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RESEARCH PAPER

Understanding how platform modularity enhances network effects

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Abstract
With modular architecture, digital platforms comprise decomposable modules and well-defined interfaces that provide the technical capabilities for reconfiguring, extending, and evolving products. Drawing on research in engineering design and industrial economics, we investigate how the architectural modularity of platforms can be employed to enhance network effects. We illustrate how the structural elements and capabilities of modular architecture can be leveraged to strengthen network effects and how the objective of scaling platforms can drive the formulation of modularization principles to define modules and interfaces. We then discuss Microsoft Power BI, a business intelligence platform, as a specific example and describe how the components and functions of Power BI are utilized to strengthen network effects. Our study highlights the interplay between platform architecture and network effects, showing how architectural modularity can lead to network growth. It contributes to research on digital platforms and digital product innovation.

Keywords Digital platforms · Platform architecture · Modularity · Modular design · Network effects · Power BI

JEL Classification L15 · M15

Introduction

Digital platforms are an important form of product innovation and organizational model that are driven by interactions and exchanges enabled by information technologies (Parker et al., 2016; Gawer, 2014; Hein et al., 2020). The structure, design, and evolution of platforms give rise to a range of research topics and issues in various academic disciplines. These issues cover internal factors that are strategies, the technical design of IT artifacts and governance, and environmental dynamics that include third-party participation, network effects, competition, multi-homing, and trust (Poniatowski et al., 2022). Platform architecture is a conceptual design that describes how a digital system can be partitioned into stable and complementary components, and it demonstrates how these components interact with each other and with the user (Baldwin & Woodard, 2008; Tiwana et al., 2010; Gawer & Cusumano, 2014). It is a key internal factor that has profound impacts on the platform itself and its ecosystem as platform architecture, its governance, and the environmental dynamics coevolve (Tiwana, 2018). Platform architecture design is a strategic decision through which platform owners choose whether the platform is integral or modular (Constantinides et al., 2018). In modular architecture, a platform can be decomposed into separable but interdependent parts, such as the core and peripherals, while an integral architecture treats the platform as a single component that cannot be decomposed into functional parts (Baldwin & Woodard, 2008; Yoo et al., 2010).

For platforms, modular architecture is the technical infrastructure, and this infrastructure enhances the generativity of the platform (Tiwana et al., 2010; Hein et al., 2020). In practice, the adoption of modularity is an important step toward building a platform. For example, SAP adopted a modular design when it launched its cloud platform (Schreieck et al., 2021). Similarly, when ABB transformed its product into a platform, it went through a phase of product modularization (Sandberg et al., 2020). Furthermore, platform modularity directly affects value creation and value capturing (Bonina et al., 2021). One finding from a case study in comparing mobile payment platforms in the UK is that modular platforms outperform integral ones in creating value but underperform in capturing value (Kazan et al.,

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2018). In addition, when a product can be decomposed into separable modules that can be interchanged and re-combined, there is an increasing opportunity for platform-based new entrants, intensifying market competition (Cennamo et al., 2022).

Although the importance of modularity is recognized in the literature, there is limited research on how modularity allows platforms to create value and gain market share. Specifically, there is relatively little knowledge about "strategies that new entrants employ for modular design and loose coupling while overcoming the classic 'chicken-and-egg' problem of attracting enough complements and consumers" (Kretschmer et al., 2022, p. 417). The "chicken-and-egg" problem originates from network effects at the nascent stage of a platform. Rietveld and Schilling (2021) echoed the need for more empirical studies on the interplay between network effects in the business environment and the technological innovation of digital platforms, especially regarding the competition between new entrants and incumbents. The concept of network effects is a key characteristic of platforms and is considered a prominent factor in platform environmental dynamics (Jacobides et al., 2018; Poniatowski et al., 2022). Therefore, the issue is how the architectural modularity which is an internal factor interplays with network effects which are an aspect of the environmental dynamics.

Although platform architecture coevolves with environmental dynamics (Tiwana, 2018), architectural modularity and network effects are studied separately in the literature. Architectural modularity is primarily studied from the viewpoint of engineering design with a focus on internal product integration and interfaces with complementary products, while network effects are studied from the perspective of industrial economics through topics about pricing, inter-platform competition, and market adoption (Gawer, 2014; Jacobides et al., 2018; Poniatowski et al., 2022). It falls into the intersection between engineering design and industrial economics to study the interplay of architectural modularity and network effects. We draw on these two perspectives to formulate an integrative view of the interplay between platform modularity and network effects in the ecosystem. Our particular research question is as follows: *How can architectural modularity be employed to strengthen network effects?*

In engineering design, modular design has three major elements: separable loosely-coupled modules, well-defined interfaces, and hierarchical structure (Ulrich, 1995; Baldwin & Clark, 2000). With modular design, a product constitutes subassemblies and components that can perform individual functions. Specifications are clearly defined and can be implemented to assemble the components together as a holistic product. At the same time, a component can be further decomposed into sub-components, forming a hierarchy of components and subcomponents. In addition, digital technologies have properties that allow for low-cost modification and recombination of components, users' participation in enacting functions, and wide deployment across distributed computing infrastructures (Yoo et al., 2010; Kallinikos et al., 2013). In this essay, by integrating the features of modular design and the properties of digital technologies, we argue that digital platforms with modular architecture will have capabilities such as reconfigurability, extensibility, and evolvability. Reconfigurability is the ability to recombine inputs to form heterogeneous product configurations. Extensibility is the ability to extend product functions. Evolvability is the ability to innovate at a fast pace and at a low cost.

From the perspective of industrial economics, a platform is an organizational form and marketplace through which a product or service facilitates interactions of multiple user groups (Parker et al., 2016). The value of the platform to users partly comes from offering access to other users for exchanges and transactions. Hence, the more users adopt a platform, the more valuable the platform becomes to users. This increasing return to adoption is referred to as "network effects" and is a prominent feature of platforms (Katz & Shapiro, 1986; Jacobides et al., 2018). We categorize network effects into four types according to how users interact through the platform: direct, cross-side, indirect, and inter-platform. Direct network effects originate from interactions among homogeneous users (Rohlfs, 2001; Penttinen et al., 2018), while cross-side network effects occur when heterogeneous user groups interact with each other (Rochet & Tirole, 2003; Tessmann & Elbert, 2022). Indirect network effects exist between users and complementary product providers (Katz & Shapiro, 1994; Rietveld et al., 2019). Inter-platform network effects occur when users have access to another platform's users and functions (Farrell & Saloner, 1992; Dou & Wu, 2021).

While architectural modularity is an internal parameter of a platform's technological design, and the network effects describe an external dimension of a platform's environmental dynamics, we argue that modularity supports the construction of platforms by strengthening network effects through the reconfigurability, extensibility, and evolvability of the platform architecture. A platform-oriented strategy provides inputs for modular design, as it highlights the requirements for functionality that encourage interactions among multiple user groups. In this essay, our arguments are first summarized as propositions on the interplay between modularity and network effects. We then apply this conceptual framework to Power BI, a business analytics platform. Power BI constitutes a hierarchy of functional modules, and it expands functions by adding more modules. At the same time, certain modules and their functions are specified to encourage and support user interactions that generate network effects. In other words, the goal of promoting network effects provides functional specification for given modules. From this perspective, we highlight the design of Power BI as an example of integrating modularity and network effects in building a digital platform.

