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Review

Exploring the Boundaries of Success: A Literature Review and Research Agenda on Resource, Complementary, and Ecological Boundaries in Digital Platform Business Model Innovation

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Abstract: Digital platform business model innovation is a rapidly evolving field, yet the literature on resource, complementary, and ecological boundaries remains limited, leaving a significant gap in our understanding of the factors that shape the success of these platforms. This paper explores the mechanisms by which digital platforms enable business model innovation, a topic of significant theoretical and practical importance that has yet to be fully examined. Through a review of the existing literature and an examination of the connotations of digital platforms, the design of platform boundaries, and the deployment of boundary resources, the study finds that (1) the uncertainty of complementors and complementary products drives business model innovation in digital platforms; (2) the design of resource, complementary, and ecological system boundaries is crucial to digital platform business models and manages complementor and complementary product uncertainty while promoting value co-creation; and (3) boundary resources establish, manage, and sustain cross-border relationships that impact value creation and capture. Based on these findings, four research propositions are proposed to guide future research on digital platform business model innovation and provide insights for effectively innovating business models and influencing value creation and capture.

Keywords: business model innovation; digital platform; boundary resources; dual uncertainty

Citation: Daradkeh, M. Exploring the Boundaries of Success: A Literature Review and Research Agenda on Resource, Complementary, and Ecological Boundaries in Digital Platform Business Model Innovation. *Informatics* **2023**, *10*, 41. https://doi.org/10.3390/informatics10020041

Academic Editor: Antony Bryant

Received: 29 January 2023
Revised: 19 March 2023
Accepted: 10 May 2023
Published: 11 May 2023

1. Introduction

With the rapid development and in-depth application of digital technology, it has become a new development trend for enterprises to build digital platforms to realize the complementary resources of various subjects and promote the flourishing of the digital economy. Along with the anti-monopoly regulation of digital platforms, promoting the regulated, safe, and sustainable development of digital platforms has become the policy tone, driving digital platform enterprises into a new development stage of deepening application, fair regulation, and inclusive sharing [1]. At present, although the development strategies and business models of digital platforms are facing changes, the long-term positive trend of digital platforms and the general trend of booming platform economy are still obvious, and the digital economy remains an important means to restructure global factor resources, reshape the global economic structure and change the global competitive landscape [2].

Digital platforms, as the backbone of the digital economy, leverage the power of multi-party participation and cross-border interaction to achieve scalability and extensibility, thereby transforming traditional industrial and value chains. As a cross-boundary value co-creation medium, digital platforms forge strong connections with consumers, complementary businesses, external resources, and socio-technical systems, leading to the emergence of innovative business models. In the consumer internet industry, digital platforms have effectively engaged consumers in the product development, production,

and distribution process, fostering active value co-creation practices [3–5]. In the industrial internet sector, digital platforms have given rise to new cross-boundary value co-creation models, such as sharing platforms for capacity and equipment, logistics service platforms, and equipment monitoring platforms. However, these platforms often face challenges in terms of flow and cost efficiency, and have difficulty attracting users due to a lack of unified device communication protocols and complexity in industrial processes, resulting in limited value co-creation practices. As a result, cross-boundary data communication and data empowerment have become crucial drivers for traditional manufacturing companies to achieve platform transformation and shift from a goods-centric to a service-centric approach. This represents a new path for business model innovation by incorporating external stakeholders into the platform ecosystem [6].

The emergence of digital platforms has disrupted traditional business models, breaking down the rigid boundaries that once confined companies. These porous boundaries now provide a more expansive and decentralized approach to innovation on digital platforms. By seamlessly integrating resources from various sources, digital platforms blur the lines between what belongs to the company and what belongs to the market, giving rise to a dynamic and ever-evolving ecosystem where companies and markets collaborate to unlock new opportunities and value [7,8]. However, the blurring of digital platform boundaries does not signal their disappearance, but rather a complexity of boundary structures, and the meaning of company boundaries in digital platform business models extends far beyond its traditional connotations. In practice, digital platforms are constantly navigating a balance between streamlining resources and expanding possibilities. They minimize limitations by embracing a light asset model and maximize opportunities by creating vibrant ecosystems. Through strategic resource deployment at the boundaries, they seamlessly integrate, reconfigure, and optimize the various factors that drive innovation within the ecosystem [9]. On the one hand, the design of platform boundaries is a crucial decision that shapes the resources, organization, and ecological scope of digital platforms and effectively manages uncertainty. On the other hand, platform owners can dynamically alter and fine-tune resource allocation through boundary resources, fostering open and complementary innovation [10,11]. Therefore, a comprehensive approach and thorough examination of the details of platform boundary design and boundary resource deployment from a boundary perspective can provide a deeper understanding of the underlying mechanisms of digital platform business model innovation and their impact on value creation and capture. In light of this, the research questions of this study are as follows:

RQ1: How do digital platforms innovate their business models through the design of platform boundaries and the allocation of boundary resources?

RQ2: To what extent does digital platform business model innovation impact value creation and capture, and how can a comprehensive approach and thorough examination of the details of platform boundary design and boundary resource deployment contribute to a deeper understanding of these underlying mechanisms?

To answer the above research questions, this study delves into the mechanics of digital platform business model innovation by reviewing and synthesizing the relevant literature in the field. The study emphasizes the role of uncertainty in complements and complementary products in digital platform business models, and examines how digital platform companies foster value co-creation through boundary design. Furthermore, the paper illustrates how digital platform companies innovate their business models through boundary resource deployment. By summarizing and analyzing the process of digital platform business model innovation, this study adds to the existing knowledge on digital platforms and business model innovation and has implications for both theory and practice.

- First, it deconstructs the innovation process of digital platform business models from a boundary perspective and offers a new perspective of understanding the digital platform business models;
- Second, it explores the boundaries of success in digital platform business models, which are critical for practitioners and researchers to fully understand the complex

interplay between resources, complementary assets, and the broader ecological context in which these platforms operate;
- Thirdly, it combines structural and relational elements of digital platforms to explain the process of value creation and acquisition, which can help digital platform owners understand the process of creating value and capture it more effectively;
- Fourthly, it provides an in-depth analysis of the importance of boundary design and boundary resource deployment in digital platform business model innovation, which can help digital platform owners to effectively manage complementor and complementary product uncertainty and promote value co-creation;
- Lastly, it provides guidance for digital platform owners to achieve business model innovation through boundary design and boundary resource deployment and achieve sustainable growth.

The remainder of the paper is structured as follows. The next section describes the research methodology, including details of the data collection and analysis. The subsequent section provides a comprehensive review of the literature related to the topic, encompassing existing research on the significance of complementors and complementary assets in digital platforms, and the impact of boundary design and resource deployment on value creation. The following section highlights key findings and examines their implications for resource, complementary, and ecological boundaries in digital platform business model innovation. Finally, the paper summarizes the main contributions of the study and suggests potential areas for future research.

2. Research Methodology

To gain a deeper understanding of the boundaries of success and the mechanisms that drive business model innovation on digital platforms, a comprehensive literature review of relevant studies published in the past 20 years (2002–2023) is conducted, which includes articles from leading international journals in management science and innovation. To ensure the inclusion of all the relevant literature, a systematic literature search was conducted on various databases such as Web of Science, Scopus, and JSTOR using a combination of keywords including "digital platforms", "innovation", and "business model". Additionally, to avoid any oversights, the literature search was also conducted using the broader concept of "platform business model", and the resulting literature was further screened by reading the articles. The specific search and screening process was conducted in multiple stages, starting with an initial search using the aforementioned keywords, followed by a screening of the titles and abstracts of the articles to identify those that were relevant to the research question. Then, the full text of the remaining articles was analyzed to ensure that they met the inclusion criteria and were relevant to the research question. The literature review was conducted with a particular focus on uncovering the underlying mechanisms that drive business model innovation on digital platforms, and how they contribute to value creation and capture.

In order to retrieve the literature on the topic of platform business models, different phrases and terms were used as search keywords. These included "platform business model innovation", "platform model innovation", "platform business model design", and "platform model design". These keywords were used to search several Chinese and English databases, and the results were narrowed down by looking at the titles, abstracts, and keywords of the retrieved literature. After removing any duplicate articles, a total of 250 articles were obtained. However, since the search keywords used were quite broad, the next step was to further review the abstracts and full texts of these articles to ensure that they were relevant and of high quality in terms of their focus on digital platform business models. This was performed by applying specific screening criteria, which included the following:

- The main subject of the literature must be a digital platform, meaning the literature should focus on businesses or organizations that operate primarily online or through digital means;

- The perspective of the literature should be on business model innovation, meaning the literature should focus on the development and implementation of new and unique business models within the digital platform industry.

Based on the screening process and criteria outlined earlier in this study, a total of 204 articles were obtained for analysis. These articles were divided into two categories: 76 management articles and 128 innovation articles. The distribution of these articles over time is illustrated in Figure 1.

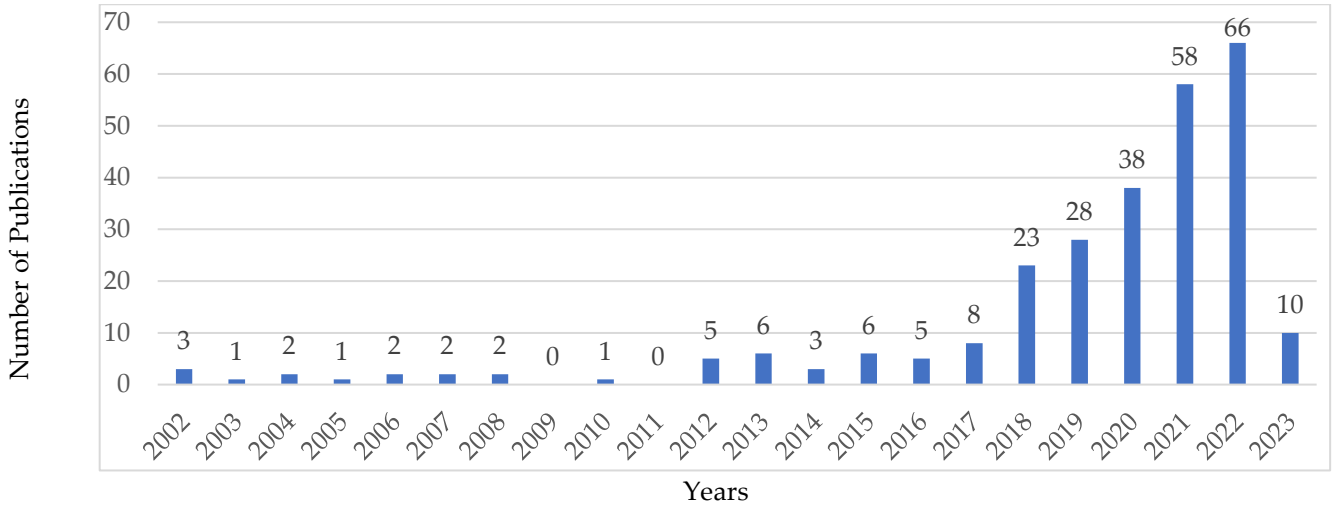

Figure 1. Number of annual publications of research papers on digital platform business model innovation (the data labels in the figure are the overall number of publications per year; publication data as of January 2023).

