferate user-centred innovations by developing new products for themselves and other users (Sussan & Acs, 2017). The overall success of a PE (typically made up of the individual success of all actors, i.e. the platform leader and the complementors) attracts end users to a platform (Joost Rietveld et al., 2019). In some instances, end users become the co-creators in product/service development, and are accounted as contributors in enhancing the overall value of a PE (Lusch & Nambisan, 2015). Users also add value to the platform via other contributions, such as leaving user ratings for offerings available on the platform and the overall platform performance; positive opinions of existing users can attract new users (Xu, Ribeiro-Soriano, & Gonzalez-Garcia, 2015).

4.3.4 Network effects/externalities

As platforms put together a multitude of network stakeholders, they generate network effects, also referred to as network externalities (De Reuver et al., 2018). Such effects are positive when there are more users for a product/technology (making them more attractive). The same can become negative, because more users on one side of the platform can result in increased competition and unattractive pricing (Koh & Fichman, 2014). Network effects can also be direct or indirect based on stakeholder dynamics (Fig. 3.). They are generally *direct* (*same-side*) when different users buy and use services on the same platform, resulting in an exponential increase in product value (De Reuver et al., 2018). In essence, the usefulness of a technology will rise with an increase in its users (Cennamo & Santalo, 2013; Zhu & Iansiti, 2012). For instance, the value of a video game platform will increase, if users (friends, acquaintances, and so on), who own the same console, exchange video games amongst themselves (Zhu & Iansiti, 2012).

The *indirect* (*cross-side*) network effects are triggered when more applications developed by complementors increase consumer utility (Tanriverdi & Chi-Hyon, 2008). Given the

interdependence between consumer demands for platforms, and the associated demands for applications, such indirect network effects come into play, i.e. higher the number of applications on a platform, greater will be the demand for that platform (Zhu & Iansiti, 2012). There is increased interdependency between users and complementary asset providers at different ends of the platform (Helfat & Raubitschek, 2018). Thus, the platform value is dependent on number of users in different user groups (De Reuver et al., 2018). For instance, game buyers and game developers are at different ends of a video game platform (Zhu & Iansiti, 2012), and value of the game console will increase, if more game developers build more games for that console (Facin et al., 2016).

Insert - Fig. 3. Network externalities - Here

In addition, when customer preferences are homogenous, network externalities lock out rivals and tip the market in favour of one platform; however, in case of heterogeneous user preferences, there is more differentiation, reduced market tipping, and increased coexistence of platforms (Tanriverdi & Chi-Hyon, 2008). Moreover, if the platform is too restricted (internal), network effects will be slowed down as desirable complementors may not be included in the platform, and if the platform is too open (external), there is a rise in risk of misbehaved complementors and low quality complements (Broekhuizen et al., 2019).

Literature also suggests that a platform should rapidly increase the installed base of users to attract more complementors to participate in their platform, in effect, winning platform competition. However, some studies (Huotari, Järvi, Kortelainen, & Huhtamäki, 2017; J. Rietveld & Eggers, 2018) challenge this notion. According to them, from a PE perspective, if a late entrant platform successfully renews complementary products and maintains high quality compared to the earlier entrant, then the late entrant will receive more adopters, positively impacting their competitiveness (Huotari et al., 2017). On the other hand, from the user perspective, late platform adopters have a tendency to avoid new and less popular complements, changing the competitive dynamics; thereby suggesting, there is more to network externalities than just the number of complementors and users on the supply and demand side, respectively (J. Rietveld & Eggers, 2018).

Key finding 3: *A PE predominantly witnesses interactions between three actor groups: (a) platform leaders, who own the platform; (b) complementors, who innovate in a PE to develop extended offerings complementary to a platform leader's original offerings; and (c) the end users, who are consumers of such innovative offerings. Interactions between these three actor groups triggers same-side or cross-side network externalities that influence the performance, success, and overall sustainability of a platform in comparison to the competitors.*

4.4 Structure aspects of a platform ecosystem

The structure dimension captures literature relevant to the issues of decision-making and interface sharing across different platform structures/types. In addition, as the structure and related boundary conditions control how platforms compete, various competitive strategies are also discussed here.

4.4.1 Classification of platforms

Most scholars classify platforms in three categories (See Annabelle Gawer & Cusumano, 2014) – *internal* or *product* or *company-specific platforms* and *external* or *industry-wide platforms*, also including a special case of internal platforms, called the *supply chain platforms*. In identifying the different platform types, researchers tend to focus on factors such as: platform influence on product innovation (Facin et al., 2016); scope of production focus (De Reuver et al., 2018); input control and boundary conditions exercised by the platform leader (Karhu et al., 2018; Tiwana et al., 2010), and so on. Therefore, this sub-section builds on the aspects of architectural openness, interplay between network actors, boundary conditions, and innovative and industrial advantages in underpinning the following classification.

Internal/product/company-specific platforms: represent an arrangement of assets organized in a common structure, employed by a single company to design, develop, and produce a selection of derivative products or a product family (Annabelle Gawer & Cusumano, 2014). Such platforms enable the recombination of sub units within one company (De Reuver et al., 2018). The company has product proprietary, and the product is controlled by the company that produces it (Facin et al., 2016). The innovativeness of this platform, therefore, revolves around a company's own capabilities. Platform coordination here flows through architectural design templates, organisational hierarchy and design rules, and the control is more central (Den Hartigh et al., 2016; Thomas et al., 2014). These platforms have a closed interface, where the interface specification sharing occurs internally within a firm, with no external disclosures (Annabelle Gawer & Cusumano, 2014). Internal platforms enable flexibility, benefits of component reuse, and savings in fixed costs (Brown et al., 2017).