This essay offers two main contributions. First, it bridges the two separate research themes on digital platforms: architectural modularity from engineering design and network effects from industrial economics. We analyze the interplay between the internal factor of platform technical design and the external factor of platform environmental dynamics, revealing the role of network effects in designing platforms. Second, our essay contributes to the literature on digital product innovation (Wang et al., 2022) by showing that the objective of enhancing network effects provides an important dimension of specifying design principles for digital product development. The proliferation of digital product innovation has increased the need for design knowledge that guides product developers, including platform owners, in designing digital products (Wulfert et al., 2022). This essay's analyses reveal how the goal of building up network effects can guide the formulation of modularization principles in designing digital platforms, which expands the knowledge base of digital product innovation.

The remainder of the essay is organized as follows. The next section reviews the major concepts of modular design and network effects as the theoretical background. The "Modular design and network effects" section elaborates on the interplay between platform modularity and network effects and develops five propositions. The "The example of Power BI" section presents an overview of the structure and functions of Microsoft Power BI, focusing on its major functional modules and capabilities as a platform. The "Discussion" section discusses the managerial and theoretical implications of this study and explores directions for future studies. The paper concludes with a summary of the essay's main thesis and contributions.

Background

This section reviews the research background for our study regarding the features of modular architecture from engineering design and patterns of network effects from industrial economics.

Features of modular architecture

Modularity is an important characteristic of product architecture, and it has profound impacts on product development, organizational design, market competition, and industry evolution (Brusoni et al., 2023; Baldwin & Clark, 2000). Product architecture is "a scheme by which the function of a product is allocated to physical components" (Ulrich, 1995, p. 419). It is the design and specification of the components and subsystems in the product and the relationships among them (Gershenson et al., 2003). It encompasses information on how the components work together, how they are built and assembled, how they are used, and how they are disassembled (Fixon, 2005). Product architecture can be broadly classified into two types: integral architecture and modular architecture (Shibata et al., 2005; Burton & Galvin, 2020). In integral architecture, components are tightly coupled and interdependent, connected through interfaces that are proprietary and nonstandard (Sanchez, 2008). In modular architecture, components are loosely coupled, which means the between-component interdependence is much weaker than within-component interdependence (Baldwin & Clark, 2000). A product is built from components or modules that provide the basic functions necessary for the product to operate as desired and that can also be removed from the product non-destructively (Ulrich, 1995). For purposes of this paper, the terms "modules" and "components" are used interchangeably to refer to product units that perform specified functions. While integral architecture can maximize value capturing (Schilling, 2000), modular architecture reduces product-development cycle time (Danese & Filippini, 2013). With digital technologies, the layered modular architecture has emerged as a common product architecture to embed digital components into physical products (Yoo et al., 2010). In digital ecosystems, modular architecture is used to structure interdependence between the core platform and complementary subsystems (Tiwana et al., 2010; Tiwana, 2015).

A modular architecture has three essential elements. First, a product module is independent of — or *loosely coupled* with — other modules (Gershenson et al., 2003). A product constitutes modules "whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units" (Baldwin & Clark, 2000, p.63). The second element is that modules interact through *well-defined interfaces* (Ulrich, 1995). Interface specifications define how components interact with the larger system and help hide the complexity of components (Baldwin & Clark, 2000, p. 64). While there are minimum interactions among modules, they should be assembled together to operate as a whole so as to fulfill the desired product functions. For this purpose, well-defined interfaces that allow for the alignment and coupling of modules into one complete product are necessary to the product architecture (Sanchez & Mahoney, 1996). The third element is that modules are often organized into a nested *hierarchical structure*. Hierarchy is the basic structural form of complex systems that are composed of interrelated subsystems that, in turn, have their own hierarchical structures with subsystems (Simon, 1962). It is also the structural scheme used in modular product design. Specifically, a product's function contains a set of functional elements that are arranged in a hierarchical form with different levels of abstraction (Ulrich, 1995). When the product's functional elements are mapped into physical components, the product components and modules are organized into a hierarchy of interrelated submodules with various levels of granularity.

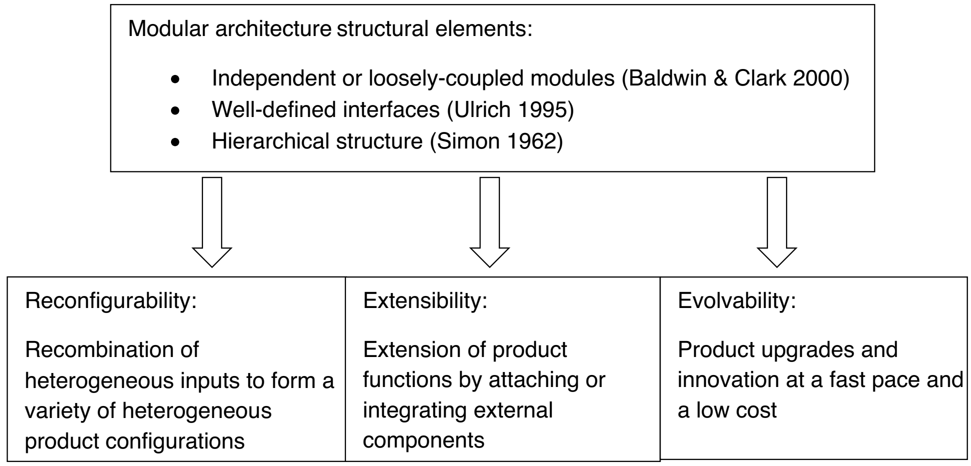

Fig. 1 Modular architecture structural elements and capabilities

Based on these structural elements, modular architecture entails a range of capabilities in the design, development, operation, and retirement of products (Efatmaneshnik et al., 2020). Regarding product design and development, these capabilities can be characterized by the product's ease in reconfiguring (*reconfigurability*), extending (*extensibility*), and evolving (*evolvability*). These structural elements and capabilities of modular architecture are discussed below and are graphically depicted in Fig. 1.

Reconfigurability The independence or loose coupling of components of modular systems provides flexibility in product configuration. Because modules can be separated from, or added to, the product without changing the rest of the product (Baldwin & Clark, 2000), modularity enables the recombination of heterogeneous inputs to form a variety of heterogeneous product configurations (Schilling, 2000), which results in reconfigurability.

Extensibility Modular architecture also makes it easy to attach or integrate external components to the product, extending the product function. This extensibility is premised on the basis of both inter-modular independence and well-defined interfaces. Inter-modular independence minimizes any changes to existing components that are needed to add another component. Well-defined interfaces make it feasible to attach an external component with reasonable effort.