As shown in the figure, research on digital platform business models has been ongoing since 2002; however, the number of articles published on the topic has grown significantly in recent years. In the early days of research on digital platform business models, the focus was primarily on information technology platforms such as computer operating systems. However, as the digital economy and digital innovation have grown in importance, the interest in this topic has also increased. As a result, the number of articles on digital platform business models has seen a marked increase since 2016. Additionally, the types of platforms that scholars have focused on have become more diverse. In addition to technology platforms, researchers are now also exploring transaction platforms, competition platforms, and community platforms. This trend reflects the growing significance of digital platforms in various industries and the need for a deeper understanding of the underlying mechanisms that drive business model innovation on these platforms.

3. Digital Platform: Connotation and Extension

3.1. Definition of Digital Platform

Through a systematic literature review, it was found that there is a great deal of diversity and different focuses in definitions of digital platforms by scholars (see Table 1). However, in general, digital platforms can be distinguished from market, technology, organization, and value perspectives. From a market perspective, digital platforms are seen as multilateral markets, emphasizing their intermediary role and network effect characteristics [6,12,13]; from a technology perspective, digital platforms are seen as the foundation of technology expansion, emphasizing their technological architecture characteristics [8,9,12]; from an organizational perspective, digital platforms are socio-technical systems that promote connection, interaction, transaction, and governance, emphasizing the combination of technical elements and social activities [6,10,13]; from a value perspective, digital platforms are value networks and value architectures, emphasizing their role in value creation, transmission, and acquisition [11,14,15].

Table 1. An overview of digital platform definitions.

Perspective	Focus	Source	Term	Definition
Market perspective	Emphasis on mediating role and network effect characteristics	[16]	Bilateral Marketplace	Products and services that bring users together in a bilateral network.
		[10]	Platform Intermediary Marketplace	Interactions between users are influenced by network effects and are facilitated by a public platform provided by one or more intermediaries.
		[6]	Multilateral Platform	Technologies, products, or services that enable direct interaction between two (more) groups of customers or participants.
Technology perspective	Emphasis on technical architecture and structural features	[17]	Software Platform	An extensible code base based on a software system that provides core functionality and operator interfaces for components that interoperate with it.
		[18]	Platform	A stable link or foundation to organize the technical development of interchangeable or complementary components and to allow interaction between components.
		[19]	Digital Platform	An extensible digital core that is open to third parties to facilitate improvements or complements.
Organizational perspective	Emphasis on integration of technical components and social activities	[20]	Platform	Supports interaction between multiple groups of participants and facilitates technology development.
		[21]	Platform	A layered architecture that combines digital technologies with governance models.
		[22]	Digital Platform	Digital systems that facilitate communication, interaction, and innovation to support economic transactions and social activities.
Value perspective	Emphasis on value creation, transmission, and acquisition role	[14]	Digital Platform	A collection of digital resources containing services and content that facilitate interaction between external producers and consumers to create value.
		[22]	Digital Platform	A combination of digital resources that connects multilateral markets through digital technology, enabling producers and consumers to co-create value.
		[15]	Digital Platform	New business innovation logic and value creation paths for participants or consumers through digital technology and infrastructure.

The various perspectives presented in the literature on digital platforms have led to a wide variety of definitions being used. However, in order to provide a more comprehensive understanding, this paper adopts a more inclusive definition of digital platforms. According to this definition, digital platforms are business models that connect external groups through boundary resources, provide interaction mechanisms to match supply and demand, and thus co-create value. This definition takes into account the technology, organization, and value perspectives, and expands the concept of digital platforms from being seen as just a technical or organizational form to a business model. This allows for a more complete understanding of the concept.

The definition used in this paper includes three core elements, which are illustrated in Figure 2. These three core elements are as follows:

- Connection: digital platforms connect external groups through boundary resources such as digital technologies, data, and algorithms.
- Interaction: digital platforms provide interaction mechanisms, such as matchmaking, feedback, and communication tools, to match supply and demand.
- Value co-creation: digital platforms enable the creation, transmission, and acquisition of value through the interactions and connections facilitated by the platform.

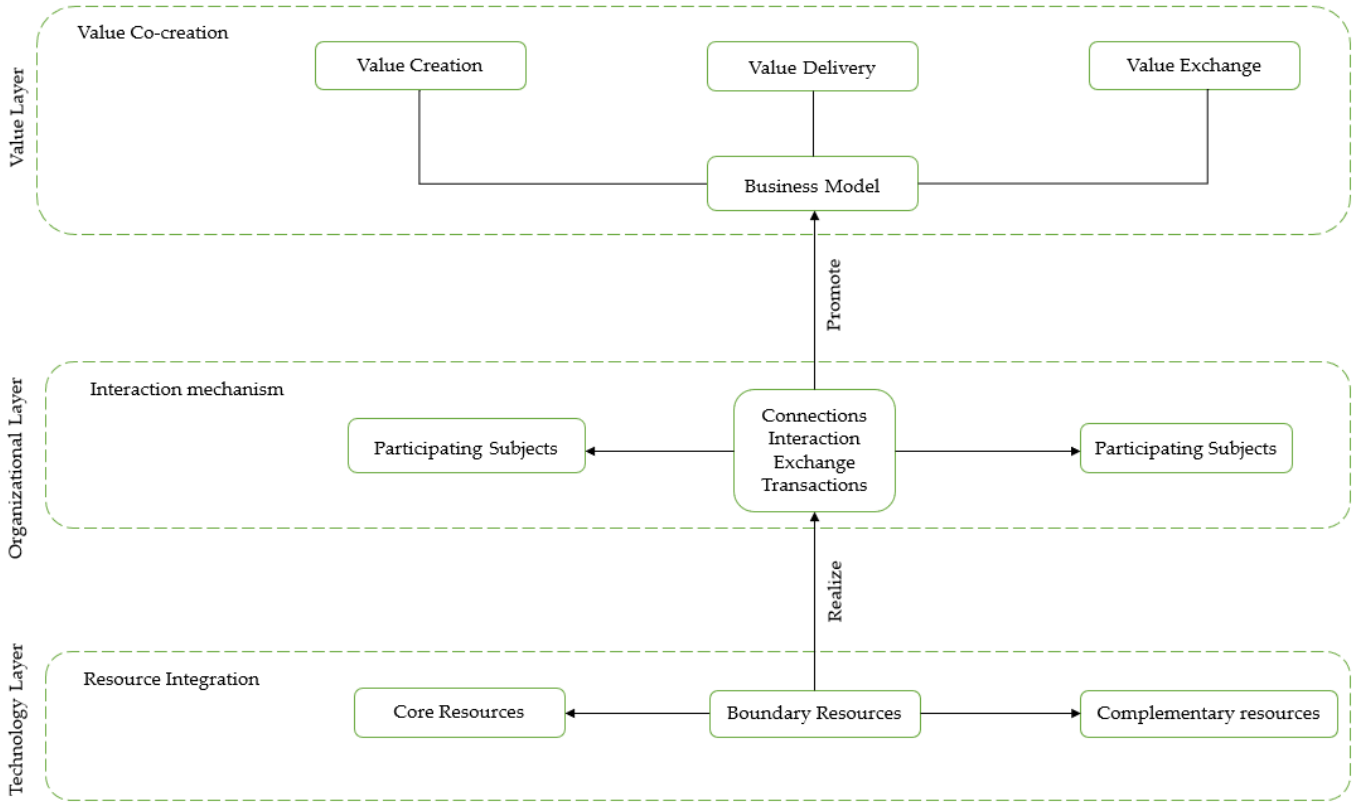

Figure 2. Digital platform structure and core elements.

(1) Boundary resources: Digital infrastructures and modular architecture support the value creation of digital platforms by shifting the focus from internal resources to the boundaries of the enterprise [23]. This means that the resources and capabilities that are outside of the organization, such as user data and third-party software, play a critical role in the value-creation process. Therefore, it is important to understand the boundaries of the platform and how they are managed in order to understand the driving force behind the platform's change and innovation. Due to the relatively independent relationship between the platform owner and complementors, boundary design and resource deployment have become important means for platform owners to integrate core resources and peripheral complementary resources. Platform owners must carefully design and manage the boundaries of the platform in order to effectively leverage the resources and capabilities of other parties. This includes managing access to the platform, defining the rules and incentives for participation, and creating mechanisms for data sharing and collaboration. By effectively managing the boundaries of the platform, platform owners can create a more efficient and effective ecosystem, which can lead to greater innovation in their business model and strategy choices [24].

(2) Interaction Mechanisms: Digital platforms promote the creation, delivery, and exchange of value through connections, interactions, exchanges, and transactions between different participating parties [25,26]. Interaction mechanisms are a key feature of digital platforms, and are used to connect and facilitate communication between different groups of people or organizations. For example, e-commerce platforms such as Amazon and Alibaba

use interaction mechanisms such as search bars and product reviews to connect buyers and sellers, thus facilitating transactions and creating value. Social media platforms such as Facebook and Twitter use interaction mechanisms such as messaging and commenting to connect users and facilitate communication and sharing of information, thus creating value through the sharing and exchange of information. Ride-sharing platforms such as Airbnb uses interaction mechanisms such as messaging and reviews to connect hosts and guests, thus facilitating accommodation bookings and creating value through the sharing of living spaces. Upwork uses interaction mechanisms such as project postings and proposals to connect freelancers and clients, thus facilitating job contracts and creating value through the exchange of services. Etsy uses interaction mechanisms such as product listings and customer reviews to connect sellers and buyers of handmade and vintage items, thus facilitating transactions and creating value through the exchange of unique goods. These examples illustrate how digital platforms use interaction mechanisms to connect and facilitate communication between different groups of people or organizations, thus promoting the creation, delivery, and exchange of value. Interaction mechanisms are the core of the digital platform. They are the key features of the digital platform; they help to connect the platform's different stakeholders and help to create value for all stakeholders.

(3) Business Model: Digital platforms connect people, organizations, and resources across boundaries in interactive ecosystems, promoting access, interaction, and transactions, thus forming new business models and paths for value co-creation [27,28]. This means that digital platforms serve as a link between technology and market demand, allowing for the creation of new business models that leverage the capabilities of digital technology to meet the needs of the market. One key aspect of digital platforms is that they allow for the creation of new business models that are not possible with traditional business models. For example, digital platforms such as Airbnb and Uber allow individuals to share their homes and cars with others, creating a new business model that is built on the sharing economy. Similarly, digital platforms such as Alibaba and Amazon allow small businesses to reach a global audience, creating new opportunities for e-commerce. Digital platforms also play a unique role at the technical, organizational, and value levels. They allow for the creation of new technical capabilities, such as the ability to process and analyze large amounts of data, and new organizational capabilities, such as the ability to manage complex ecosystems of partners and users. Additionally, digital platforms allow for the creation of new value propositions, such as personalized and on-demand services.

