Platform Ecosystems
Exploring Participation and Performance

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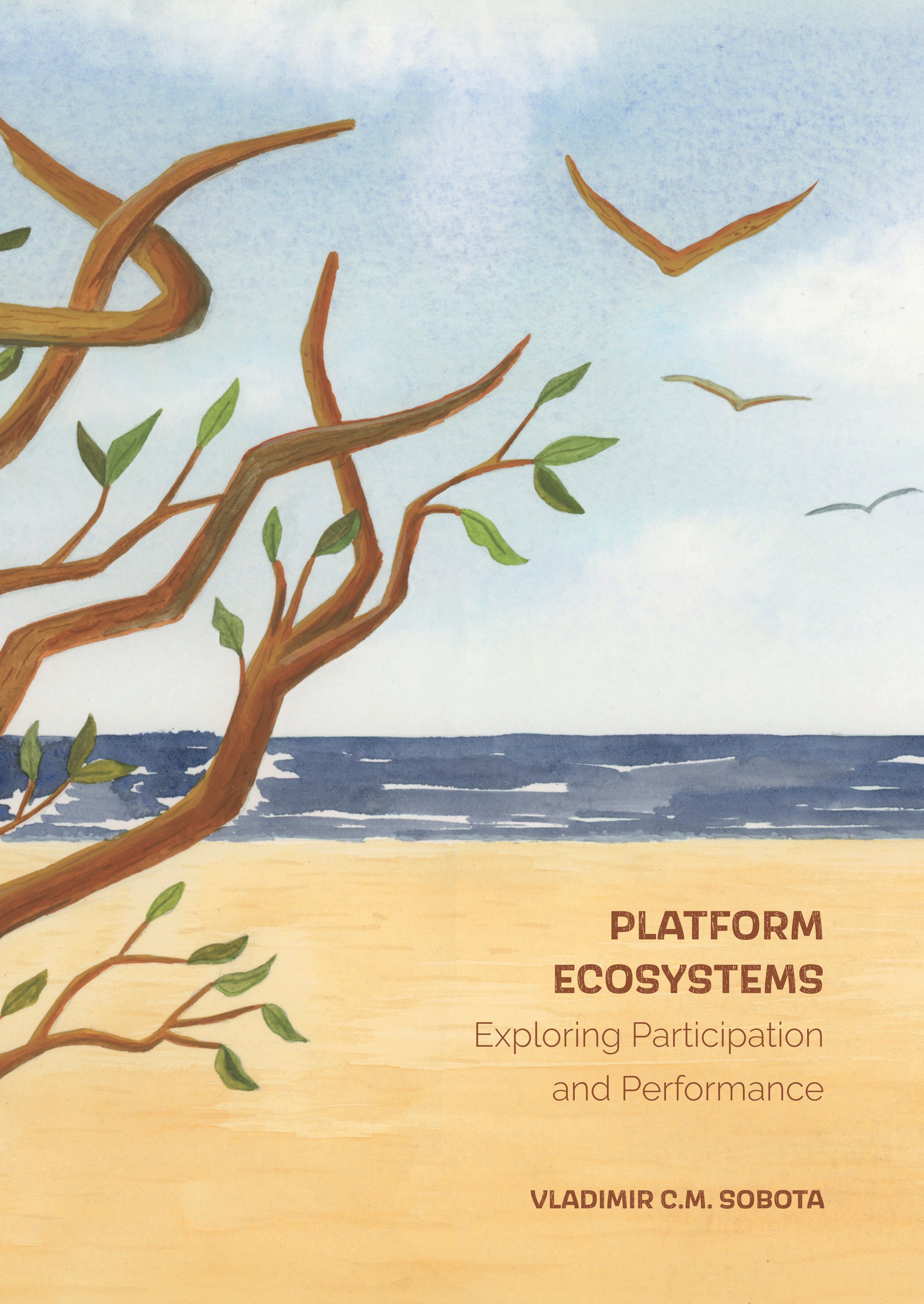

PLATFORM ECOSYSTEMS

Exploring Participation and Performance

VLADIMIR C.M. SOBOTA

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Exploring Participation and Performance

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Dissertation:
Platform Ecosystems: Exploring Participation and Performance

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We know accurately only when we know little,
with knowledge doubt increases.

Johann Wolfgang von Goethe

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Summary

Platforms are often seen as the most influential organizational form of our time. Harnessing the strengths of external parties allows for unprecedented innovation (e.g., Facebook, iOS). Platforms aggregate and match participants in fragmented markets (e.g., Craigslist, Marktplaats, Airbnb). As such, platforms often become the epicenters of industries and have often replaced incumbents. What leads to market power and growth of platforms? Understanding this is important if we want to create platforms where they are beneficial to the economy and society and counteract or regulate them where they are harmful.

This dissertation investigates *how platform participation and platform performance are related to each other*. Participation refers to installing and using a technology. From the economics perspective, performance includes mostly financial indicators such as revenues or profit. However, it can also concern other indicators, for instance, the participation of complementors or users. Under network effects, current participation increases the platform's value to future users, which is closely linked to performance. This dissertation consists of four chapters that together address the main research question. It draws on evolutionary economics, platform economics, and strategic management. It consists of conceptual (Chapters 2, 5, and parts of Chapter 3) and empirical studies (Chapters 3 and 4).

Chapter 2 compares platforms with the related concept of *dominant design*. Both can be seen as *structural metaphors* that hint at the constellation of technological systems and the involved actors. Since economists started opening the 'black box' of technology, several structural metaphors have emerged. To do so systematically, Chapter 2 presents a framework to compare concepts. It discusses commonalities (e.g., a similar structure consisting of a core and periphery) and differences (e.g., degrees of openness) and suggests directions for future research.

Chapter 3 focuses on the antecedents or *factors* that influence performance and participation. These factors can be considered determinants of both participation in and performance of technological innovation, providing an inventory of topics managers may want to address. To this end, Chapter 3 reviews several kinds of literature on factors for technology selection and synthesizes them in one framework. Prioritizing them in the context of additive manufacturing based on expert opinions revealed the most important factors in this context.

The most critical factors concern demand, relative technological performance, commitment, and the underlying business model. The most-crucial factors stem from different kinds of literature and show that synthesizing diverse literature streams adds value.