Supply chain platforms: have a single assembler, and the external suppliers are coordinated around that one assembler (De Reuver et al., 2018). They have a selectively open interface, and the interface specification sharing occurs exclusively across the supply chain (Annabelle Gawer & Cusumano, 2014) to replicate the advantages of an internal platform, but across different firms within a supply chain (Brown et al., 2017). Innovativeness of supply chain platforms revolves around the capabilities of the supplier firms in the supply chain. Supply chain platforms are commonly found in assembly industries, such as automobiles and consumer electronics (Annabelle Gawer & Cusumano, 2014).

External/open/industry-wide platforms: academics use examples of Google, Apple, and Facebook to explain the success of industry platforms (Facin et al., 2016; Perks et al., 2017). These bring together firms that are not necessarily undertaking any transactions with each other, but are interdependent and must operate together as a part of a technological system (Annabelle Gawer & Cusumano, 2014). For instance, in the software industry, operating systems, such as Macintosh and Windows are open platforms on which independent software vendors (complementors) develop applications for end users (Tanriverdi & Chi-Hyon, 2008). Another example is IBM's response to competition from Apple in the 1980s. IBM collaborated with Intel and Microsoft to develop the IBM PC, an open platform, where complementors developed compatible software such as word processing and Lotus 1-2-3 to outperform Apple's platform, VisiCalc (Den Hartigh et al., 2016). With open platforms, coordination revolves

around ecosystem governance and the control is more distributed (Den Hartigh et al., 2016; Annabelle Gawer & Cusumano, 2014). While openness implies benefits of increased freedom for complementors and reduced technical restrictions, it also makes modular components easy to copy, fork, and reverse engineer (Constantinides et al., 2018; Nambisan & Baron, 2019; Parente et al., 2018). Thus, platforms are known to restrict openness after reaching a threshold of developers, because platform value reaches a point where platform leaders can monetize the platform and regain control even with limited openness (Parker et al., 2017).

4.4.2 Platform Competition

A 2015 global survey revealed a drastic increase in the number of businesses leveraging the power of platform business models; around 176 platform companies were identified with a market capitalization of nearly one billion dollars (Evans & Gawer, 2016; Langley & Leyshon, 2017). The exponential rise in platform businesses emphasizes the need to understand the dynamics of competing platforms. With platforms, competition is no longer restricted to gaining control of the value chain, instead the focus is on attracting generative actions associated with the focal platform (De Reuver et al., 2018). Different platform businesses respond to competition differently. While some platform leaders, like Microsoft, prefer crushing complementors that threaten them, others like Cisco prefer acquisitions (M. A. Cusumano & Gawer, 2002). Platforms are constantly competing for both (a) independent complementors on the supply side, and (b) end consumers on the demand side of the platforms (Tanriverdi & Chi-Hyon, 2008). Various strategies, such as multihoming, platform tipping, platform forking, and platform envelopment are employed to stay at the top of the game.

Multihoming: complementors use multihoming as a competitive strategy to expand the size of their potential markets (Constantinides et al., 2018). Multihoming occurs when complementors use multiple platforms for their offerings; for instance, application developers using both Android and iOS platforms to publish apps (De Reuver et al., 2018). The rationale here is to *not put all eggs in one basket* so as to alleviate the risks associated with complementors relying on a single platform. Recently emerging research (Cennamo et al., 2018) challenges previous notions that suggest multihoming lowers differentiation between competing platforms, because same apps are available across multiple platforms. On the contrary, quality of the same app developed by same complementor will vary across platforms, because complementors tweak the app to incorporate the core technology of each individual platform (Cennamo et al., 2018).

Platform tipping: generally occurs when a platform strategically implements schemes to snatch complementors from their competitors. Rival platforms significantly lower multihoming costs by offering privileges, such as compatible interfaces and specialised software development kits to attract complementors (Tiwana et al., 2010). When network effects are reinforced by a technical standard, multihoming costs become extensive (Annabelle Gawer & Cusumano, 2014), which significantly affects the evolution of a platform. Multihoming costs are a sum of the operation, adoption and opportunity costs that complementors are required to invest for their participation in one platform (Tiwana et al., 2010). An increase in such costs reduces complementor willingness to participate in multiple platforms with their affiliation going to the platform with feasible costs and greater benefits.

Platform forking: research suggests forking is unique to digital platforms (Karhu et al., 2018). It occurs at the core of a platform, resulting in the creation of a new platform that is in direct competition with the host platform, whilst maintaining compatibility with the latter; compatibility assures potential to explore the complementary offerings (apps) of the host platform. Previous studies (Tiwana et al., 2010) discuss a very similar concept of *derivative mutation* – unanticipated creation of a spinoff platform with a different function/output altogether, but with similar properties as that of its host platform. Forking makes the host platform vulnerable to spying and imitation from competitors. In the interest of avoiding such forking episodes, Intel (platform leader) kept their microprocessor architecture confidential despite being open about other interfaces, such as the USB (universal-serial bus) (M. A. Cusumano & Gawer, 2002). However, this is not something that Google could avoid with their Android Open Source Project (AOSP), using which Amazon developed the Fire OS platform. Not only did Amazon copy the core of AOSP, but also carried on exploiting Android's app complements which were shared for distribution (Karhu et al., 2018). In response, Google withheld licenses preventing Amazon fire OS users from officially downloading Google Play store, and other most used apps, such as Google Chrome and Google Maps, severely stunting the growth of the Fire OS platform.