In summary, digital platforms enable the formation of new business models and paths for value co-creation by connecting people, organizations, and resources across boundaries in interactive ecosystems, promoting access, interaction, and transactions. This makes digital platforms a key interface between digital technology and market demand, playing a unique role at the technical, organizational, and value levels.

3.2. Composition and Innovation Elements of Digital Platforms

Schumpeter's theory of economic development [29] posits that innovation and entrepreneurship are the driving forces behind economic growth, rather than the accumulation of capital or the efficient allocation of resources. He argues that new technologies and products introduced by innovative entrepreneurs disrupt existing markets and create new ones, leading to economic growth and higher living standards in the long run. However, this process also involves the destruction of old industries and business models, as they become obsolete in the face of new competition. The concept of "creative destruction" highlights the dual nature of innovation and entrepreneurship: while they create new opportunities and benefits, they also entail costs and losses for those who are displaced or left behind. Therefore, Schumpeter's theory calls for a dynamic and flexible economy that can adapt to change and embrace innovation, while also providing support and protection for those who are adversely affected by the process of creative destruction.

Similarly, Aghion et al. [30], in their book "Endogenous Growth Theory", present a new framework for understanding the sources and dynamics of innovation, emphasizing

the role of endogenous factors such as knowledge accumulation, technology transfer, and institutional design. In particular, the endogenous growth theory [30] highlights the importance of innovation as a driver of long-term economic growth. It posits that innovation is not simply a byproduct of economic activity, but rather an engine of growth in its own right. By promoting competition, increasing productivity, and spurring technological progress, innovation creates new opportunities for firms and individuals to create economic value and drive progress. Moreover, the endogenous growth theory also emphasizes the importance of institutions and policies that support innovation and entrepreneurship. It argues that governments can play a crucial role in promoting innovation by creating a conducive environment for research and development, providing incentives for entrepreneurship, and protecting intellectual property rights.

Coase's seminal work on "The Theory of the Firm" [31] is highly relevant in understanding the economics of digital platforms and their role in the contemporary economy. In his early work, Coase challenged the prevailing view that the market is the most efficient mechanism for allocating resources and coordinating economic activity. He argued that the existence of firms can be explained by their ability to reduce transaction costs, i.e., the costs of negotiating and enforcing contracts in a market setting. Coase's theory suggests that firms exist because they can perform certain activities more efficiently and cost-effectively within their own boundaries than through market transactions. By internalizing certain functions, such as production, distribution, and marketing, firms can reduce the transaction costs associated with coordinating these activities with external parties. This theory has important implications for the study of digital platforms, which often function as intermediaries between multiple parties in a complex network of transactions. Digital platforms, such as firms, can reduce transaction costs by internalizing certain functions and providing a centralized platform for coordination and exchange. Therefore, Coase's theory of the firm is highly relevant in assessing the opportunity costs of digital platforms and their economic impact. It highlights the importance of understanding the underlying economic logic and transaction costs involved in the functioning of digital platforms, and how they can create value by reducing these costs and improving coordination and efficiency in economic exchange.

The learning-by-doing (LBD) approach, as introduced by Arrow [32], is highly relevant in the context of digital platforms. The LBD approach highlights the role of accumulated experience in reducing average costs and improving production efficiency. As he rightly pointed out, in the case of digital platforms, the accumulated past experience can be measured in terms of processed terabytes or actual transactions, or both. In technical terms, LBD implies that the more a platform engages in a particular activity, the more experience it gains and the more efficient it becomes in carrying out that activity. This can lead to a reduction in the platform's average cost of production, as it becomes better at producing goods or services through the accumulation of experience. In economics and management terms, the LBD approach has important implications for understanding the dynamics of digital platforms and their evolution over time. As platforms gain experience and become more efficient, they may be able to offer their services at lower prices, which can lead to increased demand and market share. This, in turn, can lead to further experience and efficiency gains, creating a virtuous cycle of growth and improvement. However, it is important to note that the LBD approach also has its limits. As platforms gain more experience, the potential for further efficiency gains may diminish, leading to diminishing returns for experience. Moreover, the LBD approach assumes that the underlying production process is stable and that the environment in which the platform operates remains relatively constant over time. In reality, however, technological advancements and changes in market conditions can disrupt the production process and alter the platform's cost structure.

Baldwin et al. [33] highlight the benefits of modularity in creating flexibility and scalability in design, which are essential in the digital platform industry. The modularity design approach allows the platform to adapt to market and technology changes without having to re-engineer the entire system, leading to faster innovation cycles. Moreover, digital plat-

forms are built on a modular architecture that enables the coordination and integration of internal and external resources of the enterprise, providing greater flexibility and scalability. The coupling of information outsourcing, software embedding, the Internet of Things, and mobile communication forms the digital infrastructure that supports different industries to shift from product competition to platform competition. By breaking down the platform into individual components, businesses can more easily adapt and change specific aspects of the platform without disrupting the entire system. This allows for greater innovation and the ability to respond to changes in the market or technology.

The work on the diffusion of innovation by Rogers [34] is highly relevant for comprehending the adoption and diffusion of digital platforms in the market. Given that platforms rely on network effects to create value, it is crucial to understand how users and other parties adopt and use the platform to create value and generate revenue. Rogers' theoretical framework provides an excellent basis for understanding how new products or services are adopted and diffused in a population, and the factors that influence the rate and extent of adoption. Therefore, incorporating Rogers' work into the discussion of digital platforms would provide a more comprehensive understanding of how platforms create and capture value, including the timing of co-created value and value capture, and the emergence of economic unicorns.

Indeed, the adoption of digital platforms follows a diffusion law that describes the rate at which a new technology or innovation is adopted by different user groups over time. The diffusion process is influenced by various factors, including the technology's characteristics, the user population's attributes, and the social and cultural context in which the innovation is introduced. As digital platforms gain popularity and attract more users, they may create significant value through network effects, which increase as more users join and interact with each other. This can lead to the emergence of economic unicorns, startups that achieve a valuation of $1 billion or more based on their disruptive business model and rapid growth. However, the timing of value creation and capture is a crucial factor in determining the long-term success of a platform. To sustain their growth and profitability, platform owners must balance the needs of different stakeholders, including users, producers, and advertisers, and create a sustainable business model that captures a fair share of the value generated by the platform. Therefore, it is essential to consider the diffusion process and the dynamics of value creation and capture when studying digital platforms and their impact on the economy. Understanding the factors that drive the adoption and success of platforms will enable us to design and manage these technologies better to maximize their benefits for all stakeholders involved.

Digital platforms are composed of various resources and business modules that are configured dynamically to gain flexibility and built with core modules to gain stability [35]. The digital infrastructure, which is formed by the coupling of information outsourcing, software embedding, the Internet of Things, and mobile communication, supports different industries to shift from product competition to platform competition [19,22]. Additionally, modular technology and organizational architecture enable digital elements to coordinate and integrate internal and external resources of the enterprise, providing greater flexibility and scalability [36,37]. By breaking down the platform into individual components, businesses can more easily adapt and change specific aspects of the platform without disrupting the entire system. This allows for greater innovation and the ability to respond to changes in the market or technology. Overall, digital platforms are made up of different resources and business modules that work together to create value and connect different parties. The technology and infrastructure that support the platform, as well as its modular design, play a crucial role in enabling the platform to innovate and adapt to the market. Therefore, previous research has emphasized the supportive role of digital infrastructure and modular architecture on digital platforms.

3.2.1. Digital Infrastructure

Digital infrastructure is considered a collection of components, networks, systems, and processes that support the operation of information systems [38]. From a socio-technical systems perspective, digital infrastructure is a combination of technical and organizational elements that support the operation of businesses and industries, including hardware devices such as computers and mobile terminals, software technologies such as cloud computing and the Internet of Things, and digital organizational and governance rules [18,39]. For digital platforms, computer hardware and other equipment support the construction of value networks, the internet and other software technologies support the flow of value, and organizational and governance standards support the creation and acquisition of value.

Overall, digital infrastructure plays a crucial role in supporting the value creation, delivery, and acquisition of digital platforms. In terms of value creation, digital infrastructure drives distributed innovation among complementors, resulting in the rapid improvement of complementary products [40] and reducing the cost of iterative innovation. In terms of value delivery, digital infrastructure ensures faster delivery of products. Research indicates that digital infrastructure supports the value network of digital platforms and helps value flow among stakeholders [41]. In terms of value capture, digital infrastructure improves the search and matching process and increases transaction efficiency. Big data technology improves value capture efficiency by quickly matching producers and consumers, and machine learning technology learns from participant behavior to improve or expand platform business [16,17].

3.2.2. Modular Architecture

Digital infrastructure elements make digital platforms increasingly complex and amplify the risks of collaborative innovation [42]. Modular architecture, on the other hand, reduces interdependencies between subsystems, making complexity easier to manage and lowering the risk of collaborative innovation. By decreasing system complexity, a modular architecture enables innovation in the following ways:

- Facilitating distributed innovation: Modular architecture allows platform owners to disperse large-scale innovation across many external complementors' innovation activities, reducing the costs of digital platform innovation while spreading the risk of innovation across complementors.
- Facilitating incremental or disruptive innovation: Scholars have different and even opposing views on the effects of modularization on incremental and disruptive innovation. Klos et al. [43] argue that modular architecture is conducive to incremental innovation but can become an obstacle to disruptive innovation. However, Kohtamäki et al. [20] argue that modular architecture expands the boundaries of resources and organizations and can acquire heterogeneous complementors while enriching innovation factors, thus favoring disruptive innovation.
- Releasing complementors' cognitive constraints: The concept of releasing complementors' cognitive constraints is a crucial aspect of promoting innovation and creativity within digital platforms. By enabling complementors, who are external entities that create value for the platform, to focus on their unique strengths and capabilities, digital platforms can enhance their overall performance and competitiveness. One notable example of this is the deep-learning development platform TensorFlow, which utilizes a modularized approach to the underlying code. This approach enables researchers to avoid the tedious and time-consuming process of reinventing the wheel, allowing them to focus on their own innovative contributions. This approach not only reduces the cognitive constraints on complementors but also provides a platform for collaboration and knowledge sharing, leading to improved innovation capacity and a more robust digital ecosystem. Through the modularization of the underlying code, TensorFlow offers complementors the opportunity to leverage existing functionalities and build upon them to create innovative solutions. By doing so, complementors

can focus on their areas of expertise and create novel applications that enhance the platform's overall value proposition. This approach also encourages complementors to share their knowledge and insights, fostering a community of practice that drives innovation and supports the growth of the platform.