Evolvability Because of the separation of intra-modular interactions from inter-modular interactions, product changes such as upgrades and add-ons can be implemented with the fewest possible components and with minimal impacts on other components (Ulrich, 1995). Furthermore, modular systems comprise nearly decomposable subsystems that provide stable intermediate forms, which allows for a more rapid introduction of innovation and an escalation of system complexity (Simon, 2002). With the option of re-using product components, modular design can control the costs and time-to-market span in developing the next-generation product (Wu et al., 2009). Empirical studies have shown that modularity shortens new product-development time and improves product performance (Lau et al., 2011; Danese & Filippini, 2013). This effect of modular architecture on product changes and innovation over time is referred to as "evolvability" in this essay.

One major task of modular design is to identify modules and specify interfaces (Gershenson et al., 2003). At the strategic level, product design objectives drive modularization principles that define the partition of modules and the specification of interfaces (Bonvoisin et al., 2016). For example, the objective of reducing a product's environmental impact and resource usage through remanufacturing translates to the modularization principle of grouping product functions by their disassembly patterns; in this way, parts that can be disassembled with the same tools are grouped into one module. At the methodological level, design rules are identified for grouping function carriers into modules and are applied to systematically reduce interdependencies among design parameters (Baldwin & Clark, 2000). As part of the modular design, developers select modularization principles and design rules in order to partition functions into modules and to define interfaces.

Patterns of network effects

The concept of network effects is one of the key characteristics of the business model canvas for digital platform ecosystems (Sorri et al., 2019). Business models describe how

Table 1 Patterns of network effects

Network effects	Sources	Common practices	Examples
Direct network effects	Interactions among homogeneous users	Search for and connect participants	Telephone services
Cross-side network effects	Interactions among heterogeneous groups of users	Open access to one group to appeal to the other group	Ride-share services such as Uber
Indirect network effects	Exchange between users and complement producers	Increase complements	Video game consoles and games
Inter-platform network effects	Access to participants and functions in other platforms	Control platform openness	Google Web Server and Microsoft IIS server

firms, including digital platforms, create and capture value (Rietveld & Schilling, 2021). They can be illustrated by the business model canvas that includes such traditional components as value proposition, revenue streams, customer segments, key resources, key activities, key partners, and cost structures (Taipale-Erävala et al., 2020). The business model canvas is adapted for digital platform ecosystems by including the additional key characteristics of network effects, filtering, and governance (Sorri et al., 2019). Next, we analyze the influence of network effects on digital platforms.

A platform is formed around a focal product when the product facilitates the exchange of goods, services, or social interactions among users (Parker et al., 2016). The value of the platform partly comes from how the focal product leverages technologies to connect users, organizations, devices, and resources. This value increases with the number of platform participants that form a network via exchanging or interacting with each other through the platform. This phenomenon is widely recognized as "positive network effects" (Economides, 1996) that are common in information technology industries (Rohlfs, 2001). Network effects play a significant role in the market adoption of platforms (Katz & Shapiro, 1986) and hence, platform-oriented strategies center around how to leverage network effects in launching and expanding platforms. Based on the patterns through which participants interact, there are four types of network effects: direct network effects (Rohlfs, 2001; Penttinen et al., 2018), cross-side network effects (Rochet & Tirole, 2003; Tessmann & Elbert, 2022), indirect network effects (Katz & Shapiro, 1994; Rietveld et al., 2019), and inter-platform network effects (Farrell & Saloner, 1992; Dou & Wu, 2021). Table 1 summarizes the sources of network effects, common practices for generating network effects, and example products or services.

Direct network effects occur when homogenous users interact with each other on the same platform by exchanging information, sharing documents or trading goods and services. This positive feedback is widely observed in the information technology industry and markets (Rohlfs, 2001). Typical products that exhibit direct network effects are communications technologies such as telephones and fax machines. Direct network effects exist in both consumer and business markets. The online marketplace eBay is an example of a consumer market with direct network effects since individual consumers find eBay more valuable when there are more participants in the marketplace. An example of a business market with direct network effects is a business-to-business e-invoicing platform, where invoice data is exchanged among trading partners (Penttinen et al., 2018). To support these direct interactions, platforms provide functions for the identification, communication, and matching of participants. A telephone directory service is an example of such functions.

Users in a platform may belong to distinct groups with heterogeneous needs that are satisfied by interacting with other user groups. These interactions generate *cross-side network effects* in two-sided markets (Rochet & Tirole, 2003). Uber provides a good example here. Drivers use Uber to find riders and vice versa; hence, the more riders there are, the more drivers there are. Similarly, cross-side network effects exist in the digital freight exchange platforms that connect trucking companies, terminal operators, rail operators, freight forwarders, multimodal operators, carriers, barge operators, and other participators in the transshipment market (Tessmann & Elbert, 2022). In the presence of cross-side network effects, a common practice for promoting market adoption is to open the platform to participants on one side in order to attract participants on the other side who will generate revenue. For example, Uber charges drivers a portion of the rider fares for using its software and services but allows riders to join for free. Although cross-side network effects often originate from the market structure, as in the case of Uber, they may be boosted by design. Specifically, a digital platform can be designed as a system that comprises parts that are used by different user groups to interact with other groups (McIntyre et al., 2021; Tan et al., 2020). One instance is the system of Web server and Web browser, where content producers use Web servers to publish Web pages, and viewers use compatible Web browsers to view the Web pages. The maker of the server–browser system offers the browser free of charge while selling the server to content producers. This practice aims to maximize the viewers' participation in order to attract content producers, who are the revenue source.

Another pattern of network effects is the *indirect network effect*, which occurs when other product makers participate in a digital platform by supplying products that complement the focal product's functions (Katz & Shapiro, 1994). End users can obtain these complementary products and use them in combination with the focal product. Such interactions between end users and complementary product providers are facilitated by, and completed via, the platform. Positive feedback occurs between the number of end users and the number of complementary product suppliers, which manifests as the indirect network effect. This effect is characteristic of the video game industry, where game consoles function as platforms on which games are complements that are provided by third-party developers (Cennamo et al., 2018). To leverage the indirect network effect to drive market adoption, platform owners often employ various strategies to attract and promote complementary product providers because the availability and variety of complements can increase the value of the platform to end users (Eisenmann et al., 2006; Rietveld et al., 2019). In product design and development, the primary task is to identify the functions that can be provided by external producers as complements and to specify the boundary between the core product and complements. The next pertinent task is to offer boundary resources for third-party developers to develop the complements, such as application programming interfaces (APIs), development tools, and governance mechanisms (Tiwana et al., 2010).