After comparing different streams of literature (Chapter 2) and making an inventory of factors (Chapter 3), Chapter 4 zooms in on specific aspects of platform strategy. It addresses the availability of complementary goods and services as a key feature of platforms. It highlights the aligning aspect of platforms by focusing on the attraction of complementors to the platform's ecosystem. Chapter 4 studies how tools and resources offered by the platform (called *boundary resources*), the platform's distinctiveness strategy (based on *exclusive content*), and the breadth of its content offerings affect the participation of future complementors.

The last chapter of this dissertation's body zooms in on the relation between participation and performance. Under the presence of network effects, it has been assumed that platform competition rests on maximizing size to leverage network effects, which strongly relates to participation. Despite that, recent theoretical advances hold that platforms comprise a second strategic dimension next to their size, called distinctiveness. The connection between the two, however, is underexplored. Chapter 5 considers these accounts and conceptualizes platform size in light of the competitive logic of distinctiveness. Drawing on optimal distinctiveness theory, it analyses how participation and performance take shape in this literature and suggests directions for future research.

Finally, Chapter 6 addresses the overall contributions. In brief, this dissertation contributes to several fields:

- to platform economics and evolutionary economics, by comparing the literature streams surrounding platforms and dominant designs and suggesting synergies between the streams;
- to innovation management, by synthesizing technology selection frameworks and integrating factors related to knowledge, training, dissemination, and business models;
- to platform economics, by testing and comparing strategies for complementor ecosystem creation;
- to optimal distinctiveness theory and platform economics, by disentangling the notions of platform participation and performance and making platform size explicit in platform distinctiveness and optimal distinctiveness research.

The research conducted in this dissertation provides several entry points for future research. This dissertation has addressed factors and strategies in their potential to affect technology selection and complementor participation. Moving forward, one could compare these in their efficiency by also considering costs. A second direction relates to assumptions about competition. Often, competition is assumed to occur between platforms, but in many markets, platforms compete with non-platform organizations and hybrids. Platforms could be studied in the context of other types of organizations. Third, the integration of platform size into optimal distinctiveness and platform distinctiveness theory could be extended by moving toward a dynamic perspective.

Samenvatting

Platformen worden vaak als de meest invloedrijke organisatievorm van deze tijd beschouwd. Zo maakt het betrekken van externe partijen en het benutten van hun krachten tot kortgeleden ongekende vormen van innovatie mogelijk (bijv. Facebook en Apple iOS). Platformen verbinden of aggregeren participanten in gefragmenteerde markten (bijv. Craigslist, Marktplaats, of AirBnB). Platformen zijn vaak de epicentra van industrieën en hebben in veel gevallen oude bedrijven vervangen. Wat heeft tot zo'n marktmacht en groei van platformen geleid? Dit is een belangrijke vraag voor het creëren van platformen die in economie en maatschappij welvaart scheppen, en ook voor de regulering van platformen.

Dit proefschrift onderzoekt *hoe platformparticipatie en platformprestatie aan elkaar kunnen worden gerelateerd*. Participatie refereert aan de totstandkoming en het gebruik van een technologie. Vanuit het economisch perspectief heeft prestatie vooral betrekking op financiële indicatoren zoals inkomsten of winst. Prestatie kan ook door middel van andere indicatoren worden weergegeven zoals, bijvoorbeeld, participatie van complementaire partijen of gebruikers. In markten die worden gekenmerkt door netwerkeffecten zijn prestatie en participatie nauw verbonden: de huidige platformparticipatie verhoogt de waarde die het platform aan toekomstige gebruikers biedt.

Het proefschrift bestaat uit vier hoofdstukken die gezamenlijk de onderzoeksvraag beantwoorden vanuit verschillende perspectieven: evolutionaire economie, platform economie, en strategisch management. Het proefschrift bestaat uit conceptuele (hoofdstukken 2, 5 en gedeeltelijk 3) en empirische onderzoeken (hoofdstukken 3 en 4).

Hoofdstuk 2 vergelijkt platformen met het gerelateerde concept *dominant design*. *Deze b*eide concepten kunnen worden beschouwd als structurele metaforen die verwijzen naar de constellatie van technologische systemen en betrokken actoren. Meerdere concepten zijn ontstaan sinds economen zich bezighielden met het openen van de ‘black box’ van technologie. Het hoofdstuk presenteert een raamwerk waarmee concepten systematisch kunnen worden vergeleken. Het bespreekt gemeenschappelijke aspecten (bijv. hun structuur die bestaat uit een kern en periferie), en diverse verschillen (bijv. gradaties van openheid), en eindigt met een agenda voor toekomstig onderzoek.

Hoofdstuk 3 identificeert antecedenten en factoren die van invloed zijn op zowel platform prestatie als –participatie. Zij vormen een inventarisatie van aspecten die in de praktijk van belang kunnen zijn. Hoofdstuk 3 bevat een systematisch literatuuronderzoek van academische stromingen omtrent de selectie van technologieën, en vat deze samen in een raamwerk. Het raamwerk wordt toegepast in de context van *additive manufacturing* (ook wel *3d-printing* genoemd) en de factoren worden gerangschikt naar gewicht gebaseerd op meningen van experts. De factoren 'vraag', 'relatieve technologische prestatie', 'betrokkenheid', en factoren omtrent het 'bedrijfsmodel' blijken het meest belangrijk. Dat de meest belangrijke factoren uit verschillende literatuurstromingen voortkomen, kan worden gezien als een bevestiging van de toegevoegde waarde van het raamwerk.

Na het vergelijken van verschillende concepten (hoofdstuk 2) en het inventariseren van factoren (hoofdstuk 3), legt hoofdstuk 4 de focus op specifieke aspecten van platform strategieën. Een belangrijke functie van platformen is het verbinden van complementaire partijen om zo te komen tot een groep van complementaire producten. Hoofdstuk 4 bestudeert een aantal strategieën die kunnen worden toegepast om meer complementaire partijen aan te trekken. Het bestudeert hoe door de platform aangeboden hulpmiddelen en externe hulpbronnen (*boundary resource* genoemd), het onderscheidend vermogen van het platform (gebaseerd op exclusieve aanbod aan inhoud), en de breedte van de aanbiedingen, van invloed zijn op de participatie van toekomstige complementaire partijen.