- Improving complementors' independence and promoting the rate of complementary innovation [17]: In the context of digital platforms, improving complementors' independence and promoting the rate of complementary innovation can be crucial factors for driving overall innovation and success. This approach involves enabling and empowering complementors, third-party developers, suppliers, and other actors who create and deliver complementary products or services on the platform, to innovate and create value more freely and effectively. One key way to improve complementors' independence is by providing them with the tools, resources, and support they need to innovate on their own terms. This may include offering access to platform data, APIs, and other resources that can help complementors create new products and services that integrate more seamlessly with the platform. It may also involve providing training, mentoring, or other forms of support that can help complementors develop their skills and capabilities. Promoting the rate of complementary innovation can also be an important factor in driving overall platform success. This involves creating an ecosystem that fosters collaboration and competition among complementors, as well as providing incentives for them to innovate and differentiate themselves from one another. For example, a platform may offer rewards or recognition to the most innovative complementors, or it may host competitions or challenges that encourage complementors to develop new and innovative products or services.

3.3. Digital Platform Business Model

Research on resource-based theory and transaction cost theory posits that business models constitute a specific combination of resources that generate value for businesses and their clients through transactions [44]. A business ecosystem is characterized as a relatively self-reliant and self-regulating system of organizations and structures, where the participating entities are loosely coupled, and value is co-created through shared institutional logic and interactive mechanisms [22]. Thus, the fundamental objective of a business model is to create and capture value, which is achieved through a careful combination of resources that generate value for both the business and its clients through transactions. The value created is not static, but rather, it is dynamic and constantly changing as the business model adapts to new circumstances and opportunities. Therefore, it is crucial for businesses to have a deep understanding of the internal logic of their business model, as well as the external ecosystem in which they operate [39]. A business ecosystem is a complex web of interdependent organizations and structures that co-create value through shared institutional logic and interactive mechanisms. It is the organization and structure formed by the business model, reflecting the intricate interplay between resources, transactions, and value creation. In essence, the business model is the foundation upon which the ecosystem is built, and it is the primary mechanism through which value is created and captured. As such, understanding the dynamics of value creation and capture in business models is critical for any organization seeking sustained success in today's highly competitive business environment [40].

Under commodity-driven logic, business models have a focal firm at the core and consider goods as the foundation of transactions, achieving value added in production. Therefore, traditional business models organize production along a linear value chain or focus on internal production within the firm. In contrast, service-dominant logic, which is based on value in use, considers service as the decisive factor in exchange and resources as the foundation of service exchange, with the exchange of service itself being a value co-creation process involving customer participation. In the binary structure of "service provider-service receiver", value co-creation occurs when the receiver interacts with the resources provided by the provider [45]. Therefore, resources define the value that can be

achieved by the service receiver. Based on a service-dominant logic, platform ecosystems can be seen as resource integration systems with a stable core and variable periphery [46]. In this "core-periphery" structure, the platform itself is a stable core that coordinates and matches resources in various "service provider-service receiver" binary structures as a mediator. Therefore, the platform business model can be seen as a value co-creation mechanism that integrates resources based on a "core-periphery" structure, promoting service exchange between different "service providers-service receivers".

First, digital platforms, as scalable digital cores, generate creativity when digital "service provider-service receiver" binary structures are organized around them due to reprogrammability and data homogeneity [47–49], making digital platform ecosystems a source of innovation for service exchange. Generativity refers to the ability of a technology to produce spontaneous and unintended changes driven by a large, diverse, and heterogeneous number of users. Second, digital platforms themselves, as digital participation architectures for "service providers" and "service receivers" in the ecosystem, can reduce cognitive distances between participants, strengthen shared institutional logic, simplify service exchange rules, innovate types of service exchange, and enrich the quantity of service exchange. In addition, the modular architecture and loosely coupled structure of digital platforms can increase digital resource density, which helps to dynamically integrate resources to promote value co-creation based on service exchange. Therefore, digital platform business models reflect how companies dynamically integrate digital resources based on a "core-periphery" structure to promote creativity, achieve digital service innovation, and drive value co-creation based on digital service exchange.

4. Innovation of Digital Platform Business Models

The core feature of digital platform business models is the transfer of value creation from within the firm to its boundaries through cross-boundary elements, connections, and activities, and the realization of value co-creation by integrating the resources of the platform owner and complementors. The essence of this is that the platform owner and complementors collaborate to produce and/or sell complementary products in order to create value together [50,51]. Unlike traditional multi-tier supply chains, the relationship between the platform owner and complementors is not usually governed by fixed contracts [52], which can lead to instability in the relationship between the platform owner and a single complementor. However, due to the platform's openness and the complexity of the complementarity network, the exit of a single complementor does not pose the risk of a value chain break.

The seminal work of Hippel [53] on open innovation is relevant to the study of digital platform business models. In these models, value creation is transferred from within the firm to its boundaries through cross-boundary elements, connections, and activities. The platform owner and complementors collaborate to produce and/or sell complementary products in order to create value together. This approach is similar to von Hippel's concept of open user innovation, where users are involved in the innovation process and contribute their own ideas and resources to create new products and services. Unlike traditional supply chains, the relationship between the platform owner and complementors is not usually governed by fixed contracts. However, due to the platform's openness and the complexity of the complementarity network, the exit of a single complementor does not pose the risk of a value chain break. By constantly matching technical architecture and organizational governance, the platform owner can drive the evolution and development of value co-creation relationships. Therefore, the ecological relationship formed by the group of platform owners and complementors is more stable than the cooperation relationships in traditional supply chains. Similar to consumer-facing platforms, industrial internet platforms also exhibit an "interactive empowerment" mechanism between the core platform and complementary firms. Complementary firms are attracted to the ecosystem, empowered with technology, organization, and strategy, and their organizational performance and change are promoted. As complementary firms join, they inject their own data, technology,

and resources into the platform, achieving the collaborative symbiosis and co-evolution of the complementary firms and the platform. Overall, the concept of open user innovation and von Hippel's work are highly relevant to the understanding of how digital platforms create value and facilitate innovation through collaboration with complementors.

Furthermore, by constantly matching technical architecture and organizational governance, the platform owner can drive the evolution and development of value co-creation relationships. Therefore, overall, the ecological relationship formed by the group of platform owners and complementors is more stable than the cooperation relationships in traditional supply chains. Similarly to consumer-facing platforms, there is also an "interactive empowerment" mechanism between the core platform and complementary firms in industrial internet platforms [54]. On the one hand, industrial internet platforms attract complementary firms to connect to the ecosystem, empower them with technology, organization, and strategy, and promote organizational performance and change in complementary firms; on the other hand, as complementary firms join, they will inject their own data, technology, and resources into the platform, achieving the collaborative symbiosis and co-evolution of the complementary firms and the platform.

Therefore, the three essential elements that distinguish digital platform business models from traditional ones are complementary firms, complementary products, and value co-creation [55]. Unlike the existing literature that describes the driving factors of business model innovation from the internal and external perspectives of the firm [56], this paper highlights the dual uncertainty of complementary firms and products as a unique driving factor for digital platform business model innovation. This factor is located externally to the digital platform firm but internally within the digital platform ecosystem. Combining the business model innovation process perspective [56] and the boundary perspective [6,7,57,58], this paper outlines the main line of "innovation drive-innovation design-innovation adjustment-innovation implementation" (see Figure 3) and addresses the research question of how digital platforms conduct business model innovation from the perspective of boundary design and boundary resource deployment.

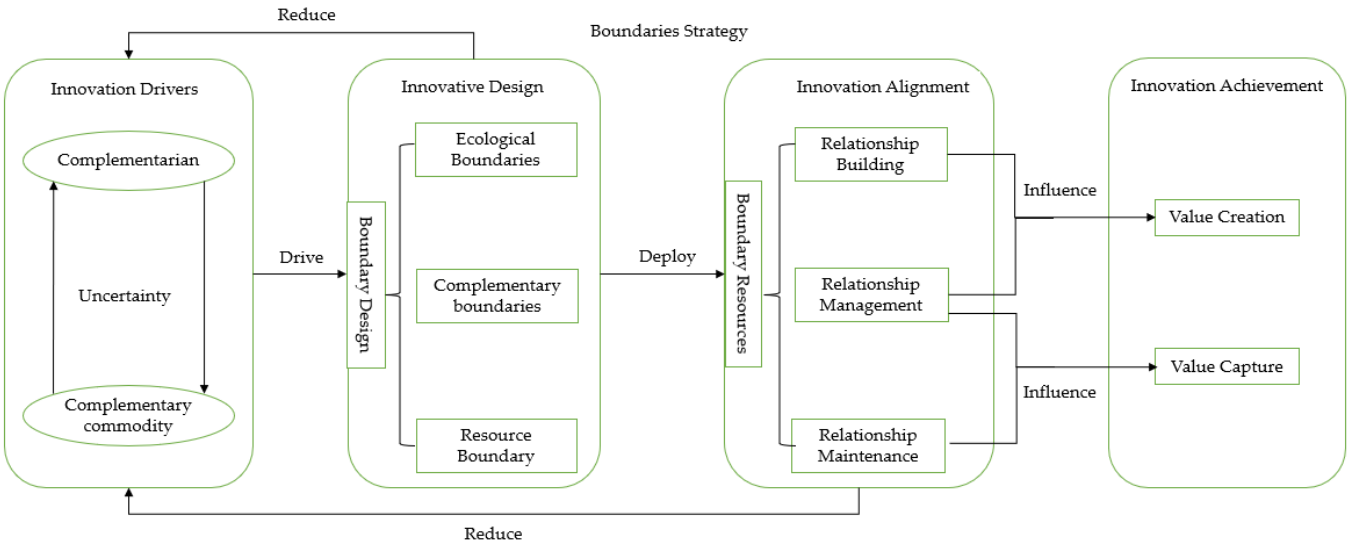

Figure 3. Digital platform business model innovation process.

Starting with the dual uncertainty of complementary firms and products, this paper emphasizes how managing this dual uncertainty is a driving factor for digital platform business models. Based on this, the study further elaborates on how the boundary strategy composed of boundary design and boundary resource deployment reduces uncertainty and how boundary resources affect value creation and implementation. Overall, this analytical framework helps to deconstruct the innovation process of digital platform business models

from the perspective of the firm's boundaries and combines structural and relational elements of digital platforms to explain the process of value creation and capture.

4.1. Innovative Design: Uncertainty and Boundary Design

This section focuses on boundary design in digital platform strategy. As shown in Figure 4, the boundary design of digital platforms is driven by the dual uncertainty of complementary actors and complementary goods, shaping different boundary functions and thus driving value co-creation. Firstly, the dual uncertainty of complementary actors and goods, which exists in terms of resources, technology, and behavior, among others, not only drives innovation in platform business models, but also drives the design of appropriate boundaries. Secondly, the platform boundary is composed of ecological boundaries, complementary boundaries, and resource boundaries. These constitutive elements respectively influence value co-creation activities through integrating resources, defining value co-creation models, and forming competitive barriers [59].