Platform envelopment: occurs when the focal platform absorbs another platform from an adjacent market to combine functionalities and offer product bundles of their own (Tiwana et al., 2010). Platform leaders follow this approach to expand the scope of their platform offerings whilst absorbing their complementary competition (Constantinides et al., 2018). For instance, Amazon, initially a bookstore, expanded into other e-commerce verticals and progressively enveloped by enabling music streaming through Amazon music, rent on demand videos through Prime Video, and everyday essentials via Amazon pantry from the adjacent markets.

Key finding 4: *Structurally, platforms can be closed nature and operate only internally within a single firm, or be partially closed but open to the supply chain of a firm, or be open for external innovators to innovate and develop on the platform. In operating across these varying platform types, PEs witness competing platforms incentivising complementors to multihome, switch between platforms by tipping, imitate core technologies by forking, and absorb superior complementary competencies via envelopment for maximizing value appropriation.*

5. SETTING A HOLISTIC RESEARCH AGENDA

Despite existing strands of PE research offering critical understandings, four key limitations emerge from this review that future research should focus investigation on:

5.1. Restrictive focus: mostly on technical aspects of PEs

Existing research is more concentrated on the technicalities, mostly platform architecture, core components, complements, and other tangible resources (Tiwana et al., 2010). The case is similar for digital platforms, where scholars are more interested in studying them either from a technical or economical perspective, with very little attention given to the organisational perspective (Rolland et al., 2018). A similar trend is observed with the inherent characteristics of a platform's technical core, mainly modularity; researchers extensively discuss flexibility as

a benefit of modularity, but flexibility decays over time and influences the associated benefits as platforms age - very little is known of this (Tiwana, 2015b).

In line with suggestions made by some of the recent studies (De Reuver et al., 2018), there exists a need to adopt other units of analysis to encourage theory development beyond mid-range theories. For instance, investigation of the boundary resource concept as a unit of analysis in highly distributed arrangements where independent actors innovate based on opportunities and hurdles of operating in layered modular arrangements (De Reuver et al., 2018) is needed. Moreover, having established PEs as social systems, as much as they are technical systems, this study calls for more research on the organisational aspects of PEs; for instance, a focus on the social challenges that can inhibit actors from thriving in a PE requires scholarly attention. In addition, with modularity recognised as one of the prominent characteristics of PEs, future research needs to focus on the effect modularity can have on wider issues, such as platform control. For instance, more research is needed to elaborate on the interplay between platform control and modularization of platform extensions, as they can affect performance of the complements in the market in which they compete (Tiwana, 2015a).

5.2.Narrow scope: limited to issues of network orchestration and governance across PEs

Most studies focus on limited aspects of authority, planning and organisation of PEs. Literature has established that governance mechanisms directly influence the sustainability of PEs, which progresses our thinking on – willingness of network actors to collaborate in a PE, development of participation incentives, managing issues of power, surveillance and overall engagement; yet, current understanding on PE governance is primarily restricted to success stories (De Reuver et al., 2018; Zhong & Sun, 2020). Platform sustainability is closely linked to the resilience of the actors collaborating in a PE (Graça & Camarinha-Matos, 2017). Despite wide acceptance of the benefits of collaboration, there is a lack of metrics and performance indicators that can help assess the sustainability of PEs. There is also limited knowledge on inter-organisational mechanisms adopted by platform leaders to ensure high quality integration with their network actors (Cennamo et al., 2018; Tiwana, 2015a). In addition, platform leaders must encourage fair distribution of value (from innovation) for complementors and other stakeholders for their contributions to the platform; managing such innovation appropriation can motivate complementors to continue innovating for the platform, in turn, improving the overall platform output and performance (Zhong & Sun, 2020).

Such mechanisms are paramount for exercising control over PE actors. Lack of research on network control mechanisms, where responsibility sharing is prevalent amongst a group of entities, can have negative consequences for a PE's overall health (Wareham et al., 2014). Studies focusing on control mechanisms and modes are more interested in the nature and antecedents of control choices that may have positive or negative outcomes, without divulging into the reasons for such outcomes (Goldbach et al., 2018). For instance, pricing is regarded as one of the key network control mechanisms, which can influence cross-side network effects, but very little insight is available on pricing and the dynamics between pricing and cross-side network effects (Song et al., 2018). This review recommends future research to – (a) step aside from success stories and investigate actions that can result in ineffective governance in a PE to

improve our understanding of the same. (b) Shift research interest towards development of necessary KPIs capable of measuring actor integration to enhance overall sustainability of a PE. (c) Investigate different ways of managing innovation appropriation and its overall impact on the performance of a platform. (d) Divulge into different control mechanisms with specific focus on the reasons for using such mechanisms and their outcomes aimed at achieving synchronous activity amongst PE actors.

5.3.Partial breadth: in investigating network actors and the resultant network effects

The review reveals that detailed insights on different aspects of PEs remain either missing or limited in the literature, overall. For instance, although literature on platform leadership is extensive, other fine details, such as distinct stages of effective leadership, success factors for platform leaders, and good practices for exercising platform leadership are still missing (Benoit, Baker, Bolton, Gruber, & Kandampully, 2017; Perks et al., 2017). Similarly, despite significant research interest in platforms, there is a continuing lack of understanding on the dynamics of platform-based business models, how they are built, and how they evolve over time across an extensive network of actors. These actors trigger network effects, and although network effects have been investigated to a large extent, particularly cross-side effects (Lin, Li, & Whinston, 2011; Song et al., 2018), research suggests these are asymmetric, given the differences in distinct features of two sides – the complementor and end user sides of the platform; inadequate literature is available on the aforementioned topic (Song et al., 2018). Research observes that complexity of such network effects can be minimized, but this topic has failed to receive attention from academics (V. Eloranta & Turunen, 2016).