Network effects also occur when a platform is compatible or integrable with other platforms, including competing ones. Such interconnectivity between platforms allows consumers in one platform to obtain products and services in another platform (Zhu et al., 2021). In this essay, this is referred to as *inter-platform network effects*. An example is the web server and web browser systems. Google's Google Web Server (GWS) and Microsoft's Internet Information Services (IIS) server are both proprietary platforms. These two servers are compatible with each other in the sense that websites hosted by GWS can be viewed by users of both the Google Chrome browser and Microsoft Edge browser, and vice versa. Users of GWS and Chrome have access to the websites hosted by IIS and Microsoft Edge, expanding the reach of GWS. The same is true for users of IIS and Edge with GWS and Chrome. In general, a platform owner can use converters and interfaces to allow for interconnection with other platforms and exert control over the access to the platform by adjusting the openness of the interfaces (Farrell & Saloner, 1992). The decision to offer such platform boundary resources is dependent on — and changes with — the ecosystem in which the platform is embedded (Eaton et al., 2015). At the launching stage, a platform needs to build up a sizable installed base of users as quickly as possible so that the positive network effect can operate in its favor (Katz & Shapiro, 1992). A nascent platform can accomplish this by connecting with existing networks through compatibility either with incumbent platforms or with previous-generation technology (Zhu & Iansiti, 2012; Dou & Wu, 2021). As the platform matures, it can expand into other markets by interconnecting with adjacent platforms, which is referred to as "platform envelopment" (Eisenmann et al., 2011).

Modular design and network effects

Drawing on perspectives from engineering design and industrial economics, we next discuss the interplay between architectural modularity and the network effects of digital platforms.

Platform-oriented modularization

From the modular-design perspective, the objective of building up a digital platform can be facilitated by modularization principles that direct the specification of modules and interfaces that form the platform's technical architecture. Modularization principles are general directions for the practical actions of constructing modules (Bonvoisin et al., 2016). Modules can be defined with the goal of facilitating interactions among users and engendering positive network effects on the platform (discussed in the "Patterns of network effects" section). Table 2 summarizes how the four patterns of network effects on platforms can be mapped into modularization principles. The table also includes functions and initiatives that exemplify these modularization principles.

To promote direct network effects, modularization principles could include constructing functional components for encouraging and facilitating user interactions such as sharing files and exchanging messages. To encourage cross-side network effects, modularization principles could group functions used by the same side of users into the same module so that the product is partitioned into modules with differentiated functions for heterogeneous user groups that interact with one another. With the pursuit of indirect network effects as the goal, the corresponding modularization principle will be to define modules that can be supplied by third-party developers as complementary products and that can be separated from modules with core functions. This is consistent with Baldwin and Woodard's (2008) suggestion about the construction of stable core components and variable peripheral components separately under platform strategy. Having well-defined and simple interfaces between the core modules and complementary modules is also desirable. To further support inter-platform network effects, the modularization

Table 2 Mapping platform network effects to modularization principles

Network effects	Example: Modularization principles	Example: Platform actions
Direct network effects	Provide functional components for user interactions	In November 2019, Sapiens provided functions for streamlined customer interactions by combining its core insurance platform with Lightico's customer-facing process solution. (PR Newswire, 2019)
Cross-side network effects	Group functions for the same side of users into the same module	In April 2008, Tableau created the Tableau Reader, which provides functions for viewing and sharing visual analysis reports. Tableau Reader is a separate module from Tableau Creator, which was used to create data visualization reports. (PR Newswire, 2008)
Indirect network effects	Construct modules to separate peripheral from core functions	In creating a cloud-based ERP platform, SAP utilized virtualization, containerization and microservice architecture to organize the applications into a set of service modules that can be deployed separately. (Schreieck et al., 2021)
Inter-platform network effects	Specify interfaces for connectivity with other platforms	In March 2016, Mozilla released *WebExtensions API* for Firefox browser to increase compatibility with Chrome. (Tian et al., 2022)

principle could include offering interfaces that are open to other platforms. Such interfaces could include APIs and development tools that other platforms can use to integrate their products. They could also include the implementation of industry standards or open standards that other products conform to as well, thereby achieving inter-platform compatibility.

Modularity for enhancing network effects

From the perspective of platform strategy, modular architecture provides the technical structure and capabilities for strengthening positive network effects. Through inter-modular independence, well-defined interfaces, and hierarchical structure, modular architecture creates reconfigurability, extensibility, and evolvability of the platform. The platform owner can leverage these capabilities to design and develop platform functions to strengthen network effects. Figure 2 illustrates how modular architecture can impact platform network effects.

First, due to reconfigurability, a product's functional modules and components can be selected and re-combined at a low cost according to users' demands and preferences. The direct effect of this capability is that the needs of heterogeneous user groups can be satisfied cost-effectively, as exemplified by the positive correlation between enterprise

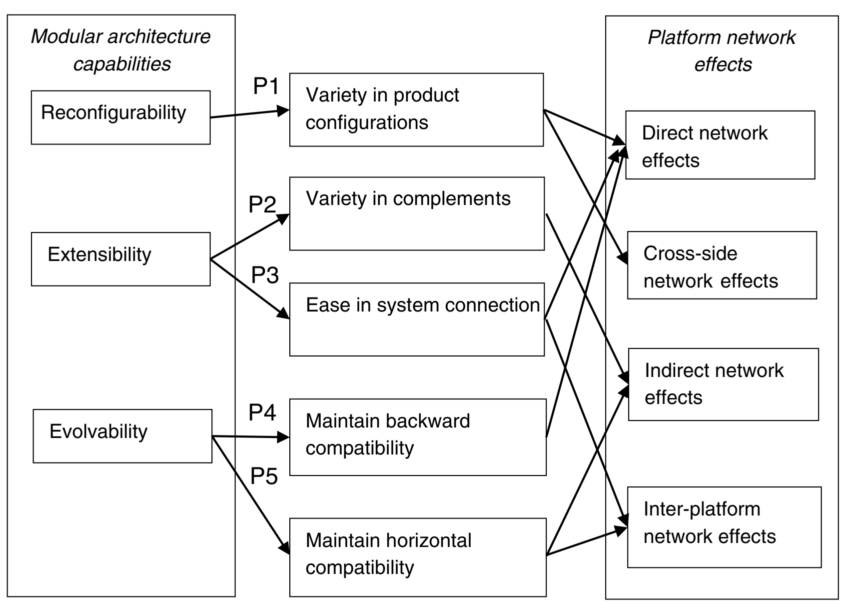

Fig. 2 Modular architecture enhancing platform network effects

software architecture modularity and mass customization of the enterprise system (Subramanyam et al., 2012). In other words, reconfigurability can expand the range of product configurations that tend to appeal to a large group of users with varying needs. In building a platform, this is conducive to expanding the installed base of users because of the low cost of attracting and accommodating new users to interact with existing users. Furthermore, when heterogeneous users are attracted to join the platform, both direct network effects and cross-side network effects are enhanced. This leads to our first proposition.

Proposition 1 (P1): The reconfigurability of modular architecture can increase the variety in product configurations, which will enhance the direct network effects and cross-side network effects of the digital platform.