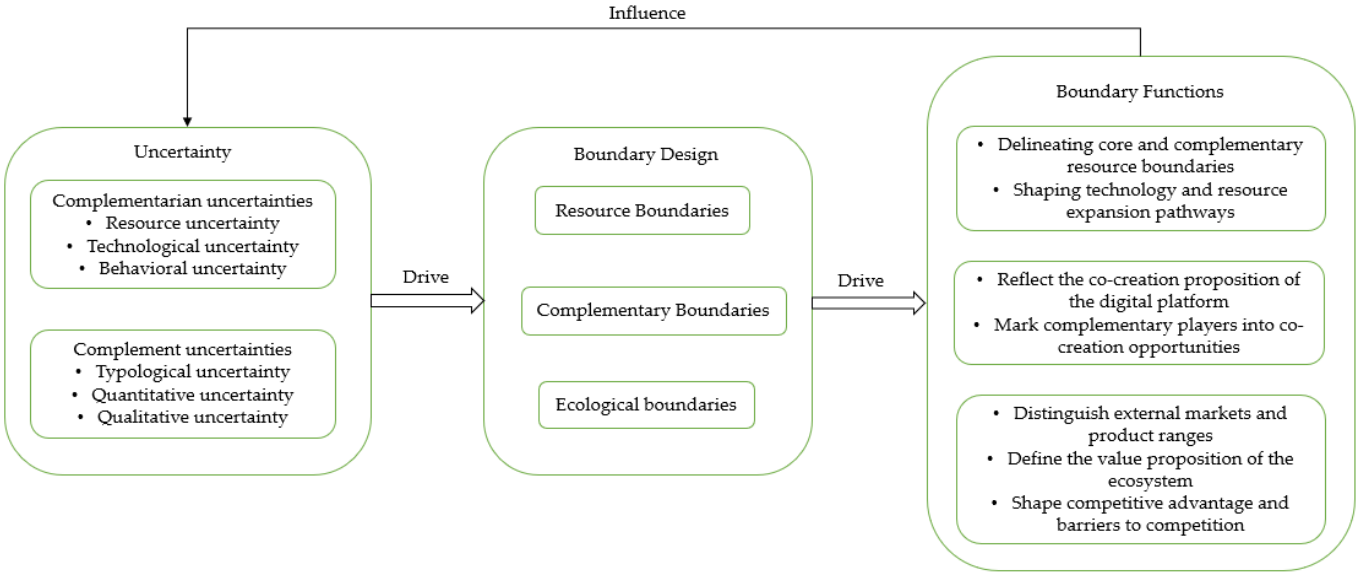

Figure 4. Uncertainty and platform structure.

4.1.1. Complementarian and Complementary Uncertainties

Dynamic capability theory [59] suggests that organizations can adapt to changing market conditions and achieve sustainable competitive advantages by integrating, building, reconfiguring, and optimizing internal and external resources and capabilities. The theory posits that organizations can sense and respond to organizational change stimuli by discovering, interpreting, and seeking out resources, and that they can achieve innovation through dynamic design and adjustment of organizational resources. In the case of digital platforms, although value co-creation can be achieved through resource integration [60], the size, industry, background, and technology of complementary firms differ, and the relationship between the platform owner and complementary firms is relatively independent, leading to a dual uncertainty of complementary firms and complementary products [61–63]. According to dynamic capability theory, this inherent change stimulus in digital platform business models drives the platform owner to adaptively reconfigure the platform, thereby driving the evolution of digital platform business models.

Digital platform participants include platform owners and complementors, with the former supporting complementors' innovation through open access to platform resources, and the latter producing complementary products through accessing and utilizing those resources [64,65]. The generativity of digital technology makes it unlikely for platform owners to solely design and produce all potential products on their own, making collaborating with complementors to tap into generative potential and co-create value a strategic

choice for platform owners [50]. Therefore, the core characteristic of the digital platform business model lies in the cooperation between platform owners and complementors to jointly produce complementary products and create value together [21,66].

However, leveraging the generative potential of digital technology requires platform owners to open up their digital platforms to complementary players, which leads to uncertainty about which complementary players will enter the platform and what resources and capabilities they possess. Thus, the openness of digital platforms is accompanied by uncertainty regarding the entry of complementary players, resulting in uncertainty for platform owners regarding the resources, technologies, and behaviors of complementary players. For platform owners, high openness is beneficial in activating network effects, but it reduces their value capture ability, as some complementary players with stronger capabilities will demand the majority of the co-created value [67,68]. For complementary players, high openness leads to a highly competitive environment, while low openness means that platform owners can demand the majority of the co-created value. Additionally, due to the generative nature of digital technology, the combination of various complementary products (such as work or entertainment applications) with digital platforms (such as the Android system) leads to the possibility of diverse complementary value claims (such as satisfying work or entertainment needs). However, this diversity of complementary value claims means that platform owners must face uncertainty regarding the types, quantities, and qualities of complementary products. Therefore, in digital platform business models, due to the openness of digital platforms and the generative nature of digital technology, platform owners face a dual uncertainty of complementary players and complementary products, not knowing who will enter the platform and produce what products.

From the perspective of platform owners, the uncertainty of complementors and complementary products not only affects the technical architecture and organizational governance of the platform, but also poses challenges for platform owners at different stages of value co-creation. First, platform owners attract complementors to establish value co-creation relationships by opening up the platform, but at the same time, they face the challenge of uncertainty in complementor entry; second, platform owners manage co-creation relationships to ensure cooperation and promote value co-creation, but also face uncertainty in complementor resources, technology, and behavior; finally, platform owners maintain co-creation relationships with complementors by distributing co-created value, but also face uncertainty in the type, number, and quality of complementary products [69,70]. Therefore, the dual uncertainty of complementors and complementary products will drive platform owners to innovate digital platform business models. In view of this, the following proposition is proposed:

Proposition 1. *The dual uncertainty of complementors and complementary products is a driving factor for innovation in digital platform business models.*

4.1.2. Platform Boundary Design

The design of the platform boundary is a key issue for the value co-creation of digital platforms. From the perspective of the platform owner, the co-creation value depends on how to attract external participation and how to conduct internal governance. However, the implicit problem here is how to define the internal and external boundaries of the digital platform. For a long time, the impact of the enterprise boundary on performance has been considered a key issue in strategic management research. Schwarz et al. [71] pointed out that digital platforms expand traditional enterprise boundaries while expanding value boundaries. Şimşek et al. [72] emphasized that the boundary is the key to understanding the evolution of digital platforms. Sahut et al. [66] believe that boundary resources are the core of analyzing the value co-creation of digital platforms. For digital platform boundaries, consider the following two extreme cases: (1) the platform owner internalizes all complementary parties and complementary products, then the uncertainty of complementary parties and complementary products disappears, and the digital platform business

model will change to an internal production model; (2) the platform owner completely externalizes the digital platform, then it loses decision-making power, and the uncertainty of complementary parties and complementary products will also reach the maximum. Thus, it can be seen that the change in digital platform boundaries will cause changes in the uncertainty of complementary parties and complementary products, so it can be managed through the design of platform boundaries.

The discourse surrounding the economics and management of digital platforms has burgeoned in recent years, encompassing a broad range of perspectives and topics [73,74]. With the continued proliferation of digital platforms across the economy, understanding their economic and managerial implications has become increasingly crucial for scholars, practitioners, and policymakers. Digital platforms are proving to be a powerful force of disruption, fundamentally altering traditional industrial and value chains while fostering new forms of value co-creation and business model innovation. Among the crucial aspects of digital platforms is their role as markets, serving as a nexus where buyers and sellers come together to exchange goods, services, or information. In most cases, the platform owner takes a commission on transactions while providing additional services such as payment processing, dispute resolution, and marketing [75]. In the realm of financial markets, the rise of digital financial platforms for blockchains and crypto-assets has been particularly significant, ushering in a new era of accessibility and affordability for users. These platforms enable users to trade and invest in digital currencies and assets with lower fees and fewer restrictions than traditional financial markets [76,77]. Moreover, digital platforms can be categorized as one-sided, two-sided, or multiple-sided, depending on the number and nature of participants in the platform ecosystem. One-sided platforms have a single type of user, such as a content platform with only creators or consumers. On the other hand, two-sided platforms bring together two distinct groups of users, such as a ride-sharing platform connecting drivers and passengers. Finally, multiple-sided platforms involve multiple groups of users with different roles and interdependencies, such as an e-commerce platform that connects sellers, buyers, payment providers, and logistics providers [78].

Digital platforms, as a model of organizational production and exchange, are the main carriers and organizational forms of the digital economy and have both market and enterprise attributes [79]. Previous studies have discussed the market, technology, organization, and value connotations of digital platforms from the perspectives of economics, technology management, organizational management, and strategic management by focusing on network effects, resource architecture, complementary governance, and ecosystem construction [80]. From the market attribute of digital platforms, economic-related research has emphasized how network effects work among different groups of participants and between them [68,69]. By internalizing network effects, platform owners are at the core of different "service provider-service recipient" interactions and can shape the competitive advantages and value creation of the ecosystem through technical design, organizational governance, and strategic planning, and reap benefits from the value created.

Starting from the attributes of digital platform enterprises, the research on technology management, organizational management, and strategic management actually reflects the different types of boundaries in the resources, organizations, and ecology of digital platforms. Based on relevant research, this paper proposes three boundaries that coexist in digital platforms, namely, the resource boundary between core resources and complementary resources chosen by the platform owner based on a modular architecture [67,70], the complementary boundary between the platform owner and complementors in the value co-creation process [71], and the ecological boundary formed by the complementors and complementary products around the digital platform [80]. Therefore, this paper aims to understand how the platform owner designs boundaries at the resource, activity, and product levels to manage uncertainty and shape value co-creation relationships and activities, as opposed to focusing on the behavior boundaries of digital platforms as market subjects in the context of market order [81]. Essentially, the digital platform resource, complementary,

and ecological boundaries proposed in this paper define the ways of integrating resources, signify opportunities for value co-creation, shape the uniqueness of digital platforms, reflect the dimensions of internal governance of digital platform owners, and are an important tool for internal governance.

Research in the field of technology management has proposed structural theories of digital platform resource allocation by focusing on the technical and architectural characteristics of digital platforms, attempting to explain how digital platforms innovate based on architectural decisions such as modularity and interface openness [51,82–84]. Through a review and summary of the relevant literature, this paper proposes that the resource boundary distinguishes between the core resources of the platform and peripheral complementary resources. It essentially involves how the platform owner achieves resource integration and to what extent platform resources are shared. Studies that emphasize technological elements argue that the resource boundary reflects the scope of technological expansion based on the core resources of the platform [85]. On the other hand, studies that focus on organizational elements link the technical system with organizational activities [86], and argue that the resource boundary reflects the scope of resources integration between internal and external participants of the digital platform. Therefore, the resource boundary is both a boundary and a bridge, separating the boundary between core resources and complementary resources and shaping the way of technological expansion and resource integration [87]. Additionally, through open and closed resource boundaries, platform owners can promote or limit complementors' access and use of core resources, thus promoting or limiting the development of complementary products [23]. Therefore, appropriate resource boundary design can shape complementors' participation paths [35,88] and the governance capabilities of the platform owner [89], and reduce uncertainty for complementors entering and developing complementary products.