Furthermore, existing research is more platform-leader oriented, with little contribution on the perspectives of other platform actors, like the end users (M. Ceccagnoli et al., 2012). This can also be extended to the complementors, who represent greater majority of firms critical to value creation within an ecosystem, and yet, there is not enough information in literature on the performance consequences of such complementors (Kapoor & Agarwal, 2017). Despite the fact that understanding behavioural orientations of complementors can make or break a platform, there is insufficient evidence of motivations that drive complementor participation on a platform (Boudreau & Jeppesen, 2015).

With this review, it is recognised that further learnings on platform dynamics and determinants of network effects will lead to better orchestration of PE actors (Rong et al., 2018). As network effects are triggered from interactions between various actors, they directly impact the evolution of a platform-based business model; the recommendation for future research is to inspect the dynamics of different actor groups; for instance, insights into the interaction between suppliers and customers. In addition, future research should simultaneously account for both same-side and cross-side network effects to help account for the net effect on PE behaviour and the participants (Fang, Li, Huang, & Palmatier, 2015). Another research direction would be to invest attention in actors other than platform leaders to account for network dynamics triggered by complementors and end users. More importantly, for some PEs, their complementors are also the end users of their offerings; for instance, Airbnb can have the same people as users and providers of a property (Benoit et al., 2017). Future research should

offer insights into how such multiple roles assumed by the same actor group affects a PE, for instance, impact on user expectations from a PE.

5.4. Limited evidence: for strategies concerning platform structure and competition

Significant part of extant literature covers aspects of platform competition and related strategies, but there remain some pressing concerns in this area. Despite increasing episodes of exploitation of open platforms and open innovation, academic focus is mostly concentrated on the advantages of platform openness (Karhu et al., 2018). The literature fails to analyse these competitive strategies as a threat to the host platform. From the platform leader's perspective, there still is insufficient information on the competitive tactics aimed at establishing boundaries for the complementors (Constantinides et al., 2018). In a parallel vein, from the complementor's perspective, there is evidence of competitive strategies, such as multihoming in the literature, but not much is known about how they can build or expand a business.

The same is true for yet another competitive strategy, platform forking. Literature explains the concept, but focus on identifying factors that lead to forking, i.e. its determinants is very limited; knowledge is also limited on effective responses for tackling forking episodes, or at the extreme opposite, tapping on opportunities to build a successful platform fork (Karhu et al., 2018). Another popular strand of literature is platform leader's entry into complementary markets. While some link such entries to - better control over platform evolution, effective integration, and allowing platform leaders to appropriate rents, other studies (Foerderer, Kude, Mithas, & Heinzl, 2018) consider such entries to negatively impact complementors' revenues resulting in complementors exiting such platforms. This process of exiting, i.e. platform abandonment or desertion by the complementors constitutes yet another research gap. More studies are interested in how and why app developers (complementors) join a platform, but very few (Tiwana, 2015b) have only recently started to look at why they exit a platform.

While studies (M. A. Cusumano & Gawer, 2002; Karhu et al., 2018) have recognized the need for platform leaders to control and balance the degree of openness and confidentiality in dealing with the platform's core, there is little interest in academia as to how to achieve such a balance. In addition, there is also limited understanding on the complementor's perception of platform openness, with no validated items available to measure the degree of openness of a given platform (Benlian et al., 2015; Wessel et al., 2017). Additionally, studies examine the effects of platform openness from either an leadership or technological perspective, with almost no attention paid to the policy side of things (Wessel et al., 2017).

Some authors (Benlian et al., 2015; Constantinides et al., 2018; Tiwana et al., 2010) also report stunted understanding of the fine balance required between the control exercised by platform leaders and the independence given by them to their network actors. In addition, platform leaders have to make critical choices about how much to outsource (boundary conditions) in accounting for returns on innovation and managing associated costs, and yet, there is very limited information available on such transaction costs (Helfat & Raubitschek, 2018), associated resource allocation costs (Sridhar, Mantrala, Naik, & Thorson, 2011), and those incurred due to misaligned technology and related strategies (Nambisan & Baron, 2019).

Another type of cost with insufficient clarity is the multihoming cost, which is largely considered to be emerging from an external source, spread uniformly across platforms; researchers (Cennamo et al., 2018; Lin et al., 2011) challenge this notion to suggest these are determined by the platform leader themselves, and are possibly heterogeneous. Moreover, app coordination costs and app development costs, which have received very little attention in the literature have significant impact on the sustainability of a platform, as they influence complementors' choices of multihoming and platform desertion (Tiwana, 2015b).

Overall, more complementor-oriented research inclined towards managing this actor group in a PE is needed. For instance, this could be achieved via increased understanding of competitive strategies, particularly forking and multihoming, to move beyond *what they are* to divulge into insights that reveal (a) how they can be implemented (b) how the dynamics between the platform leaders and complementors are affected in the process (c) what are the associated drawbacks and threats and (d) what measures can be employed to manage the negative consequences. Aligned with some recent recommendations, future research should explore the best practices that third party developers, i.e. complementors can apply in practice to operate (or multihome) across multiple platforms (Constantinides et al., 2018). More attention is also needed to understand the costs associated with issues such as platform desertion, and the tactics that platform leaders can employ to prevent the loss of complementors. There are significant number of costs associated with a PE that considerably affect the structure and resulting competitive dynamics of a PE; more research should be directed at clearly differentiating the nature and effects of each of such costs on the overall sustainability of a PE. Additionally, in line with some persistent calls for research on achieving a winning balance between the terms of openness and confidentiality in a PE, this review recommends increased research on the topic. Such research can be targeted at investigating how exerting/relaxing control over PE actors helps/hinders the growth of a PE and/or how operating in a closed setting with increased confidentiality can limit a PE to fewer resources and innovation opportunities. Finally, as policies and regulatory frameworks play an important role in designing guidelines that dictate the permeability of a platform boundary (Benoit et al., 2017; Wessel et al., 2017), more scholarly attention is needed on the topic, for instance, investigating how resilient PEs can be in accommodating policy changes, and how the different actor groups can prepare to absorb the disruptions that such changes are likely to introduce.