Second, the extensibility of modular architecture implies a low cost for adding functional modules to extend the product functions that are developed by external providers. This generates two effects for platform construction. The first effect is that third-party developers are attracted to create add-on systems or applications that complement the platform, contributing to both the quantity and variety of complementary products, which boosts the positive feedback of indirect network effects. For example, when SAP introduced its ERP cloud platform, it used a modular architecture in order to attract third-party developers to co-create value with its ERP platform (Schreieck et al., 2021). The second effect is that the platform can be connected or integrated with other platforms at a low cost by adding converters, reducing the effort required to stimulate inter-firm network effects. This capability can also be exploited to integrate with users' internal organizational systems so that the system integration costs are reduced. This will attract more users to join, enhancing direct network effects.

The use of APIs exemplifies the effects of extensibility. Under a modular architecture, APIs are separate modules that can be added onto the core functional modules so that other systems can be integrated. To platforms, APIs are boundary resources for engaging with complementors and other platforms. They provide technological means for third-party developers to add new functions and applications to the platform with less effort and less time, embodying the extensibility of modular architecture. Through APIs, platform owners collaborate with complementors to achieve technical alignment and integration between their products, developing new functions or enhancing existing functions (Engert et al., 2022). Overall, there are three types of APIs: mediation service, professional service, and open access APIs (Wulf & Blohm, 2020). Mediation service APIs are used by third-party developers to create complementary products so that more complements become available for the platform, promoting indirect network effects. Open access APIs allow organization users to integrate their internal systems with the platform, which encourages more users to join the platform. This contributes to direct network effects. Professional service APIs are used to distribute the platform's functions as installed software through other cloud-based systems, creating inter-platform network effects. These arguments are summarized in the following propositions.

Proposition 2 (P2): The extensibility of modular architecture can increase the variety in complements, which will enhance the indirect network effects of the digital platform.

Proposition 3 (P3): The extensibility of modular architecture can increase the ease in system connection, which will enhance the direct network effects and inter-platform network effects of the digital platform.

Third, the evolvability of modular architecture makes platforms nimble in responding to market changes and technological advancements over time because updates and innovations can be deployed in relevant modules with minimal or no impact on other parts of the product. Platforms' strategies change during the course of their growth as they adapt to user requirements and environmental dynamics. For example, platform companies acquire companies in the same market niches first and then procced to acquire companies from different product markets as they mature (Miric et al., 2021). When business strategies change through the growth phases, the demands for platform technical features change accordingly and these changes are made possible by the modular architecture (Tiwana et al., 2010). With modular architecture, new and enhanced technical features can be implemented in only relevant modules with limited scope, cost, and time spent on necessary changes.

The evolvability of modular architecture can influence the scale of platform network effects over time on two fronts. First, when the platform transitions to the next-generation technology, it is technically feasible and cost-effective to offer backward compatibility with modular design, which is important in retaining the installed base of users of the previous-generation platform. Users vary in their purposes for, and approaches to, adopting innovative technologies in general and in upgrading to new-generation platforms in particular. Innovators and early adopters will embrace the new-generation platform at its early stage when the platform is newly introduced into the market, while the majority will hold onto the previous-generation platform even after the new one becomes mainstream. Therefore, when introducing the new-generation platform, backward compatibility becomes essential for the users of the new-generation platform to have access to the previous-generation platform's network of users (Katz & Shapiro, 1994). This compatibility between the new-generation and previous-generation technologies can be facilitated by modular design via a translator module (Baldwin & Clark, 2000, p.185) or additional service layer (Bekkers, 2001). As a result, technological innovation is adopted while offering users the simultaneous connectivity to both new-generation and previous-generation platforms, enhancing direct network effects.

Proposition 4 (P4): The evolvability of modular architecture can maintain backward compatibility, which will enhance the direct network effects of the digital platform.

A second impact of the evolvability of modular architecture on network effects is that the platform can retain its compatibility with complements and its interconnectivity with other platforms while adopting innovative technologies. Specifically, platforms rely on technical boundary resources such as APIs and data to provide compatibility and interconnectivity with other systems, including complementors and other platforms (Eaton et al., 2015; Engert et al., 2022; Otto & Jarke, 2019). In modular architecture, these boundary resources are interface modules through which internal functional modules interact with external components and systems. At the same time, interface modules hide the complexity of the internal system from the external systems (Baldwin & Clark, 2000) so that the interconnectivity with external systems is sustained even when the internal modules are updated, with interfaces remaining the same. Similarly, when complements or other interconnected platforms evolve with new technologies, the platform's corresponding interfaces can be updated in response in order to retain compatibility without changing internal functional modules. Overall, in the presence of technological innovation (whether internal or external), modular architecture allows the platform to maintain compatibility with complementary products and interconnected platforms, strengthening indirect network effects and inter-platform network effects. In this essay, such compatibility is referred to as "horizontal compatibility" (in contrast with backward compatibility). The above effect is summarized in the following proposition.

Proposition 5 (P5): The evolvability of modular architecture can maintain horizontal compatibility, which will enhance the indirect network effects and inter-platform network effects of the digital platform.

The example of Power BI

Power BI, Microsoft's business-intelligence (BI) system, is a collection of software applications and services that integrate data from a variety of sources and visualize the integrated data interactively. Since 2013, Power BI has been positioned as a leader in Gartner's annual reports on business intelligence and analytics platforms (https://www.gartner.com/en/documents/3996944).

Microsoft publishes online documentation for Power BI[1] and maintains a blog website for Power BI,[2] where official announcements have been posted about new Power BI features, updates, and events since July 2013. The blog website includes monthly summaries of new features and introductions of newly developed and updated services and features. These online resources provide a chronological record of the product structure, functions, and performance of Power BI. In 2013 and 2014, Power BI was announced with the three components of PowerQuery, PowerView, and PowerMap that were embedded in Microsoft Office Suite. In 2015, Power BI became a separate business application and contained the three core parts of Power BI Desktop, Power BI Service, and Power BI Mobile applications. Since then, new features of these modules have been announced individually and then aggregated in regular summary reports for modules. When new modules were created, they were announced in blogs, and their features were described as well. We collected the blogs on these modules and features from July 2013 to May 2021 and then categorized these features based on their purpose and scope according to the conceptual framework in the "Modular design and network effects" section. In particular, we strove to identify whether, and how, product features influence the four types of network effects and how modularity supports the development of these features. In the following sections, we summarize our findings.