In the field of organizational management, research suggests that digital platforms are a vehicle for value co-creation, where the creation and acquisition of value depend on specific complementary forms between the platform owner and the complementors. Through a review of the relevant literature, this paper proposes the concept of complementary boundaries, which defines the roles of the platform owner and complementors in jointly creating value. Essentially, this involves the platform owner's choice of value co-creation model and the degree of participation in value co-creation [90,91]. In relation to the value co-creation process, two extreme cases are proposed: value creation is completed solely by the platform owner, or value creation is completed solely by complementors. The former means that the platform owner enters the complementors' product market through resource and complementary boundaries and produces products internally, and sells directly to consumers. The latter means that complementors do not enter the platform ecosystem and are in a competitive relationship with the digital platform. In both of these cases, there is no value co-creation relationship, and the value creation process is no different from the traditional business model of internal production within a company [38]. Therefore, it can be seen that the complementary boundary reflects how value is co-created in digital platforms and shapes the platform owner's claim of value co-creation. Additionally, since the complementary boundary divides the tasks of the owner and complementors in value co-creation, and the platform owner can fully control its internal production, the platform owner can reduce the uncertainty of complementors' product development by designing the complementary boundary. In conclusion, the design of the complementary boundary can reflect the value co-creation model of digital platforms, mark the opportunities for complementors to enter value co-creation, and reduce the uncertainty of complementors' product development.

Research in the field of strategic management suggests that all companies, including traditional and digital companies, platform and non-platform companies, have a business boundary [24,51,83,84,92]. This boundary determines the resources, product innovation, market entry, and product sales of digital platform companies [93]. Through a review of the relevant literature, this paper posits that the digital platform ecological boundary

differentiates the external market or product scope in competition with it and defines the value proposition of the entire platform ecosystem. For complementors, the ecological boundary prompts their entry and exit from the platform by shaping the value proposition; for consumers, the ecological boundary determines the products, services, and content available on the platform; for the platform owner, the ecological boundary shapes the competitive advantage of the digital platform and further forms competitive barriers. Some scholars have examined the phenomenon of digital platform ecological boundary expansion, where the platform owner binds other platforms' products or functions to its own platform [66,94,95]. They argue that when there is a significant overlap of user groups, it is feasible for platform owners to bind complementary platforms; when there is a significant scope economy, it is feasible to bind weakly competitive platforms; and when there is significant user group overlap and scope economy, it is feasible to bind unrelated platforms [21].

In summary, the resource boundary defines the approach for technological expansion and resource integration, the complementary boundary shapes the way in which the platform owner and complementors co-create value, and the ecological boundary determines the competitive advantage of the digital platform ecosystem. In light of this, the following proposition is proposed:

Proposition 2. *The resource boundary, complementary boundary, and ecological boundary are the core of digital platform business model design and are important in managing the dual uncertainty of complementors and complement products to promote value co-creation.*

4.2. Innovative Alignment: Boundary Resources and Relational Governance

Previous research has focused not only on boundary design but also on the deployment of boundary resources and the governance of relationships between platform owners and complementary partners [96,97]. Boundary resources refer to interfaces, tools, and rules that maintain relative independence between platform owners and complementary partners [41]. Relationship governance refers to the ability of platform owners to create, manage and maintain value co-creation relationships with complementary partners in order to promote resource integration, information flow, and technological expansion within the ecosystem [98,99]. As shown in Figure 5, platform owners establish relationships with complementary partners through the deployment of boundary resources, manage these relationships during the value co-creation process, and distribute value to maintain these relationships.

4.2.1. Boundary Resources and Relationship Creation

Through the deployment of boundary resources, digital platform owners can open up platform resources, boundaries of complementarity, and ecological boundaries [60], and establish cross-boundary connections to form value co-creation relationships with complementary partners. According to existing research, platform owners can establish connections within and between digital platforms [100]. With regard to relationship establishment within the platform, scholars have identified two functions of boundary resources: access connections and resource provision [57,58]. Access connections refer to the platform owner's ability to open up access to core resources by making resources boundary-open (such as deploying application interfaces) to allow complementary partners access. Resource provision refers to the platform owner's ability to transfer production capabilities to complementary partners by deploying boundary resources at the complementary boundary (such as integrating development environments), providing technical feasibility for complementary partners to participate in value co-creation. From existing research, ways of establishing relationships between platforms include open boundaries, platform authorization, and open source. Among them, open boundaries refer to the platform owner's ability to establish access mechanisms with other platforms at the ecological boundary [88], platform authorization refers to the platform owner's choice to give autho-

rization of digital platforms to other companies, and open source refers to the platform owner's decision to fully open all three types of platform boundaries [38]. It is worth noting that the relationship establishment strategy of digital platforms may change over time, shifting from boundary closure to boundary opening or from boundary opening to boundary closure. For example, in the development process, WeChat Pay chose to establish user dependence on the platform by opening up its boundaries for free at the beginning, but later on, it chose to charge a service fee to reduce the openness of its boundaries. Additionally, through the study of platforms that combined open and closed strategies, Preghenella et al. [61] argue that mixed strategies reflect the balance between relationship establishment and value acquisition and suggest that mixed strategies may be superior to pure-open or pure-closed strategies.

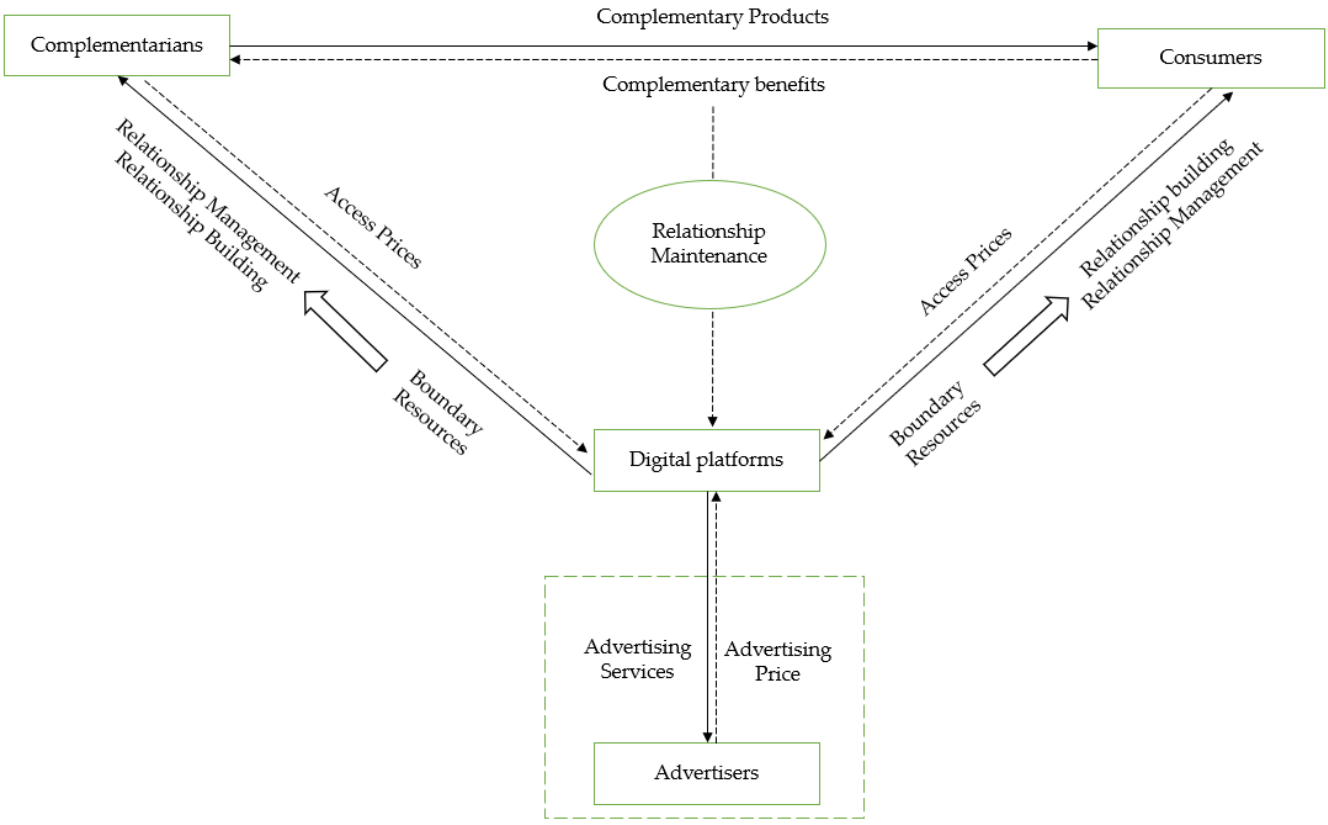

Figure 5. Boundary resources and relationship governance.

4.2.2. Boundary Resources and Relationship Management

In addition to helping establish cross-boundary connections, boundary resources also serve as tools for platform owners to achieve relationship management. Digital platforms need to balance market mechanisms with organizational control in order to manage value co-creation relationships with complementary partners in order to ensure diversity and standardization of complementary products [56]. On the one hand, due to the different motivations and businesses of complementary partners, in order to coordinate and resolve conflicts within the platform and reduce opportunistic behavior, platform owners need to deploy social boundary resources (such as platform guidelines and training activities) to reduce cognitive distance among complementary partners, forming a common value system among complementary partners, thus reducing behavioral uncertainty among complementary partners [101]. For complementary partners, their scale, industry, background, technology, and abilities are different, and a common value system helps coordinate their own interests and goals with the platform. For platform owners, a common value system helps form platform identity and reduces the cost of relationship management [5]. On the other hand, platform owners need to manage the establishment, process, and output of

value co-creation based on the behavior and output of complementary partners. In the establishment of value co-creation relationships, by screening mechanisms and restricting the use of boundary resources, platform owners can ensure the expected complementary partners enter the platform's value network [27]. In the process of value co-creation, boundary resources such as anomaly detection tools can correct improper behavior of complementary partners and ensure that value co-creation activities are carried out normally. In the output of value co-creation, boundary resources such as consumer evaluations can reflect the preferences of the demand side for complementary products and complementary partners, reduce the uncertainty of platform owners for complementary partners and complementary products, and promote the strengthening of co-creation relationships with high-quality complementary partners [2].

4.2.3. Boundary Resources and Relationship Maintenance

Maintaining relationships on a digital platform involves how the platform owner allocates revenue to sustain mutually beneficial partnerships with complementors [24]. As previously discussed, platform owners and complementors establish connections across resource boundaries, complementary boundaries, and ecosystem boundaries to create, transfer, and gain value. However, deploying resources, building relationships, and managing them incur costs. To compensate for these costs, the platform owner must price access and output to allocate revenue, thus maintaining the value-creation partnerships. In terms of access pricing, the resource-based theory states that resource rent must be obtained through isolation mechanisms or positional barriers. Digital platforms use a compromise strategy by designing resource boundaries and sharing boundary resources that have relationship value to establish and manage value-creation relationships with complementors while protecting core resources that have barrier value to ensure ownership and obtain resource rent [25,26].