In collating the research agenda, the limitations identified in this review are mapped against the S-T dimensions (fig 4) to show that not only are these limitations spread across all four S-T dimensions, but they also overlap between dimensions. The overlapping research limitations suggest that none of these S-T dimensions are operating on a standalone basis, and are constantly interacting with each other. The overlapping topics are reflective of the fact that occurrences in a given dimension are either influencing, or are under the influence of another S-T dimension (table 2). This reiterates our primary assertion that PEs are composed of technical, task-oriented, actor-oriented and structure-oriented elements. An explanation of such overlapping limitations has been collated herein.

Insert - Fig. 4. Research agenda across the S-T model - Here

(a) Overlap between *technical and task* dimensions – in using pricing as one of the network control mechanisms (task-level actions), any investment in improving a platform's technical core to meet changing industry needs will also reflect in the final price (price increase) of the offering produced by that platform. In addition, as such mechanisms are used to control and manage PE actors, this argument also extends to reflect the overlap between *actor and task* dimensions. Further research on pricing mechanisms with respect to these aforementioned overlapping dimensions could reveal different facets of platform competition (section 4.4.2) triggered by changes to the technical core. Moreover, such changes could bear significant implications for the value appropriated by both the platform leaders and their complementors, overall, impacting the conditions of network orchestration and platform governance.

(b) Overlap between *technical and actor* dimensions – in managing platform complexity, an inherent characteristic of a platform's technical core (section 4.1.2), it is imperative to account for the technical interdependencies experienced by the complementors and end users of a PE. More insights on the complexity of network effects representing an overlap of technical and actor dimensions could both – guide platform leaders in managing the technical core, i.e. modularity and complexity, as the platform grows to include new actors to meet changing end user needs; and also help complementors and other third parties navigate through the technical intricacies of a PE, as they create value for the platform leader whilst securing their own position in the PE.

(c) Overlap between *technical and structure* dimensions – changes made to the technical core of a platform in terms of increasing/reducing its modularity and complexity (see section 4.1) directly influences the ability of platform to adapt to different strategies, such as platform forking and multihoming. Further delving into such strategies from the overlapping perspectives of technical and structure dimensions could shed some light on the new formats of structural boundaries capable of improving efficiency of the technical core of a PE

(d) Overlap between *task and actor* dimensions – in managing an extensive ecosystem of actors, an understanding of the PE dynamics is crucial, i.e. how it evolves with different task-level actions triggered due to internal (organisational) and external (political, environmental etc.) changes. Platform leaders have to implement certain task-level actions (section 2.2) for developing suitable inter-organisational mechanisms to enable integrative working with their network actors. Focusing on the gaps identified (table 2) for the overlapping dimensions of task and actor could improve our understanding of certain issues, such as: platform leaders' capacity to measure which incentives have the potential to boost complementor performance; effective management of stakeholder expectations in a PE; and also managing network effects without jeopardising the incentives offered to network actors for value creation

(e) Overlap between *actor and structure* dimensions – in devising competitive strategies, structural decisions of openness and confidentiality (section 4.4.1) are undertaken, which tend to have a direct influence on the rules (restriction/freedom) imposed on PE actors; this not only affects their behaviours, but also impacts their decision to participate in a PE. Further research on the overlapping gaps identified for the actor and structure dimensions (table 2) could have key implications for platform leaders in

mitigating the risks of platform desertion; more insights could help them negotiate decision rights with the complementors, which are often intertwined with the structural design of a PE.

(f) Overlap between *structure and task* dimensions – anticipated changes in policies and regulatory frameworks can significantly influence how the PE evolves with such new changes, i.e. a platform reorienting itself by making necessary structural changes to accommodate the new policy and regulatory changes. More research on the topic could reveal important insights on: the extent to which regulatory frameworks alter governance structures that control stakeholder operations across structural boundaries; the effect policies and regulatory frameworks have on the overall growth of a PE; and also, if this impacts the quality of the outputs/complements produced by that PE.

Insert - Table 2. Overlapping research gaps - Here

6. CONCLUSIONS, IMPLICATIONS AND LIMITATIONS

Rise in platform economy and conceptual development of platform thinking mandates scholarly investigation of the disruptive platform approaches penetrating most business models these days. This paper synthesizes and highlights the supporting strands of available research for enhancing our understanding of platforms, in general, and PEs in particular. The research collated herein aims to increase awareness on PEs, and encourages advanced research and discussion on the topic. In accounting for the four S-T dimensions, this review identifies (a) core and peripheral components, modularity, and complexity as important research considerations for the *technical* dimension; (b) governance, network orchestration and incentives for participation as key research considerations for the *task* dimension; (c) role of platform leaders, complementors, and end users, alongside the network effects that they trigger as vital research considerations for the *actor* dimension; and (d) structural conditions of different platform types and the various competitive strategies adopted by the PE actors as the main research considerations for the *structure* dimension. Furthermore, this study collates research gaps identified by the journal articles reviewed herein, and positions them across the four S-T dimensions, whilst also exploring future research directions based on the interaction/overlap of these four dimensions.