Hoofdstuk 5 legt de nadruk op de relatie tussen platformparticipatie en -prestatie. In markten die worden gekenmerkt door netwerk effecten wordt vaak verondersteld dat de grootte van het netwerk doorslaggevend is voor succes van het platform. Echter recentelijk is men tot de conclusie gekomen dat een ander aspect, namelijk het onderscheidend vermogen van het platform (*distinctiveness*) ook een strategische opties is voor platformen. De connectie tussen deze twee dimensies is tot nu toe onderbelicht. Hoofdstuk 5 bouwt hierop voort en conceptualiseert, met behulp van de strategische balanstheorie, hoe de schaal van platformen door onderscheidend vermogen wordt beïnvloed. Het hoofdstuk sluit af met richtingen voor verder onderzoek.

Tenslotte vat hoofdstuk 6 de wetenschappelijke bijdrage samen. Het proefschrift draagt in het kort bij aan de volgende velden:

- aan platformeconomie en evolutionaire economie, door de literatuurstromingen omtrent platformen en dominant designs te vergelijken, en door synergiën tussen de stromingen voor te stellen;
- aan innovatiemanagement, door raamwerken omtrent de selectie van technologieën te weer te geven en nieuwe factoren betreffende kennis, opleiding, verspreiding, en bedrijfsmodellen te combineren;
- aan platformeconomie, door strategieën voor het creëren van een complementor ecosysteem te testen en te vergelijken;
- aan optimaal onderscheidend vermogen theorie en platformeconomie, door de concepten platformprestatie en platformparticipatie te ontrafelen, en door de schaal van platforms expliciet in platform onderscheidend vermogen en strategisch balans theorie te integreren.

Het proefschrift heeft factoren en hun potentiele effect op technologieselectie en complementor participatie onderzocht. Het onderzoek kan in meerdere richtingen worden voortgezet. Ten eerste zouden deze factoren met betrekking tot efficiëntie kunnen worden vergeleken door ook kosten expliciet te beschouwen die gepaard gaan met het aanpakken van de factoren. Een tweede richting relateert aan veronderstellingen omtrent concurrentie tussen platformen. Vaak wordt aangenomen dat concurrentie tussen platformen plaatsvindt. In veel markten vindt concurrentie plaats tussen platformen, niet-platform organisaties en hybride organisaties. Ten slotte zou de integratie van de schaal van platformen in optimaal onderscheidend vermogen theorie uitgebreid kunnen worden door een dynamisch perspectief te kiezen.

Glossary

Boundary resources: tools and regulations that serve as an interface between platform owners and complementors (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Petrik & Herzwurm, 2020)

Breadth of content offerings: relates to the variety of markets that a platform is represented in via complementary products.

Complementors: the producers of complementary products and services, such as apps in the context of Apple iOS.

Dominant design: When it emerges, it defines what form and features users will expect from future products (Abernathy & Utterback, 1978). It is part of the technology cycle and ends the era of ferment and initiates an era of incremental technological change (Tushman & Murmann, 2002)

Ecosystem: "... set of actors with varying degrees of multilateral, nongeneric complementarities that are not fully hierarchically controlled" (Jacobides et al., 2018, p. 2264) that are intermediated by a platform.

Exclusive content: is content (for instance, complementary products) that is only published on the focal platform (Cennamo & Santaló, 2013; Corts & Lederman, 2009; A. Srinivasan & Venkatraman, 2010)

Increasing returns: "... the tendency for that which is ahead to get further ahead, for that which loses advantage to lose further advantage"(Arthur, 1996, p. 100).

Indirect network effects: occur if the value offered to users on at least one side depends on the number of users on another side. These occur if "the benefit to users in at least one group (side A) depends on the number of other users in the other group (side B). An indirect network effect arises if there are cross-group network effects in both directions (from A to B and from B to A) and side B's participation decision depends on the number of participants on side A so that the benefit to a user on side B depends (indirectly) on the number of users on side A" (Hagiu & Wright, 2011, p. 5)

Network effects: "The circumstance in which the net value of an action (consuming a good, subscribing to telephone service) is affected by the number of agents taking equivalent actions..."(Liebowitz & Margolis, 1994, p. 135)

Organizational identity: concerns what others believe an organization to be, or what it claims to be (Ravasi et al., 2020), and its "members 'consensual understanding of 'who we are as an organization'" (Nag et al., 2007, p. 824)

Participation: refers to installing and using a technology both at the end-consumer level and at a more aggregate level based on market mechanisms.

Platforms: are "meta-organizations that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery" (Gawer, 2014, p. 1239)

Platform owner: the focal firm that manages an ecosystem surrounding its platform by regulating access to the platform and creating governance arrangements (Adner, 2017).

Side: different collections of actors intermediated by the platform. The term side does not imply that these are necessarily different groups of actors, as actors can be active across multiple sides. For instance, in the case of eBay, an actor can be active both as a seller (side 1) and a buyer (side 2).

Structural metaphors: such as dominant design or platforms, hint at the constellation of technological systems and the involved actors (Gillespie, 2010).

Technology cycle: a cyclical pattern of technology development – periods of variation (eras of ferment) initiated by technological discontinuities, are closed by the selection of a dominant design and may eventually be overturned by the next technological discontinuity (Anderson & Tushman, 1990)

List of abbreviations

3DP	Three-dimensional printing
AHP	Analytic Hierarchy Process
AIC	Akaike information criterion
AM	Additive manufacturing
BIC	Bayesian information criterion
BWM	Best-worst method
DMD	Direct metal depositioning
DMLS	Direct Metal Laser Sintering
DOI	Diffusion of innovation
EBAM	Electron Beam additive manufacturing
FE	Fixed-effects
ICT	Information and communication technology
IGDP	The Internet Game Database
IP	Intellectual property
MCDM	Multi-criteria decision-making
MLE	Maximum-likelihood estimator
MOOC	Massive open online course
MSP	Multi-sided platform
NB	Negative-Binomial
OD	Optimal distinctiveness
SLS	Selective laser sintering
SME	Small and medium-sized enterprises
VIF	Variance inflation factor
WTA	Winner-take-all

Chapter 1

Introduction

The present dissertation investigates how platform participation and platform performance are related to each other. The present chapter introduces the focus of the dissertation, technology platforms. It defines platforms, explains how platforms work, and lays out their main characteristics. It then introduces the research problem and objectives and sketches the primary literature streams the dissertation draws on to address the research problem. The last section of this introduction provides an overview of the remaining chapters.