Functional modules of Power BI

Power BI has three core modules: Power BI Desktop, a Windows desktop application; Power BI Service, an online SaaS (Software as a Service) service; and Power BI Mobile applications, which are available on phones and tablets.[3] To create a BI report, a user begins by connecting to data sources in Power BI Desktop and building a report with tiles of visualizations such as charts and graphs. The user then publishes that report from Power BI Desktop to the Power BI Service. From this point on, other users can view and interact with the report in the Power BI Service and through Power BI Mobile applications on mobile devices. Power BI Mobile offers applications for different mobile devices with different mobile operating

[1] https://docs.microsoft.com/en-us/power-bi/

[2] The blog is available at https://powerbi.microsoft.com/en-us/blog/

[3] https://learn.microsoft.com/en-us/training/modules/introduction-power-bi/2-describe-using-power-bi-build-data-driven-analytics

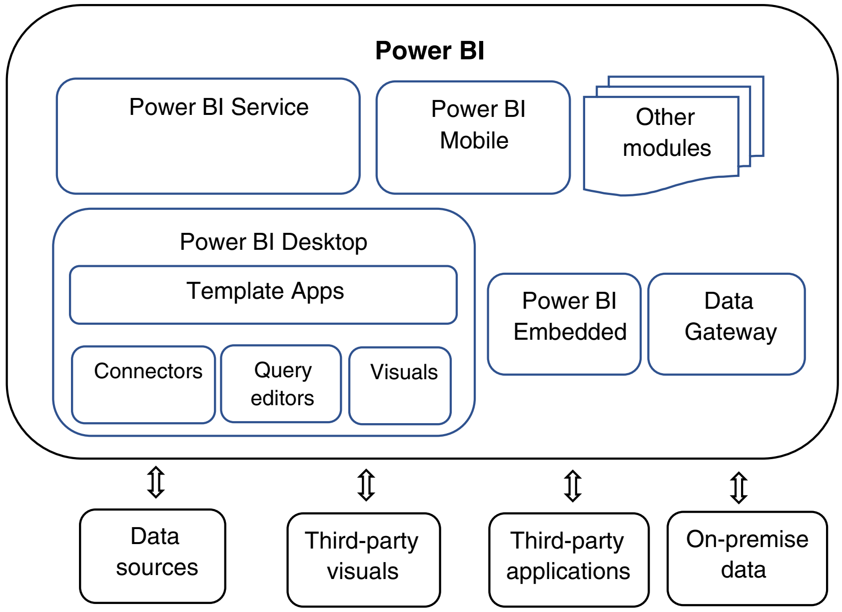

Fig. 3 An illustration of major Power BI modules

systems.[4] Power BI Desktop and Power BI Mobile applications differ in that Desktop is used to create reports while Mobile applications are used to view or consume reports. In each of these modules, there are sub-modules that perform specific functions. For example, the Power BI Desktop contains data connectors, Power query editor, and visualizations or visuals. Figure 3 provides an illustration of these Power BI modules.

Since its inception, Power BI has been evolving, with modules and features added and updated continuously over time. In 2013, Microsoft launched Power BI for Office 365 as its business-intelligence tool, which was part of the Office 365 suite on the cloud and which relied on Excel for user interface. This cloud-based BI service had two functions: PowerQuery for extracting data and PowerMap for visualizing data. Over the next two years, Power BI Desktop and Power BI Mobile were added to the Power BI system. In July 2015, Power BI Service was officially released as an independent service that can be either subscribed to through Office 365 or licensed separately.[5] Since then, additional functional modules have been added to Power BI. Power BI Data Gateway was added in 2015 for importing data from other internal enterprise systems into Power BI. Power BI Embedded was formed in 2016 to offer APIs and other tools that developers use to integrate Power BI into other applications. Report Server was created in 2017 for business users to publish and share reports on private servers within organizational borders instead of using the Power BI service over the public Internet. Paginated Report was introduced in 2018 and allowed users to generate highly formatted and print-ready reports in various file formats. Also in 2018, Dataflows was brought into Power BI to allow analysts to define and reuse data-preparation processes.

The above-described development journey demonstrates the *evolvability* of modular design. Power BI modules and functions have been added quickly and continuously since the official announcement of Power BI as a separate product in 2015. When a particular BI requirement is recognized and defined as a product function, a module or a modular component fulfilling this function is developed and integrated into Power BI. This results in superb responsiveness to customer needs and market trends through product innovation (Richardson et al., 2021). Power BI entered the market of business analytics applications when the market was being served by offerings from incumbents like IBM and Oracle along with niche players such as MicroStrategy[6] and Tableau.[7] Nevertheless, Power BI quickly gained a foothold and established itself as a market leader. This success in a hyper-competitive market is attributable to the product architecture that supports the rapid addition of functional components and increase in system complexity while maintaining overall product stability and quality (Simon, 2002). In short, this illustrates the *evolvability* of Power BI product architecture.

During this evolving process, Power BI has gradually built up connections with other applications, which exemplifies the *extensibility* of modular design. For example, Power BI Desktop added data connectors to a range of database systems so that users can use Power BI together with

[4] https://learn.microsoft.com/en-us/power-bi/consumer/mobile/mobile-apps-for-mobile-devices

[5] https://powerbi.microsoft.com/en-us/pricing/

[6] http://www.microstrategy.com

[7] http://www.tableau.com

external databases and applications from other providers.[8] In addition, through integration with SharePoint in 2017[9] and Microsoft Teams in 2020,[10] Power BI extended its functions for organizations' collaborative discovering and using of data. *Extensibility* is also achieved through interface modules that connect Power BI with other applications and data sources. Specifically, Power BI Embedded is the module for integrating with third-party applications, and Connectors, a sub-module in Power BI Desktop, is used to integrate with various data sources. In the ecosystem of digital technology characterized by layered modular architecture (Yoo et al., 2010), Power BI connects with systems in the same layer or across layers through these interfaces that serve as part of boundary resources for Power BI as a platform.

The development of Power BI also exemplifies the *reconfigurability* of modular design, leading to different versions with price discrimination.[11] This versioning and pricing scheme was introduced along with the addition of new functions over time while the functional modules were re-bundled and re-packaged into various versions for different user groups. Furthermore, *reconfigurability* can be exploited at the sub-modular level. For example, in Power BI Desktop, for a particular data-analytics project, users can choose data source connectors for a given set of data, select methods for data analysis, and pick visualization charts for outputs. To users, the advantage is the ability to customize Power BI to meet their specific needs. The disadvantage is the extra work in configuring and integrating the functional components. To reduce the burden for users, Power BI offers Template Apps that are pre-configured for given data sets with integrated functions. A Template App is a pre-packaged application that automatically imports data from a given data source, performs specified data analyses, and displays the results in a pre-assembled dashboard. An example is the template application for Facebook Ads overview report.[12] This application allows the user to connect to Facebook Ads data and load the data into Power BI, and it automatically refreshes the data. It provides a set of pre-packaged tools for summarizing and visualizing the data, including breakdowns by country and age, and provides metrics about cost and clicks. The analysis is conducted automatically and a report is produced as the deliverable. With the application, a user does not need to take separate steps to set up the data connector, design the analysis metrics, and choose graphs for presenting the results. These functions are integrated and packaged into one application, and the process is streamlined. The user simply needs to sign in to Facebook through the template application in Power BI. This greatly reduces the user's efforts in using Power BI by removing the need for assembling components into a functioning system. While template applications are an implementation of integrating core functions, they are offered as a sub-module by itself along with other lower-level modules in Power BI Desktop.

Network effects on Power BI platform

Power BI is constructed as a platform on which various users can participate and collaborate in accomplishing business-intelligence and analytics tasks. The core feature of a platform is to facilitate users' interactions, engendering positive network effects as the value of the platform to users increases with the number of users. We next discuss the patterns of network effects on the platform of Power BI. With specific examples and functions, we examine how Power BI's technical properties, such as the various modular functions, support the network growth.