6.1. Theoretical and managerial implications

This paper categorises available literature across four dimensions of technology, task, actors, and structure to understand PEs from an S-T perspective. Derived insights are highly relevant bearing significant theoretical implications. With the emergent themes identified in this paper, the authors contribute towards initial conceptual clarity on the topic of PEs. The adapted S-T framework not only identifies research topics requiring further work, but also highlights the overlap between these topics across the four S-T dimensions. There is an evident need for future research to focus on these intersecting topics to ensure scholarly progression on PEs. This paper also identifies key topics by developing a research agenda for advancing holistic understanding of the topic, encompassing both social and technical aspects of PEs.

With respect to practical implications, the terms, platforms and PEs are in increased usage these days and are raising fear of disruptions and displacements amongst businesses. The businesses do not fully understand what platforms and PEs mean, but mostly envision these to be technology. However, as evident from this review, technology is only one of the many components that go into building an ecosystem. In addition to clarifying various aspects of platforms and PEs, such insights can help businesses understand the different actor roles (platform leader, complementors, etc.), and in turn, identify other businesses to pursue collaborative innovation. Businesses can also benefit from insights collated herein on platform competition, and the strategies outlined for managing PE actors to understand the basics of platform management and orchestration.

6.2. Research limitations

Besides the aforementioned contributions, there are some limitations of this study. Categorization of literature across the four dimensions of an S-T system is based on authors' interpretation of the concept, and could be subjective. Furthermore, in applying a systematic literature review approach, one of its inherent limitation might now be a part of this review, i.e. reviewing previously published literature may have a constraining effect on the possibility of contributing to theory development (Webster & Watson, 2002). This limitation is tackled here by adopting an established theoretical lens of socio-technical systems to ensure a coherent and theoretically grounded framework is used to map the reviewed literature.

In addition, the review focusses on a selection of high-ranking journal articles (ABS ranking), meaning not all available literature on PEs has been reviewed. In the interest of maintaining rigour, exclusion of lower ranked journal articles often comes with the risk of limiting the range of topics/perspectives covered, a trade-off that is widely recognized in the academic community (Rafols, Leydesdorff, O'Hare, Nightingale, & Stirling, 2012). Future research should consider the impact of such journal selection process, and extend their investigation to other available research, if need be, to further clarify the four S-T dimensions in the PE context.

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Tables

Table 1. Characteristics of platforms and platform ecosystems

Key Characteristics	Illustrative sources
PEs may be built around a core technology or value proposition that acts as the platform	Adner (2016); Beltagui et al. (2020); Nucciarelli et al. (2017)
PEs include providers of complements that make the platform more valuable	Marco Ceccagnoli et al. (2012); Cenamor (2021); Annabelle Gawer and Cusumano (2014); Story et al. (2020)
PEs have a platform sponsor that orchestrates, co-ordinates or partially regulates the ecosystem	Jacobides, Cennamo, and Gawer (2018); Lütjen, Schultz, Tietze, and Urmetzer (2019); McColl-Kennedy, Cheung, and Coote (2020); Parida, Burström, Visnjic, and Wincent (2019); Wareham, Fox, and Giner (2014)
PEs incorporate multiple stakeholders in systems that can be nested or be overlapping	Blasco-Arcas et al. (2020); Michael A Cusumano et al. (2020); Eisenmann, Parker, and Van Alstyne (2011); Rong, Patton, and Chen (2018); Trischler, Johnson, and Kristensson (2020)
Platforms alter firm boundaries by including both competition and collaboration, i.e. stakeholders furthering collective and individual interests	Bacon, Williams, and Davies (2020); Hullova, Laczko, and Frishammar (2019); Kohtamäki, Parida, Oghazi, Gebauer, and Baines (2019); Nambisan and Baron (2019)
Platforms require changes to the business models, internal structures and capabilities of firms, to suit new technologies	Chandna and Salimath (2018); Jovanovic, Raja, Visnjic, and Wiengarten (2019); Parker et al. (2017); Sklyar, Kowalkowski, Tronvoll, and Sörhammar (2019)
PEs connect complementors to the central platform through shared or open-source interfaces, technologies and standards	Broekhuizen et al. (2019); Marco Ceccagnoli et al. (2012); Jacobides et al. (2018); Morgan-Thomas, Dessart, and Veloutsou (2020); Mukhopadhyay and Bouwman (2019); Parker et al. (2017)
PEs represent multisided markets, with inputs from distinct groups of consumers, service providers and manufacturers	Cennamo and Santalo (2013); McIntyre and Srinivasan (2017); Peltier, Dahl, and Swan (2020); Sharma, Jain, Kingshott, and Ueno (2020)
PEs influence the evolution or adoption of technology through stakeholder interaction	Annabelle Gawer and Cusumano (2014); Annabelle Gawer and Henderson (2007); Nysveen, Pedersen, and Skard (2020); Vargo, Akaka, and Wieland (2020); Wareham et al. (2014); Yang and Han (2019)