1.1. Platform ecosystems

This dissertation analyzes how platform participation and platform performance are related to each other. Platform-based businesses create value by enabling interactions between third-party producers of complementary products. The platform's primary purpose is to create value for all participants (Parker et al., 2016). More formally, platforms have been defined as "evolving organizations or meta-organizations that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery" (Gawer, 2014, p. 1240). All the actors linked to the platform are referred to as *platform ecosystem*.

Typically, a platform ecosystem consists of several kinds of roles (Dedehayir et al., 2018) – a platform owner, platform provider,[1] third-party producers called complementors, and consumers (Van Alstyne et al., 2016). The platform owner is the focal firm that creates governance arrangements that participants in the periphery must follow if they wish to participate in the platform (Eisenmann et al., 2009). The platform provider supplies the interface for the platform (e.g., Android as a platform runs on smartphones by multiple producers). Third-party producers, called *complementors*, make complementary products that consumers demand.

Although mostly associated with the digital age, platforms have been around for a long time. The oldest examples of platforms are early market squares in the middle of a city which have existed for millennia (Martens, 2016). Sellers and buyers would exchange goods on these markets, usually overseen by the village chief, who may collect taxes to use physical space on the market. More recent examples that also precede the (largescale) diffusion of the internet are printed yellow pages (Rysman, 2004) or shopping malls (McIntyre & Srinivasan, 2017). Yellow pages contain ad-based business directories that are valuable to consumers because of the information provided and valuable to businesses due to the opportunity to advertise to customers. Shopping malls are valuable to shoppers by offering a variety of shops under one roof, while vendors are attracted to a diverse group of shoppers.

To a large extent, the strength of platforms stems from third-party offerings such as third-party games developed for Facebook, the countless apps developed for smartphones, or offerings by market stalls on traditional markets. Think of

1 Also called platform leader or platform sponsor

Apple's iOS platform: Owners of iPhones running on iOS are offered many apps that cater to all needs. Next to offering the apps, a value-creating transaction is enabled via the AppStore. The different groups of users connected via the platform are referred to as *sides*. Connecting these different sides (e.g., smartphone users that want to use apps, and app developers) creates value for both. As more users demand apps, it becomes more attractive for app developers to join, and vice versa.

These examples have in common that they feature feedback loops between the connected sides. These feedback loops are called *network effects*. A market square with more sellers offers more choice to customers, and likely attracts more customers. More customers, in turn, mean higher sales and likely attract more vendors. Mind that these feedback loops may also spiral downwards – as recently seen in the demise of shopping malls (Evans & Schmalensee, 2016). Fewer shoppers decrease sales for vendors, which makes it less attractive to run a shop in the mall. Eventually, some shops will close, making the mall less attractive to customers.

Although somewhat similar, there is a crucial difference between old examples of platforms and modern platforms as complex socio-technical artifacts. Older platforms differ from digital ones because they typically cannot learn from aggregation at the transaction level (Choudary, 2016). Shopping malls have been able to track streams of people but did not learn from every transaction in the mall. The advent of the internet and information technology has changed that and allowed platforms to internalize transactions. Airbnb learns from every interaction (such as a search) on its platform and can hence improve its services. Alternatively, compare Uber to the traditional way of using a cab: Earlier, one would wave at a taxi to signal the demand for a ride. Now, all this takes place in Uber's app, and Uber can learn from its users' activities.

The advent of the internet has also changed the requirements for setting up and running a platform (Van Alstyne et al., 2016). The need for physical infrastructure and asset ownership is strongly reduced, making it easier to scale up platforms. As participation increases, the platform's services improve, making future participation more effortless. Airbnb, for example, improves the efficiency of future intermediations by collecting reviews of offerings. Reviews allow hosts to build a reputation and guests to choose accommodations more efficiently. With a much lower dependence on infrastructure and assets, the operations of digital platforms are less constrained by geography. For instance, listings can be added to Airbnb independent of the listing's location. Based on this model, Airbnb has surpassed all major hotel chains in market capitalization, being worth more than Marriot, Hilton, and Intercontinental together (Sonnemaker, 2020). Together, these characteristics mean that modern-day platforms can be more easily set up, scale quicker, and hence are more dynamic than analog platforms.

In that sense, platforms are multi-facetted phenomena:

1) Platforms are *technological systems*. The term platform is used in various contexts (Gillespie, 2010), but this dissertation focuses on technology platforms. The technology behind a platform is usually organized in a modular fashion (Baldwin & Clark, 2004). Platforms consist of stable components at the core upon which innovation occurs on modules by using stable interfaces (see Chapter 4), as in the case of mobile apps, that connect via interfaces to the operating system. Technology, as understood here, comprises both software and hardware. Viewed as a technological system, the platform consists of a technological core of both hardware and an ecosystem of complementors that build on the core (de Reuver et al., 2018)

2) The *social side* of platforms. Platforms, however, also comprise organizational processes and standards in addition to the technological elements (described in 1)). For instance, access to the platform is a requirement for complementary products by third parties and is regulated through the provision of boundary resources, such as application programming interfaces (APIs) or standards. The diverging interests between different platform sides require alignment by the platform owner.

3) Platforms *are innovations* and *enable innovations*. A platform must be adopted and selected by these different sides to succeed. It is because of this reason that this dissertation refers to *participation*. It includes aspects that earlier would have been addressed separately and may have fallen under labels such as selection or adoption. Adoption and selection as terms stem from different academic streams and carry different connotations. Roughly speaking, both terms refer to installing and using a technology (or service). Adoption does that at the end-consumer level. Selection takes place at a more aggregate level, studying groups focusing on market mechanisms. Growing a platform hence requires the involvement of various sides and actors, as opposed to many durable goods that are marketed to only one group.