In summary, pricing access is based on creating value-creation relationships with complementors using boundary resources and collecting rent on core resources during the value-creation process. In terms of output pricing, complementors originate from the value-creation activities of platform owners and complementors based on core resources, boundary resources, and complementary resources. Therefore, output pricing involves how the platform owner allocates the value of output in order to sustain value-creation relationships with complementors and foster future value-creation activities. Although the resource-based theory can explain the access pricing of digital platforms, it is unable to account for the mechanism of output value allocation by platform owners. This is because platform owners and complementors achieve value creation through resource integration, a process that fundamentally relies on breaking down resource barriers. In light of this, the following proposition is proposed:

Proposition 3. *Boundary resources are crucial tools for digital platforms to establish, manage, and sustain value-creation relationships.*

4.3. Innovation Realization: Relationship Governance and Value Analysis

In traditional business models, the foundation of value creation is the transformation of suppliers' inputs into consumers' demanded outputs, providing value added to consumers. Unlike traditional business models, value creation on digital platforms is the result of integrating heterogeneous resources through cross-boundary participation and interaction. As shown in Figure 6, platform owners establish, manage, and maintain value-creation relationships through boundary resources, thus impacting the creation and acquisition of value. In digital platforms, the key to value creation and acquisition lies in constructing cross-boundary interactions and integrating resources both within and outside the boundaries. Building cross-boundary interactions requires boundary design and boundary resource deployment, while achieving resource integration requires establishing, managing, and maintaining relationships with complementors through boundary resources [18,37]. There-

fore, strategies for establishing, managing, and maintaining value-creation relationships will impact value creation and acquisition on digital platforms.

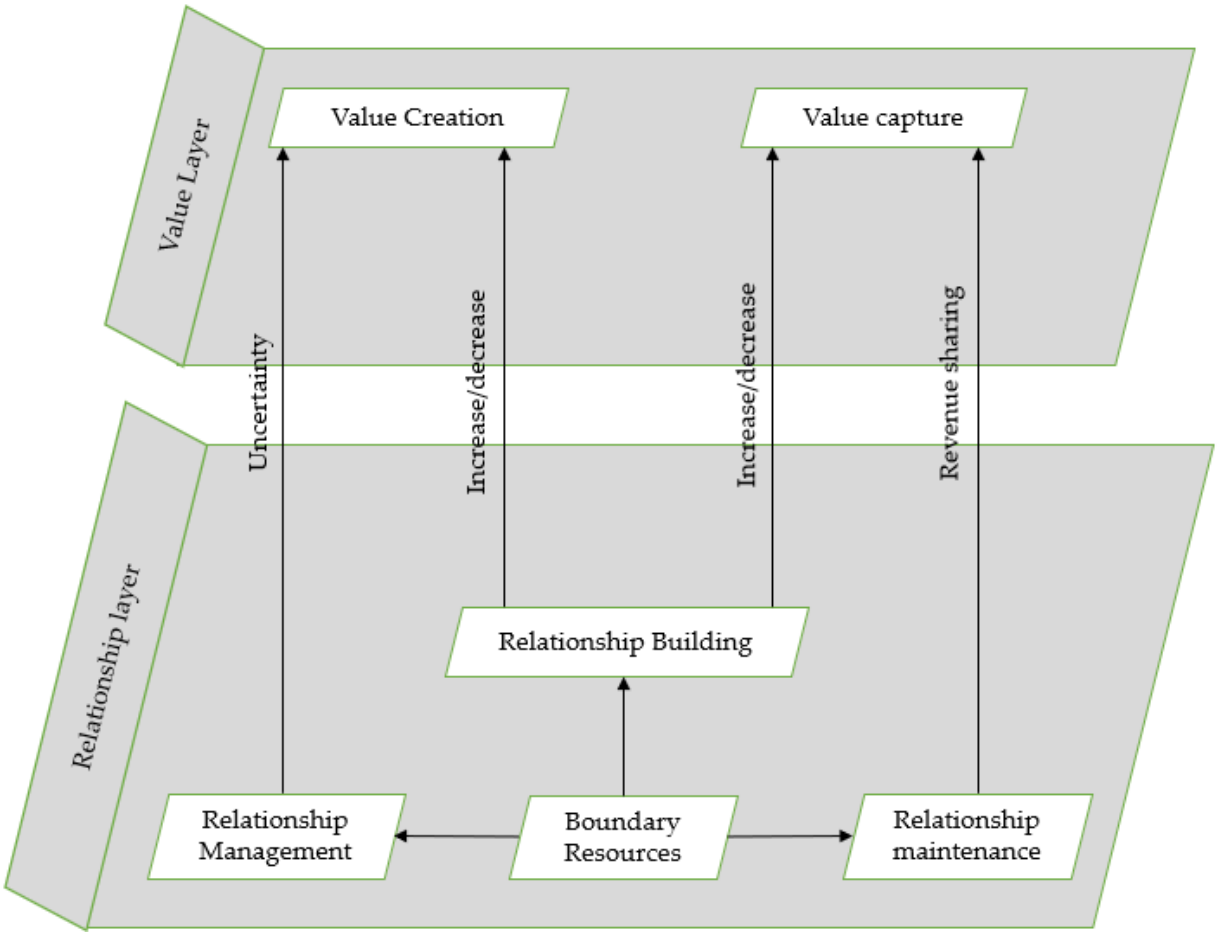

Figure 6. Boundary resources, relationship governance, and value capture.

According to the service-dominant logic, value is only created when it is used; thus, resource providers do not create value but propose value propositions, while resource users are the value realizers [39]. In the "platform owner-complementor" service exchange relationship based on boundary resources, the platform owner proposes value propositions, and the complementors create value; in the "complementor-consumer" service exchange relationship based on complements, the complementors propose value propositions, and the consumers create value; in the "platform owner-consumer" service exchange relationship based on boundary resources, the platform owner proposes value propositions, and the consumers are value creators [40]. However, it should be noted that in the relationships between platform owners and complementors and consumers, if the platform owner uses resources from complementors and consumers (such as data), the platform owner becomes a value creator. Similarly, in the "complementor-consumer" relationship, if the complementor uses resources from consumers, the complementor becomes a value creator.

4.3.1. Relationship Building and Value Creation

Digital platform owners' cognitive decisions toward external uncertainty determine their relationship-building strategies. For platform owners, establishing connections with complementors through open platform boundaries allows them to diversify complementary products through cross-selling and to share costs and risks, thereby enhancing their ability to create and capture value [16]. However, the openness of a digital platform's boundaries is not always beneficial. Excessive openness of resource boundaries increases dependence on complementors and reduces the platform owner's ability to capture value; excessive

openness of complementor boundaries reduces complementors' platform conversion costs, leading to multi-platform presence, thus reducing the platform owner's ability to create and capture value; and excessive openness of ecosystem boundaries increases the costs of coordination, monitoring, and communication for the platform owner, thereby reducing their ability to create and capture value.

4.3.2. Relationship Management and Value Creation

Boundary resources can shape public values within complementary boundaries and indirectly promote value creation on digital platforms through complementors' autonomy [43]. Complementors' autonomy can promote value creation, but due to their behaviors and the heterogeneity of resources, digital platforms need formal relationship management mechanisms to reduce the uncertainty of complementors and complements, thereby ensuring value creation [46]. First, too high boundary openness may facilitate relationship building but can also squeeze out complementors' contributions, dilute complementors' identity, and lower the quality of complements, thereby obstructing value creation [48]. Therefore, platform owners need to manage relationship building based on boundary resources to reduce complementors' uncertainty of entry. Second, due to the relatively independent relationship between digital platforms and complementors, platform owners lack the legitimate authority to issue commands, and complementors do not have an obligation to obey commands. Therefore, platform owners need to manage the co-creation process to reduce complementors' behavioral uncertainty. Finally, complementors' resource heterogeneity can lead to uncertainty in the type, quantity, and quality of complements, impede the exchange and trade of complements, and lower the platform's value creation capacity [48]. Therefore, digital platforms need to manage the co-creation output based on boundary resources to reduce the uncertainty of complement quality [56].

4.3.3. Relationship Maintenance and Value Capture

The symmetry of access pricing directly affects the value acquisition ability of digital platforms [7]. Studies have shown that charging access prices may not necessarily be beneficial for platform owners' value acquisition, depending on consumers' demand substitution effects between digital platforms and other channels [2,102]. Output pricing reflects the mechanism by which platform owners profit from value co-creation, including sharing of complement revenues and platform entry into the complement market. Research has found that demand uncertainty, platform growth stage, and complementors' bargaining power are three factors that affect complement revenue sharing [22,36], while acquisition, imitation, and coverage are three ways for platform owners to enter the complement market [44]. Among them, acquisition refers to the platform owner incorporating complement production into the platform enterprise through the acquisition of complementors, imitation refers to the platform owner entering the complement market by providing similar products, and coverage refers to the platform owner expanding the platform's core functions by launching products previously provided by complementors [46].

It is worth noting that both imitation and coverage can lead to competition between platform owners and complementors, but the two have different impacts on value co-creation relationships. When the platform owner enters the complement market through imitation, the competition relationship and value co-creation relationship between the platform owner and complementors coexist. However, when the platform owner enters the complement market through coverage, the platform owner will destroy the value co-creation relationship with complementors and regard complementors as direct competitors. In view of this, the following proposition is proposed:

Proposition 4. *By establishing, managing, and maintaining value co-creation relationships, boundary resources can affect the value creation and acquisition of digital platforms.*

5. Discussion and Future Agenda

Based on the perspective of the business model innovation process, this paper systematically reviews the relevant literature and answers the research question of how digital platforms innovate business models by focusing on the design of platform boundaries and the allocation of boundary resources, forming four research propositions that can guide future research.

In particular, the article highlights two key areas that need attention when innovating business models for digital platforms: the design of platform boundaries and the deployment of boundary resources. The design of platform boundaries refers to the way a platform is structured and operates, including the rules and regulations it follows, the types of services it offers, and the way it interacts with other players in the ecosystem. The deployment of boundary resources refers to how a platform uses its resources, such as data, technology, and partnerships, to create and capture value. The key findings, therefore, suggest four revisited propositions—statements or hypotheses about the topic—that could guide future research. These propositions have the potential to provide insights or recommendations on how digital platforms can effectively innovate their business models and stay ahead of the competition.