Table 2. Overlapping research gaps

Overlapping topics	Research gaps	Sources
Technical-Task	- Pricing as a control mechanism	Song et al. (2018)
Technical-Actor	- Complexity of network effects	V. Eloranta and Turunen (2016)
Technical-Structure	- Determinants of forking - Best practices for multihoming	Constantinides et al. (2018), Karhu et al. (2018)
Task-Actor	- Metrics and performance indicators - Inter-organisational mechanisms for actor integration - Dynamics of platform-based business models - Pricing and cross-side network effects	Tiwana (2015a), Cennamo et al. (2018), Rong et al. (2018), Graça and Camarinha-Matos (2017), Song et al. (2018)
Actor-Structure	- Competitive strategies - Platform desertion	Karhu et al. (2018), Foerderer et al. (2018)
Structure-Task	- Policies and regulatory framework	Wessel et al. (2017), Benoit et al. (2017)

Figures

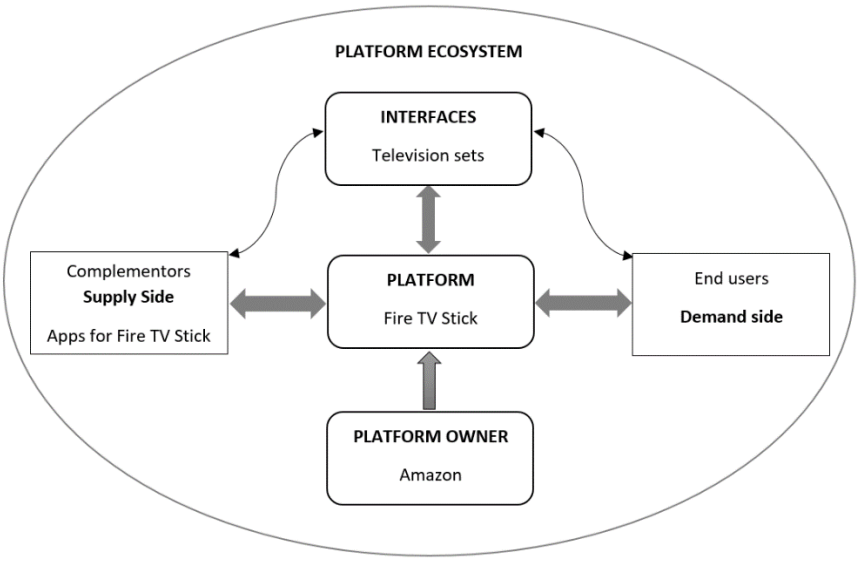

Fig. 1. Platform ecosystem for Amazon Fire-TV stick.

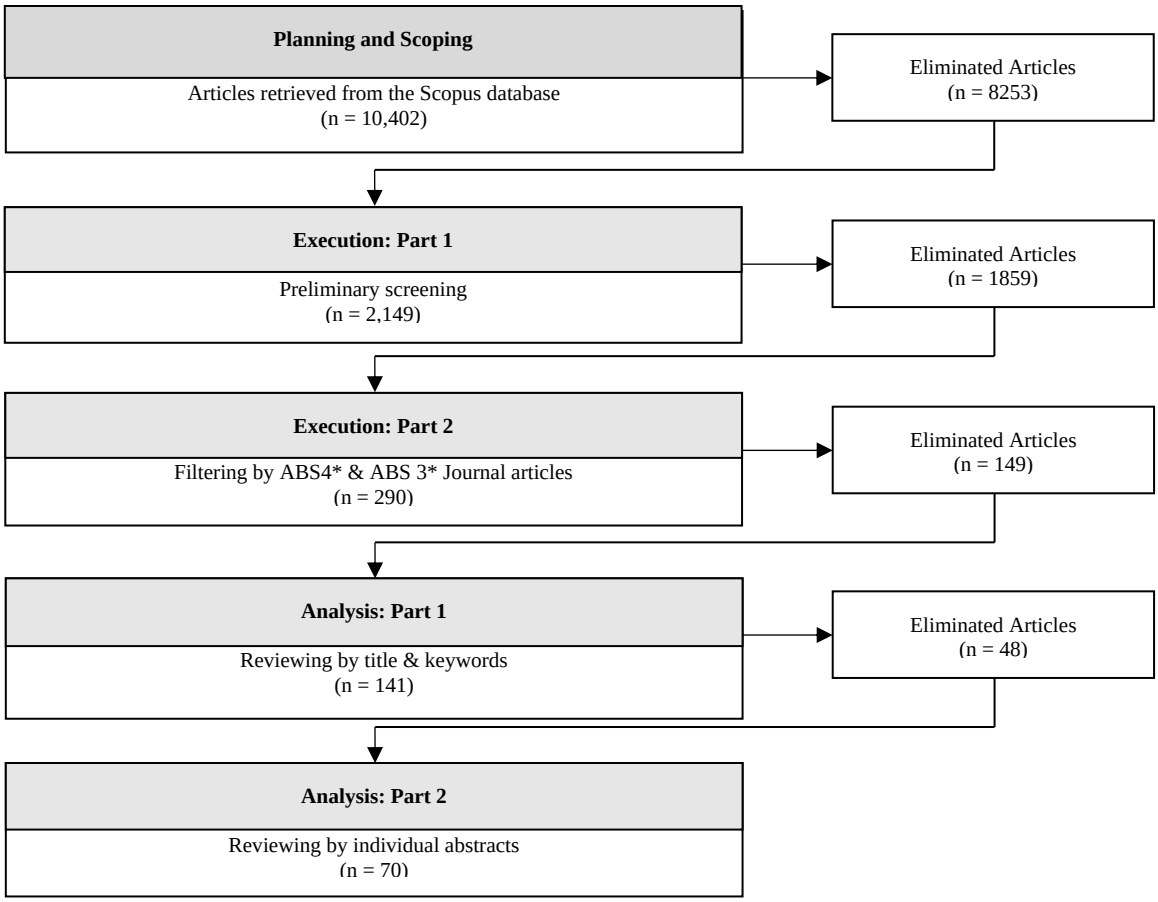

Fig. 2. Systematic literature review.