In this dissertation, platforms are considered managerial artifacts. Some platforms may be proprietary, meaning that the platform owner possesses the intellectual property (IP) and manages access to the platform (Van Alstyne et al., 2016). Next to their function as intermediaries, platforms also perform the role of gatekeepers by strategically influencing the type and quantity of complements and complementors they attract to their platforms (Claussen et al., 2013). This type of platform is not fully hierarchically controlled (Jacobides et al., 2018), meaning that all members of the platform ecosystem retain some control. At the same time, this dissertation focuses on platforms that can be assumed to exhibit platform-level management and strategizing. It is not ruled out that decision-making is, to some extent, distributed (Jacobides et al., 2018), but it does assume some hierarchical control over the core with influence over the periphery.

Further, a business element is present in the type of platforms that are the focus of this dissertation. Actors participate at least partially with the expectation of material incentives and not purely out of intrinsic and social motivations. Examples of platforms not belonging to the type described above are open-source software (OSS) platforms such as Drupal. Founders of OSS platforms usually exert leadership (Raymond, 1999). However, on the module level, most of the platform is developed in a peer-to-peer production manner based on intrinsic, social, and non-material incentives (Benkler, 2017).

Still unanswered is the question whether the concept of platforms indeed describes a different entity than more traditional units and levels of analysis, such as the organizations. Non-platform organizations derive power and control from ownership of assets and production equipment. In contrast, platforms derive power and control from ownership of the technological architecture that forms the platform's core (Kretschmer et al., 2022). Third parties participate because the platform owner's coordination, which is possible based on its central position, offers the prospect of greater rents. These coordination efforts by the platform owner offer greater value than what platform ecosystem participants would be able to achieve based on dyadic cooperation (Wareham et al., 2014).

Incentives in platform ecosystems differ from those in organizations as business participants transact directly and are rewarded via these transactions rather than receiving salaries (Kretschmer et al., 2022). In non-platform organizations, decisions are made via tight hierarchies. Platform ecosystems, in contrast, are populated by autonomous individuals or organizations who independently make decisions within the rules and resources of the platform. Through boundary constraints, incentives, and communication channels, the platform provider defines what participants can do and how they are compensated, but the participants decide whether and how they will contribute.

1.2. Different types of platforms

Several different types of platforms exist. Based on the primary outcome achieved by the platform, Cennamo (2021) distinguishes three types of platforms: *transaction platforms*, *information platforms*, and *complementary innovation platforms*. Multi-sided transaction platforms mainly provide computational and networking resources that allow participants to meet their service and content needs (Constantinides et al., 2018). It connects providers of goods or services with their final customers and facilitates transactions between these parties (Rochet & Tirole, 2003). Examples of such platforms are eBay (facilitating auctions and transactions between sellers and buyers of products or services) or Uber (facilitating matching and transactions between people seeking a ride and drivers). Sellers benefit from joining such a platform by being exposed to many potential customers. Customers benefit from exposure to a wide variety of goods and services sellers offer. The platform intermediates by providing search and curation tools that facilitate finding a suitable offering or customer.

Information platforms mainly function as “information-channeling infrastructures” that enable the search and categorization of relevant information, and the matching and information exchange (Cennamo, 2021, p. 270). Google search, Twitter, and Facebook all provide this type of function. Across these examples, the platform filters and groups information to make it relevant to users. Also, the platform facilitates sharing, interacting, and engaging with information, and connecting with other users, based on shared interests. The value offered to users predominantly depends on the quality of information. Unlike transaction platforms, there are no monetary transactions between users on information platforms. These monetize information flows by offering indirect services such as advertising (Seamans & Zhu, 2014).

Complementary innovation platforms function as innovation engines by providing the technological core architecture on which others build to create additional functionality (Gawer, 2014). The platform’s modular design based on a more stable core and a more variable periphery allow for a division of innovation tasks and labor (Baldwin & Woodard, 2009). The core constitutes the platform, and the periphery of firms specialized in complements is referred to as the ecosystem. The platform ensures ex-ante connectivity and product system integration (Cennamo et al., 2018) so that complementarities arise between the core and the provider of external functionality. Examples are

Apple's iOS platform, which serves as the basis for developing innovative applications that extend the productivity and entertainment capabilities of the device (Cennamo, 2021). These platforms can be seen as a new organizational form of innovating and creating complementarities in assets (Gawer, 2014; Thomas et al., 2014).

1.3. Research problem

What has led to market power and growth of platforms? Understanding this is important if we want to create platforms where they are beneficial to economy and society and counteract or regulate them where they are harmful (Cusumano et al., 2021). This dissertation studies *how platform participation and platform performance are related to each other*.

Performance is the dependent variable of this study. From the economics perspective, performance includes mostly financial indicators such as revenues or profit. However, it can also concern other indicators, for instance, the participation of complementors or users. Under network effects, current participation increases the platform's value to future users, which is closely linked to performance. We refer to participation to acknowledge that platforms must attract two if not more groups of complementors and users to the platform to succeed. It also entails that these roles may be fluid – an actor can simultaneously be a user and a complementor or change sides over time. Participation includes aspects that earlier would have been labeled separately, and may have fallen under labels such as selection or adoption (see Section 1.1).

This dissertation has the following objectives:

- Increase our understanding of platforms with related concepts by studying their antecedents and outcomes as dealt with in the literature
- Increase our understanding of how specific antecedents affect participation in and performance of platforms

1.4. Theoretical perspectives

This dissertation draws on several theoretical perspectives to answer the main research question and achieve its objective. The following paragraphs outline the main perspectives. This section starts with sketching the literature streams that have evolved around the central phenomenon of this dissertation, platforms. Broadly speaking, it builds on and contributes to two perspectives: platform economics, and evolutionary economics.

Platform economics. The first perspective emphasizes the value a platform offers to users (Gawer, 2014). This view stresses platforms as intermediaries – multisided platforms emerge to facilitate transactions between distinct sides affiliated with the platform. This stream is often thought to have its roots in network economics (Cusumano, 2022; Gawer, 2014). Network effects play an essential role, with the underlying assumption that platforms operate under *positive feedback* (Katz & Shapiro, 1985) and increasing returns (Arthur, 1989). That is, a platform is more attractive to complementors the more users it has, which increases the value to users (Cusumano & Gawer, 2002). The notion of indirect network effects, which is the value to one side of users due to the presence of the other, has been the underpinning of many studies on multi-sided platforms (Evans, 2003; Rochet & Tirole, 2003, 2006).