As a platform, Power BI offers a set of functions to support direct interactions between users by sharing dashboards and reports — the outputs of data analytics. To a certain extent, the more users who can access and share a Power BI report, the more valuable Power BI becomes to the analyst who creates the report. This is typical of *direct network effects*. First, creators of reports and dashboards can invite others to view these contents through email. They may also maintain a list of invited viewers who receive notifications of updates. Second, users can subscribe to given reports so that they can be notified whenever the reports are updated. Third, Power BI provides seamless integration with other groupware such as Microsoft Teams and SharePoint so that users can collaborate on data-analytics tasks and share reports conveniently as a team within the groupware. These functions for sharing and collaborating are designed to facilitate direct interactions between users, which is one facet of Power BI as a platform.

In addition to the direct user interactions, Power BI is also constructed with a two-sided network structure. Consequently, there exist *cross-side network effects* that characterize many platforms for content management, such as web servers and browsers for publishing and viewing web pages. Similarly, BI reports are viewed as content created by data analysts that is consumed by managers who use these reports. From this viewpoint, BI systems such as Power BI allow users to produce, distribute, and consume the BI reports (the content). Users can be placed into two groups by design: Those who create the BI reports are in one group as content producers, and those who view the reports are in the other group as content consumers. These two groups

8 https://docs.microsoft.com/en-us/power-query/connectors/

9 https://powerbi.microsoft.com/en-us/blog/integrate-power-bi-reports-in-sharepoint-online/

10 https://powerbi.microsoft.com/en-us/blog/announcing-new-power-bi-experiences-in-microsoft-teams/

11 https://powerbi.microsoft.com/en-us/pricing/

12 https://appsource.microsoft.com/en-us/product/power-bi/windsorgroupgmbh1585043281642.facebook-ads?tab=Overview

use different features of Power BI, but at the same time, they need to interact with each other through Power BI. Hence, Power BI becomes a two-sided platform with *cross-side network effects* between these two groups of users, and it is structured with modules that correspond to the distinct user groups. Specifically, Power BI Desktop is designed for analysts to create BI reports, while Power BI Service and Power BI Mobile are designed for content consumers to view reports.

Another facet of Power BI as a platform is the interdependence between the platform and complementary products, which brings about *indirect network effects*. Visualizations, or visuals, are a sub-module in Power BI Desktop that presents data analysis results as graphs and charts. Examples of Power BI visuals include a chart design such as a Gantt chart or a graphic design for a word cloud. Visuals are an essential component of Power BI as a BI application. Power BI Desktop includes a range of common data visualization charts and graphs. At the same time, Power BI provides an interface for independent software vendors (ISVs) to develop visuals as separate applications that users can download and use in the same way as inherent visuals in Power BI Desktop. An example is the *Advance Pie Chart and Donut* from an ISV, xViz, that can be installed on Power BI Desktop.[13] With this design, the visualization that was originally an inherent product component becomes a complement to the platform that can be supplied as a plug-and-play module by third-party developers. The visuals from ISVs expand both the number and variety of available data visualization tools, which can attract more Power BI users with heterogeneous needs and preferences for data visualization.

In addition to facilitating interactions between users and providers of complements, Power BI also offers interfaces to connect with other business applications, which promotes *inter-platform network effects*. First, Power BI provides APIs that other developers can employ to integrate their applications with Power BI. Furthermore, Power BI Embedded, an online service via Azure cloud server, allows developers to easily fit Power BI reports and datasets in their applications.[14] For example, Edsby, a cloud-based learning management system, embeds Power BI analytics in its offerings to teachers, students, administrators, and parents who use its online services.[15] To Edsby and its users, Power BI is integrated into its platform as a component that complements its core services of managing the learning experiences. To Power BI, this exemplifies the horizontal compatibility for network products (Katz & Shapiro, 1994) that generates *inter-platform network effects* by connecting with other platforms. By doing so, Power BI, as a business application specializing in data analytics, can be integrated with other business applications through interfaces such as APIs.

The use of interfaces and the loose coupling between modules allow Power BI to develop and improve functions and services while sustaining network effects. For example, Power BI Desktop uses DAX for data modeling,[16] and new DAX functions are continuously added. For instance, in year 2020, two new DAX functions were added in February, one in March, one in May, one in September, and forty-nine in October. These functional improvements took place within the data modeling part of Power BI Desk and have had no impact on other functions or connectivity with third-party applications because the data connectors and APIs that offer interfaces with external systems remain the same. In other words, Power BI sustained its compatibility and, hence, network effects while continuing to improve its internal functions.

In summary, Power BI has been developing both its functionality in data analytics with a modular design and its capability as a platform in facilitating user interactions in such a way as to meet users' needs that vary in preferences and evolve over time.

Discussion

Based on the above integrative perspective of modular design and platform strategy, as well as the example of Power BI, this section examines the implications of platform-oriented modular product development for research and practice.

Managerial implications

In terms of practical application, managers for digital product development are encouraged to consider the platform-building requirements in specifying functional modules. As this essay reveals, platform strategy can transform into modularization principles so that functions and components are constructed in a way that promotes positive network effects. For example, one pertinent question in product development is: Which functional modules should be created in-house and which should be made by external providers? This strategic decision has a long-term effect on the product's performance and the constituents of the ecosystem that is to be formed (Parker et al., 2017). From the perspective of platform

[13] https://appsource.microsoft.com/en-us/product/power-bi-visuals/WA200001917?tab=Overview

[14] https://azure.microsoft.com/en-us/services/power-bi-embedded/#overview

[15] https://customers.microsoft.com/en-us/story/edsby-education-technology-power-bi

[16] https://learn.microsoft.com/en-us/power-bi/transform-model/desktop-quickstart-learn-dax-basics

growth, one factor to consider is how much the users' preferences vary regarding the module's function. When there is a significant variance in users' preferences, it will be desirable to increase the product's functional variety by allowing external ISVs to provide the module as a complement to the core and hence make the product more valuable to users. Power BI serves as a useful example. Visuals in Power BI Desktop are the components that can be provided by third-party developers, and these externally supplied visuals can be seamlessly integrated into Power BI under the modular design. This increases both the types and the total number of visuals available to Power BI users, making Power BI more valuable.

A second implication for practice is that managing the digital product development as a platform requires coordination with other participants on the platform. This includes promoting the participation from providers of complementary products and services. For this purpose, the platform owner devises a set of tools that third-party providers can use to develop and distribute the compatible complements. These include technological tools such as SDKs and supporting services for developing the complements, akin to what Microsoft does for ISVs to create visuals.[17] Moreover, these complementary products should be made available to platform users. One example of such a distribution channel is the online store or marketplace the platform owner operates. Microsoft AppSource and Apple App Store are examples of online marketplaces where platform users can obtain complementary applications.