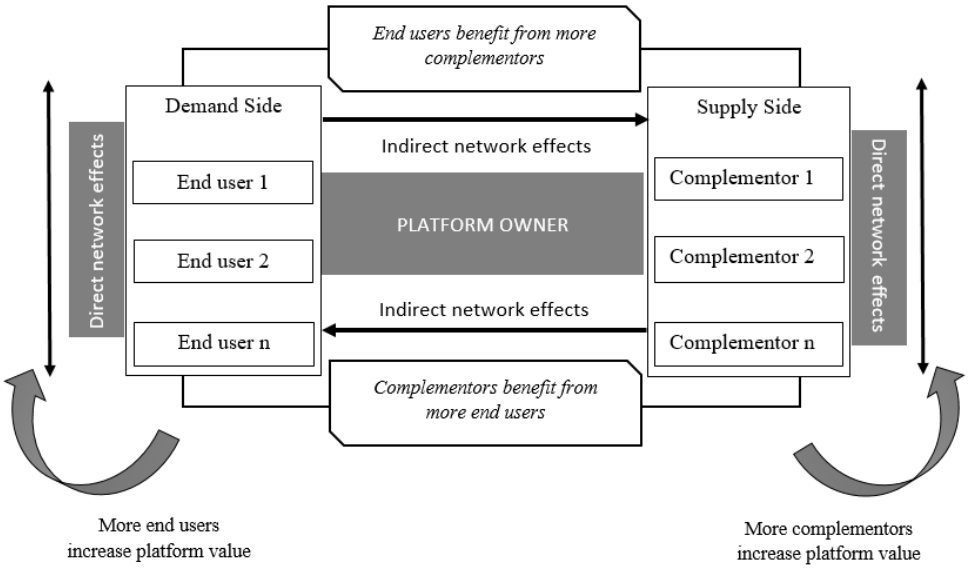

Fig. 3. Network externalities.
(Source: Adapted from Kim (2016))

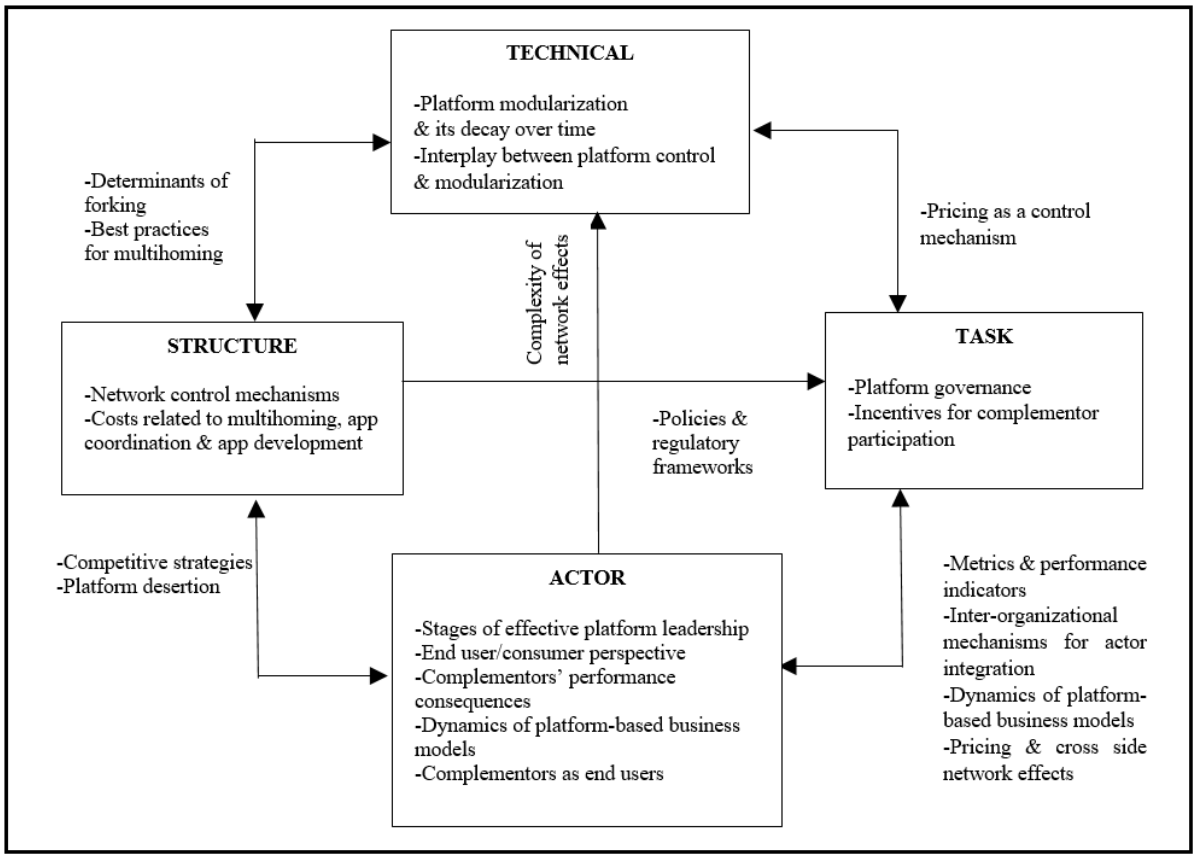

Fig. 4. Research agenda across the S-T model.

(Source: Adapted from Lyytinen and Newman (2008))