Scholars have studied management and strategizing of platforms at several levels. Some have focused on platform-level strategy and management by centering around the *platform owner*. Research has focused on strategic aspects of platform leadership (Cusumano & Gawer, 2002; Gawer & Henderson, 2007), such as entry timing (Chintakananda & McIntyre, 2014), or pricing strategies and quality considerations (Claussen et al., 2015). Much emphasis is placed on the installed base as a critical asset in platform competition, but recent advances suggest a more nuanced view. User loyalty or strong ties may be more critical than the size of the installed base (Afuah, 2013; Fuentelsaz et al., 2015).

A second perspective, ecosystem-level management and strategy, stresses interactions and complementarities among the platform's different user groups (McIntyre et al., 2020). The platform ecosystem comprises the platform leader[2] and

2 It may sound redundant to mention the platform leader. However, there are platform-less ecosystems (Jacobides et al., 2018), and streams of research referring to the concept of ecosystems that do not focus on the notion and phenomenon of platforms.

all producers of complementary products (Jacobides et al., 2018). This perspective is relatively young – many studies have been published after 2010, and influential conceptual contributions are only a couple of years old (Adner, 2017; Jacobides et al., 2018). Recent advances characterize the nature of complementarities, what holds ecosystems together, and contrasts with platforms (Jacobides et al., 2018).

A central question in this stream is how to create an ecosystem and, specifically, how to attract complementors to the platform (Cennamo & Santaló, 2013; McIntyre & Srinivasan, 2017). Research stresses platform openness for complementor attraction (West, 2003) or how the technological architecture of a platform interacts with governance principles and influences platform evolution (Cennamo et al., 2018; Gawer, 2014). Implicitly, this stream emphasizes the federative aspect of platform ecosystems (Gawer, 2014) – meaning that actors must be gathered or joined together before they can be orchestrated or governed. In that respect, this view is complementary to the network economics view, which carries the tacit assumption of pre-existing sides ready to be intermediated.

The economic perspective on platforms, especially the platform owner and ecosystem perspective, has a strong actor-centric and cross-sectional perspective. All chapters of this dissertation draw to some extent on the literature on platforms, especially Chapters 2, 4, and 5.

Evolutionary economics. Technology selection is the process of selecting one technological solution out of various alternatives based on market mechanisms. Scholars of various backgrounds have stressed the importance of technology for organizational outcomes (Tushman & Murmann, 2002). It is recognized that technological change is one of the main instigators of industrial, strategic, and organizational change (Henderson & Clark, 1990; Tushman & Anderson, 1986). Nevertheless, economists have long treated technological development as inside a *black box*. In the 1960s, some economists argued that one had to look at the inner workings of technologies and not only at their performance characteristics in order to understand economic change (Murmann & Frenken, 2006). Scholars such as Abernathy, Utterback, and Rosenberg were among the first who worked on the opening of the black box of technology. Understanding this black box is essential for firms to prosper in competitive markets (Rosenberg, 1976; Rosenbloom & Christensen, 1994).

The dominant design is a central concept in studying the interaction between technology and organizations. When a dominant design emerges, it defines what form and features users will expect from future products (Abernathy & Utterback, 1978). The dominant design marks a shift from radical to incremental product innovation with more intense price competition and an increased focus on process innovation starts. However, the dominant design might have a limited life – it can be disturbed by a so-called technology shock, which evolutionary economists define as another technology that substantially increases production output (Shea, 1999).

This thinking is grounded in the observation that technological progress is based on trial and error. When a new product class emerges, the technology's inherent potential and its anticipated users' needs are unknown. Creating different designs and introducing them to the market is one crucial way to reduce uncertainty (Pinch & Bijker, 1984). Thus, technology selection strongly focuses on market mechanisms as the drivers of change.

Technology selection focuses on the evolution of industries resulting from technology development. Technologies are conceptualized as nested, consisting of a hierarchy of core and peripheral systems. Empirical studies have focused on when shifts in industry dynamics occur relative to the selection of a dominant design (Argyres et al., 2015), survival (Suarez & Utterback, 1995), or the performance effects of design adoption relative to dominant design selection (Park et al., 2018).

While this view promotes a view of technologies against their industry context, which is useful for analytical and descriptive purposes, it has little emphasis on the manager and carries little room for agency (Gawer & Cusumano, 2014). Little emphasis is put on actors in the system – dependencies follow from the modular and hierarchical design of the technology. Core and more peripheral systems are connected through linking mechanisms.

All tastes of platform research described so far focus on cross-sectionalism, highlighting the complementarity with the technology selection view. It is precisely this longitudinal aspect that makes this perspective complementary to the platform ecosystem literature. The perspective of technology selection is mainly used throughout Chapters 2 and 3 of this dissertation.

1.5. Research questions and dissertation outline

The main research question (how are platform participation and platform performance related to each other) is addressed by investigating four sub-questions (see Figure 1-1).

Platforms are a relatively recent phenomenon, but the constellation of technologies and actors, or even broader, the evolution of industries, has been dealt with earlier and under other labels. Concepts like platforms or the related *dominant design* (Gawer & Cusumano, 2014), but also the increasingly popular concepts of *ecosystems* (Jacobides et al., 2018), can be seen as *structural metaphors* (Gillespie, 2010). Structural metaphors hint at the constellation of technological systems and the involved actors. The concept of a platform joins the ranks next to other structural metaphors, such as dominant designs. As a concept in business, management, and strategy, the concept of platforms indeed has descriptive value. Though, it is recognized that concepts are also used for their discursive value, which may change over time. For instance, in 2007, YouTube stopped calling itself a *service*, *website*, or *forum*, and started going by *distribution platform* (Gillespie, 2010). Chapter 2, hence, contrasts the concept of platforms with another structural metaphor, dominant designs. It reads as follows:

RQ1: *What are the systematic differences and commonalities between dominant designs and platforms*?