5.1. Digital Infrastructure and Modular Architecture of Digital Platforms

This paper posits that digital platforms, based on digital infrastructure and modular architecture, are complex sets comprising technical elements, organizational processes, and value architectures. The dual uncertainty stemming from complements and complementaries is identified as a key driver for business model innovation in digital platforms. The paper argues that the value co-creation relationships and activities among heterogeneous participating subjects are the core elements that differentiate digital platforms from traditional business models. However, the study also acknowledges that digital platform business models are consistently challenged by the double uncertainty of complements and complementaries, which not only impact the technical design, organizational governance, and value networks of digital platforms, but also pose challenges to value co-creation.

Given this, future research should delve deeper into the study of the uncertainty within digital platforms and their ecosystems. The essence of digital platforms lies in the cooperation of platform owners and complements, utilizing digital technology to jointly produce complementary goods and co-create value. However, due to the openness and technological generativity of platforms, platform owners cannot anticipate who will enter the platform or what will be produced by those who have entered, and thus face a dual uncertainty of not knowing who will enter the platform and what will be produced. As a result, the fundamental challenge facing digital platform business models for platform owners is the dual uncertainty of complements and complementary goods [49,50]. Combining existing research, future research can further identify the following five types of uncertainty: resource uncertainty, or uncertainty about how external complements' resources are integrated across boundaries to create value; technological uncertainty, or uncertainty about whether the platform's technology will dominate in market competition; adoption uncertainty, or uncertainty about whether the digital platform will dominate in user and complement adoption; coordination uncertainty, or uncertainty about how to coordinate technical architecture and organizational governance to implement the platform's value proposition regarding complements and complementary goods; and market uncertainty, or uncertainty about consumer demand for complementary goods and demand for digital platforms [66–68].

The above uncertainties challenge digital platform business models to varying degrees; thus, future research needs to focus on the following issues: (1) the impact of the uncertainty faced by different participating subjects within digital platforms on digital platform business models; (2) despite this article identifying that boundary design and boundary resource deployment can reduce the dual uncertainty of complements and complementary goods, the impact of the structural characteristics of digital platforms on the

aforementioned five types of uncertainty still deserves further exploration; (3) existing research mostly focuses on the impact of uncertainty on value creation [41,60], but there is little research on the impact of uncertainty on value transfer and value capture.

5.2. Digital Platform Business Model Design

Resource boundaries, complement boundaries, and ecological boundaries are the core of digital platform business model design, and are crucial in managing the dual uncertainty of complements and complementary goods, as well as in promoting value co-creation. Boundary design is a key decision in digital platform boundary strategy. The boundary structure of digital platforms involves the platform owner's design choices for opening resources to complements, the allocation of tasks between the platform owner and complements in value co-creation, and the value proposition of the ecosystem to be constructed. Among these, resource boundaries determine how complements access and use platform resources, complement boundaries transmit value creation opportunities to complements, and ecosystem boundaries define the competitive potential of the digital platform.

In light of this, future research should aim to expand existing theories of corporate boundaries based on digital platforms, or even construct new theories. Digital platforms feature interactions that coordinate across multiple boundaries to create value, and thus possess characteristics such as multi-stakeholder participation, open boundaries, and cross-boundary connections. Corporate boundary theories indicate that boundary choices are related to incentives and coordination [45,46]. However, in the case of digital platforms, the transfer of value creation to the platform's multiple boundaries often leads to conflicting incentives and coordination goals [55]. For example, research has found that a trade-off is necessary between contracting boundaries to grant autonomy and motivate participation, and expanding boundaries to coordinate specific areas [40]. Based on this, future research can focus on how the multi-boundary structure of digital platforms enriches existing theories of corporate boundaries. For example, existing research posits that the fundamental reason for the existence of corporate boundaries is transaction costs, so it remains to be explored how transaction costs lead to the multi-boundary structure of digital platforms. In terms of transaction costs, it is worth investigating whether and how the multi-boundary structure of digital platforms is superior to that of traditional corporate boundaries. In terms of the driving factors of boundary design, one can study the driving factors based on the inherent opposing attributes (such as autonomy and control, openness and closure) of digital platform business models.

5.3. Boundary Resources and Value Co-Creation

This study posits that boundary resources are an important tool for digital platforms to establish, manage, and maintain value co-creation relationships; through establishing, managing, and maintaining value co-creation relationships, boundary resources can influence value creation and capture on digital platforms. Thus, boundary resource deployment becomes another key element in digital platform boundary strategy. Boundary resources can transfer innovation capabilities to complementors, and result in distributed and complementary innovation feedback throughout the ecosystem [49]. For companies with established digital platforms, boundary resource deployment is an important means of adjusting boundary strategy. Through the deployment of boundary resources, digital platform owners can both promote value co-creation through dynamic resource allocation and indirectly influence value creation and capture through relationship governance decisions [63].

In terms of boundary resources, existing research has mainly focused on how the introduction of a certain type of boundary resource affects the behavior and performance of complementors [19,35,69], but research on the characteristics of boundary resources is inadequate, and the mechanisms by which different types of boundary resources influence value co-creation need further exploration. Firstly, future research can focus on the impact

of social boundary resources on value co-creation on digital platforms. By exploring the impact of different types of social boundary resources on value co-creation activities, research on platform boundary resource strategy can be further deepened. Comparing the different effects of technical boundary resources and social boundary resources can also help improve platform business model innovation practices. Secondly, as platform boundaries are not fixed once determined, it is worth investigating how and whether boundary resources influence boundary adjustments. Exploring the dynamic characteristics and evolutionary process of platform boundaries also has important theoretical and practical implications. Finally, as digital platforms have different types of boundaries, and resources deployed on different boundaries have different characteristics, future research can also explore how the different characteristics of boundary resources influence value creation and capture.

In terms of relationship governance, future research should further explore the core mechanisms by which relationship governance decisions influence value creation and capture. Firstly, the role of relationship establishment in value creation is heterogeneous, and future research can further explore under what conditions relationship establishment decisions will promote or inhibit value creation. Secondly, boundary resources can reduce the uncertainty of complementors and complementary products through relationship management to promote value creation, and the mechanism by which boundary resources reduce uncertainty also needs further exploration. Finally, the resource-based theory can explain the access pricing of digital platforms, and future research can further clarify the theoretical basis, mechanisms, situational conditions, and potential consequences of platform owners entering complementary markets and competing directly.

In the traditional market, companies are the operating entities, the market is the matching place, and regulatory bodies are the governing entities. However, in digital platforms, the platform owner plays all three roles simultaneously, providing matching mechanisms and participating in operations while also having governance functions. Due to its dynamic competition, network effects, and cross-border operations, there are often conflicts between the three roles played by the platform owner, resulting in issues of inequality and injustice, such as "two-choice", "cutting off the tip and merger", and "forced bundling". Therefore, it is necessary for government regulation to promote the healthy development of digital platforms, balancing efficiency and fairness in digital platform business models. Government regulation should focus on strengthening the innovation and competition of digital platforms, reducing market entry costs, protecting the interests of complementary entities, and encouraging platform sharing of development benefits. Additionally, the framework and boundaries of regulatory measures can also be explored to balance efficiency and fairness in the development of digital platforms.

The notion of value capture in digital platforms alludes to the ability of platform owners to extract a portion of the value generated by complementors through fees, commissions, or other means [103]. If left unchecked, this practice can result in market disruption and potentially monopolistic or oligopolistic profits. As stated previously, governmental regulations are essential to balance efficiency and fairness in digital platform development. These regulations can focus on reducing market entry costs, safeguarding the interests of complementary entities, and encouraging platforms to share development benefits. Furthermore, the framework and boundaries of regulatory measures can be explored to address issues such as the capture of value and market disruption. To comprehend the concept of market disruption and its relationship to value capture on digital platforms, it is vital to define market disruption. Market disruption refers to a situation where a new product, service, or technology disrupts the existing market and creates a new market that is fundamentally different from the previous one. This new market often leads to a significant shift in market share and may even displace existing players in the market.

In the context of digital platforms, market disruption can occur when a platform introduces a new service or feature that fundamentally alters the market's nature. For instance, the introduction of ride-sharing services such as Uber and Lyft disrupted the traditional taxi market by providing a more convenient and accessible alternative to consumers [104].

Similarly, the introduction of online marketplaces such as Amazon disrupted traditional brick-and-mortar retail by providing consumers with a wider selection of products and more competitive prices. The capture of value in this context alludes to the ability of digital platforms to extract economic value from the markets they disrupt. This can take various forms, such as capturing a larger share of the market through increased user adoption, charging higher fees for services, or leveraging data to create new revenue streams. In some cases, the capture of value can result in monopoly or duopoly profits, where a single or a small number of firms capture a large share of the market and generate outsized profits.

To effectively capture value, digital platforms must have a clear market strategy and a strong understanding of the economics of the market they operate in. This includes factors such as market entry barriers, the bargaining power of suppliers and customers, and the competitive landscape. By leveraging their strengths and understanding the market dynamics, digital platforms can create a sustainable business model that allows them to capture value while also providing value to their users [63]. It is worth noting that while the capture of value can result in significant economic benefits for digital platforms, it can also result in negative externalities such as increased market concentration, reduced innovation, and decreased competition. As such, it is crucial for regulators to monitor the activities of digital platforms and take appropriate action to ensure a fair and competitive market.

6. Conclusions

This study aims to explore the mechanisms by which digital platforms facilitate business model innovation, an area that has yet to be adequately addressed in previous research. The study recognizes the importance of this topic, as understanding how digital platforms drive innovation has significant theoretical and practical implications. The study reviews the existing literature on digital platforms and business model innovation, and examines how digital platforms facilitate business model innovation by focusing on the connotations of digital platforms, the design of platform boundaries, and the deployment of boundary resources. By analyzing these factors, the study is able to uncover key insights into how digital platforms drive innovation.

One of the key findings of the study is that the dual uncertainty of complementors and complementary products is the driving factor for business model innovation in digital platforms. This uncertainty arises from the lack of clarity around the products and services that complementors will offer, and how these will interact with the platform's own offerings. This uncertainty creates an environment in which digital platforms must constantly innovate to stay ahead of the competition.

Another key finding is that the design of resource, complementary, and ecological system boundaries is central to digital platform business models and is an important means of managing complementor and complementary product uncertainty and promoting value co-creation. Resource boundaries refer to the resources that the platform makes available to complementors, while complementary and ecological system boundaries refer to the boundaries between the platform's own offerings and those of complementors. By managing these boundaries, digital platforms can create a more favorable environment for innovation to occur.

The study also highlights the importance of boundary resources as a means of establishing, managing, and sustaining cross-border relationships that can influence value creation and capture. Boundary resources can take many forms, such as data, intellectual property, or network effects, and are an important means of leveraging the platform's own resources to create value for complementors and the platform itself.

In light of these findings, the study proposes four research propositions that could guide future research into innovative business models based on a focus on platform boundary design and boundary resource deployment. These propositions have the potential to provide insights or recommendations for how digital platforms can effectively innovate their business models and influence value creation and capture. The study concludes

by emphasizing the need for further research in this area, as understanding how digital platforms drive innovation is an important and ongoing task with significant implications for both academia and industry.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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