Another managerial implication is that the product maker needs to consider the platform dynamics when managing the product innovation and evolution. Interoperability with complementary products and connectivity with other platforms require careful planning and management when the product is modified. An innovation or upgrade in one product can trigger the need for innovations in other products partly because of the need to maintain interoperability among interdependent products (Wang, 2021). For example, when SAP introduced HANA database technology, Microsoft Power BI responded with a new connector and updates to existing connectors in order to import data from SAP HANA business warehouses. This exemplifies one effective device for maintaining interoperability: interface modules that can be adapted or added to support innovations in complementary products without changing other functional modules.

Theoretical implications

Our study's contribution to digital platform research is twofold. First, it reveals one path for integrating the two research perspectives on digital platforms: engineering design and industrial economics. Although these two perspectives address different aspects of digital platforms (Gawer, 2014; Parker et al., 2016), researchers have identified an increasing need for studying the issues that fall into the intersection between these two fields. One direction that has been chosen for future research in literature surveys is interplay between network effects in the business environment and the technological innovation of digital platforms such as modular design, especially regarding the competition between new entrants and incumbents (Kretschmer et al., 2022; Rietveld & Schilling, 2021). Our essay contributes to this line of research by studying the interactions between the modular design and network effects.

Specifically, we expound that, under modular architecture, the development of digital platforms can leverage the capabilities of the architecture in reconfiguring, extending, and evolving the product functions, spurring positive network effects for platform growth. We further expand the digital platform research at the product level with a focus on platforms' technical properties. When platforms are studied as an organizational form, the research issues are often about market competition and firm strategy at the firm level or market level (Eisenmann et al., 2006; Gawer & Cusumano 2014; Rochet & Tirole, 2003). However, from the lens of information systems development, the technical design of IT artifacts, including architecture, becomes a focal issue for study (Poniatowski et al., 2022), and one particular research direction is the value creation of platform technical properties, including platform architecture (Hein et al., 2020). Our study advances along this direction and highlights the important role of modular architecture in developing platforms, showing how the modularity can be leveraged to scale up platforms via network effects.

Second, our study contributes to research in digital product innovation with theory-based guidelines for formulating digital product design rules that are derived from research on network effects. Leveraging the affordance and generativity of digital technology, product designers not only create innovative digital artifacts and services but also integrate digital components and functions into physical products (Yoo et al., 2010; Kallinikos et al., 2013; Wang et al., 2022). This is referred to as "digital product innovation," and the development of digital platforms is representative of this type of digital innovation. Along with the growing research interest in digital innovation, there is an increasing need for design knowledge that guides the design and development of digital products (Wulfert et al., 2022). With regard to general digital product design, information system design theory is utilized to lay out design principles for service platforms through causal loops and control (Janiesch et al., 2020), and standardization is proposed as a guideline for stipulating design principles for e-commerce platforms (Wulfert et al., 2022). Our study contributes to this stream of research by adding

[17] https://powerbi.microsoft.com/en-us/developers/custom-visualization/

another facet of design principles for digital platforms. Specifically, we illustrate how the objective of enhancing positive network effects can guide modularization principles in developing digital platforms. Furthermore, platforms and partners form the ecosystem for digital innovation on the basis of the layered modular architecture of digital information infrastructures (Wang, 2021; Yoo et al., 2010). In this business context, our present study on platform modularity can also contribute to the discussion about the dynamics of digital innovation processes.

Limitations and future research

While our study strives to expand our understanding about how platforms can utilize modularization to scale up network effects, it has several limitations. We next discuss these limitations and explore possible topics for future research that may further expand and enrich the research on digital platforms and digital innovation.

This essay focuses on the conceptual framework and selects one digital product, Power BI, as an example for discussion. This approach allows us to deepen our understanding in specific business contexts, but it also limits our ability to compare across multiple platforms in varying contexts. For future research, hypotheses can be derived from this essay's propositions to be tested empirically with field data from a set of platforms. For example, a field experiment can be conducted to compare the performance of platforms with modular design and those with an integral architecture. This would further test the applicability and generalizability of this essay's thesis.

A second limitation of this study is the omission of contextual factors that can influence the interplay between modular design and network effects. This essay's thesis is centered on how network effects can be enhanced through modular design in developing platforms. However, other technological, organizational, and industrial factors can also moderate, constrain, or facilitate the impacts of modular design in the presence of network effects. For example, a platform owner's product portfolio and its position in its industry can affect the strength of the network effects the platform experiences and moderate the effects of modular design. Web browsers offer an instructive example. In the competition between the Netscape browser and the Microsoft Internet Explorer (IE) browser, modular design was important for expanding the browsers' functions while maintaining quality and stability (Cusumano & Yoffie, 1998). At the same time, firm strategy in product bundling, such as offering IE free together with Windows which was already a dominant platform, also played an important role in shaping up the browser market. It will be interesting to study further how such strategies interact with modular design in affecting platform success. Cross-sectional studies may allow us to take into account such factors and identify conditions under which the effects of modular design can be strengthened or weakened.

A third limitation is that our study does not directly address changes in platform architecture over time. Although our conceptual framework shows that the evolvability of modular design can enhance network effects when technology advances, we do not discuss the implications of the evolution of the platform architecture. For example, the Mozilla browser was redesigned in 1998 with the objective of modularization, which reduced the software's complexity (MacCormack et al., 2006). SAP modularized its ERP system architecture when it introduced the cloud platform so that it could be incorporated with more third-party applications (Schreieck et al., 2021). While our framework can help us understand the implications of such changes, it would be desirable to further examine the processes and contextual factors for the architectural changes.

Another direction for future research is to study how the product-development process can be affected by the integrative approach of modular design and platform strategy. This essay focuses on product structure and functional capabilities in product development. However, product development is a complex process that requires project management and task coordination and is tightly intertwined into the organizational structure (Baldwin & Clark, 2000; Fixson, 2005). Hence, when modular design and platform strategy are integrated, product structure and capabilities — as well as the product-development process — will be affected. It will be worthwhile to study the implications of the incorporation of platform strategy into modular product design to the product-development process and associated organizational structure. In summary, for future research, we expect that this essay's thesis and arguments can provide a stepping stone for designing and conducting other studies.

Conclusion

In this essay, we delineate how modular architecture can be utilized to enable user interactions and product variety that further strengthen positive network effects for platform growth. The objective of enhancing network effects helps platform owners formulate modularization principles for specifying module functions and interfaces, particularly those that play a role in facilitating interactions among heterogeneous user groups. We further illustrate these ideas through analyzing the design features of Power BI, which exemplifies how product modules and functions can be defined to build up a platform for business analytics. Our conceptual framework and discussions of Power BI as an example provide important theoretical and practical implications. For practice, the discussions in this essay encourage management to take into consideration the requirements for platform construction in defining functions in modular product design. The theoretical implications of this study mainly concern research in technical design and growth strategy of digital platforms. By integrating perspectives in architectural modularity from engineering design and network effects from industrial economics, we reveal the complementarity of these two perspectives in studying digital platforms, showing how functional modules of platforms can be specified to strengthen positive network effects. Along this line of research, future studies can take a step further to test these ideas with different platforms in various digital ecosystems.

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Declarations

Conflict of interest The author declares no competing interests.

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