Chapter 2 seeks to increase conceptual clarity through contrast with the concept of dominant designs. Based on the central contributions of both fields, this study reveals the intellectual foundations and introduces the theoretical perspectives that are most used in this dissertation, namely network economics and engineering design (Gawer, 2014). First, network economics analyzes instances where one technological innovation's value to its users depends on the number of users. In such situations, self-enforcing feedback loops may arise. Such feedback loops can arise within and across groups of users. Second, engineering design has its roots in complexity theory and focuses on technological architectures, i.e., the arrangement of technological components. Modularity is the building of a complex system of smaller subsystems that can be designed independently (Baldwin & Clark, 1997). As a review, this chapter focuses purely on the relation between dominant designs and platforms by disentangling the causes, mechanisms, and outcomes through which the outcomes materialize.

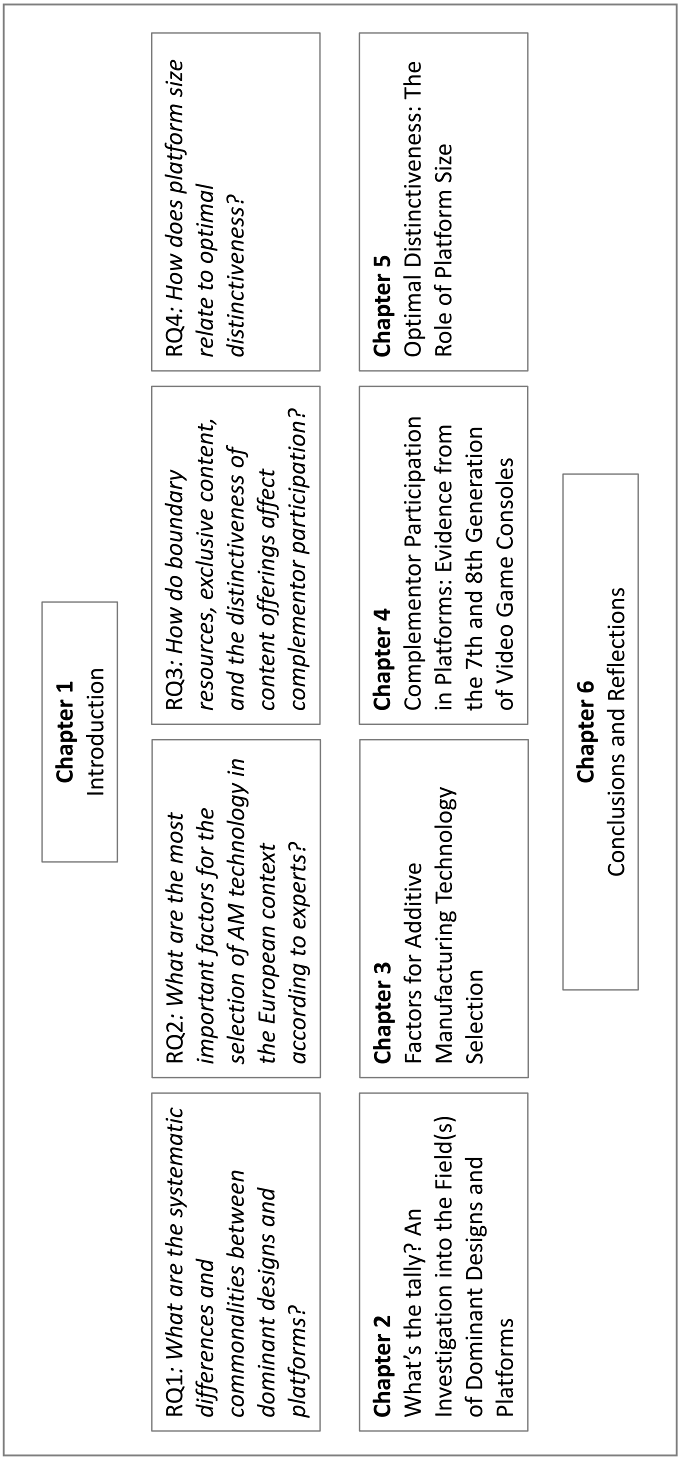

Figure 1-1. Dissertation outline.

Whereas research question 1 focuses on adopted and selected constructs, question 2 focuses on the antecedents or *factors* that influence performance and participation. Decomposing a diffuse concept like strategy into factors is a way to make it manageable. These factors can be seen as determinants of participation and technological innovation performance, providing an inventory of topics that managers may want to address. The second question hence reads as follows:

RQ2: *What are the factors for the selection of technological innovations*?

Chapter 3 addresses this question and, compared to the first question, broadens the scope, encompassing all ingredients of this dissertation's main research question. Research in various domains relevant to this dissertation has focused on frameworks of factors for the adoption and selection of technological innovations, such as standard dominance (van de Kaa et al., 2011), technology diffusion (Ortt, 2010b), business models (e.g., Demil & Lecocq, 2010; Joyce & Paquin, 2016), and technology acceptance (Davis, 1989). Chapter 3 reviews these literature streams concerning factors for the participation and performance of technological innovation. The literature study resulted in a comprehensive framework of factors for the participation in and performance of technological innovations. Prioritizing these factors in the context of AM in Europe based on expert opinions showed that business-model related factors, the relative performance of the technological innovation, commitment by the innovating party, and market demand are most-important.

After reviewing platforms and related literature (RQ1) and inventorying factors (RQ2), research question 3 zooms in on specific aspects of platform strategy. It addresses the availability of complementary goods and services as a key feature of platforms. It highlights the federative aspect of platforms (Gawer, 2014) by focusing on the attraction of complementors to the platform's ecosystem. Research question 3 studies how tools and resources offered by the platform (called *boundary resources*), the platform's distinctiveness strategy (based on *exclusive content*), and the breadth of its content offerings affect the participation of future complementors:

RQ3: *How do boundary resources, exclusive content, and the distinctiveness of content offerings affect complementor participation*?

Chapter 4 studies how platforms act as facilitators of innovation and mediators. Chapter 4 studies these three aspects of a platform's complementor strategy in the context of home video game consoles. It shows that breadth of content offerings, and boundary resources are related to the participation of future complementors.

The last research question rivets on the relationship between participation and performance. In the presence of network effects, feedback loops between current and future size may be set off, potentially leading to winner-take-all outcomes. Based on this mechanism, many platform studies have equaled participation (in terms of size) with the platform's performance. However, it has rarely been considered how platforms strategy depends on size. Hence:

RQ4: *How does platform size relate to optimal distinctiveness*?

Chapter 5 focuses on platform size and its relevance to strategy. Recent theoretical advances hold that platforms comprise a second strategic dimension next to size, called distinctiveness, which describes the platform's technological and market scope. Letting go of platform size as the primary criterion for platform value allows platforms to pursue differentiation strategies with a distinct market positioning. The concept of optimal distinctiveness (OD) implies that differentiation can be optimized to maximize performance. This chapter draws on recent OD research and elaborates on the role of platform size within the distinctiveness framework. Chapter 5 develops a refined conceptual model and suggests propositions for future research.

Chapter 2

What's the tally?
An Investigation into the Field(s) of Dominant Designs and Platforms

This chapter is co-authored with Roland Ortt, Geerten van de Kaa, and Cees van Beers. An earlier version of this paper is published as: Sobota, V. C. M., Ortt, R. J., Van De Kaa, G., & Van Beers, C. (2022). What's the tally? An investigation into the field(s) of dominant designs and platforms. *Proceedings of the 55th Hawaii International Conference on System Sciences*. Hawaii International Conference on System Sciences. https://doi.org/10.24251/HICSS.2022.818

Abstract

Dominant designs and platforms are two distinct scientific fields analyzing innovation and competition between technologies. Responding to calls for more synthesis in management research, we study the commonalities and differences between the fields surrounding these concepts. To this end, we develop a framework for comparing concepts and apply it to dominant designs and platforms. We show that dominant designs and platforms differ most prominently regarding their central mechanisms, unit and level of analysis, and timeframe. We elaborate on how they are complementary by developing a research agenda.

2.1. Introduction

In this chapter, we examine the systematic differences and commonalities between *dominant designs* and *platforms*. Dominant designs and platforms define complex technological infrastructures and connect to distinct approaches to studying technological innovation and competition. Currently, the term platform enjoys great popularity among scholars and practitioners (e.g., Gawer, 2014; Thomas et al., 2014; Zhu & Iansiti, 2019). Dominant designs (Abernathy & Utterback, 1978; Utterback & Abernathy, 1975) had their bloom earlier (Anderson & Tushman, 1990; Christensen et al., 1998), eking out a niche existence in current days.

Platforms are meta-organizations that orchestrate loosely coupled parties and facilitate economies of scale and scope (Gawer, 2014). Dominant designs are persistent architectures that define core design concepts (Gallagher, 2007). Despite their lagged development, there is good reason to assume that dominant designs and platforms as concepts are at least complementary. Table 2-1 compares the two streams based on their focus, how closed or open they are, how they relate to change over time, and to application in different domains.

Table 2-1 shows that both dominant designs and platforms deal with broadly applicable *technologies* used by different actors for different purposes. These technologies are mostly *not stand-alone* – many actors must come together to create a solution that works reasonably well *across different application domains*. The requirements of these domains *change over time*, and so do technologies.

Table 2-1. Complementarity between dominant designs and platforms.

	Dominant Design	**Platform**
Example	Automotive, airplane	eBay, Apple iOS,
Focus	Technological product/artifact	ICT-enabled service/ product, actors
Closed/ open	Complex systems, sometimes closed and hence at times stand-alone	Complex systems, often open, practically never stand-alone
Change over time	Explicit longitudinal perspective	No explicit focus on longitudinally
Application across domains	Multiple related applications for one product class, subsequent applications over time	Multiple related applications, alternative applications at one point in time, customization based on complements

In studying these technologies, the field of platforms focuses on purposefully aligning loosely coupled actors that contribute complementary products and services towards a central value proposition (Jacobides et al., 2018). For instance, Apple relies on third-party developers to produce apps for its iPhone based on its operating system, iOS. The field of dominant designs takes an evolutionary perspective that achieves coordination by settling on a value proposition's core design specifications (Gallagher, 2007). These are developed by trial and error in different application domains. An early example of a dominant design is the pneumatic-tire safety bicycle that emerged in the late 19th century (Dowell & Swaminathan, 2006). Similar to today's bicycles, this early dominant design consists of a diamond frame, a rear-wheel chain drive, and same-size pneumatic rubber tires.

With an interest in complementarities at the intersection of both fields, we first answer the following question: *What are the systematic differences and commonalities between dominant designs and platforms*? To answer this question, we sketch the development of the fields, construct a review framework to systematically compare the fields, and elaborate on the differences and commonalities. We then integrate the fields and propose directions for future research.

We find that platform research focuses on platform-internal coordination and competition between platforms and does not explain why platforms emerge. Dominant design thinking focuses on the successive dominance of designs, dubbed technology cycle. We integrate these differences into a research agenda that addresses platform design and management against the context of evolutionary mechanisms on various levels of analysis.

The central question of this chapter has been hardly investigated so far. It is relevant as, in the last decades, technological innovations have been increasingly used and applied in the framework of technological systems. In these contexts, technological innovations work together, change over time, and cater to different application domains. This corresponds to mechanisms that work in platforms and dominant designs.

The chapter is structured as follows. Section 2.2 gives an overview of the literature on dominant designs and platforms. In Section 2.3, we report the systematic search and selection procedure of key articles for the review. We develop a framework and use it to systematically compare the literature on dominant designs and platforms based on definitions found in the reviewed papers. Section 2.4 presents the results based on differences and commonalities of the fields along criteria from the review framework. The discussion in Section 2.5 reflects on the differences and commonalities between the fields and suggests areas for future research. Section 2.6 reports conclusions.

2.2. Overview of the literature

The concepts of dominant designs and platforms stem from different literature streams. These streams, in turn, are not homogeneous. Dominant designs are seen as static (e.g., Abernathy & Utterback, 1978) and dynamic (e.g., Anderson & Tushman, 1990), while the literature on platforms draws on fundaments originating from economics (e.g., Evans, 2003) and management (e.g., Meyer & Lehnerd, 1997).

2.2.1. Dominant designs

Dominant design research emerged from scholarly interest in the interaction between organizations and the environment (Tushman & Anderson, 1986). In the 1960s, some economists argued that one had to look at the inner workings of technologies and not only at their performance characteristics in order to understand economic change (Murmann & Frenken, 2006). Scholars such as Abernathy, Utterback, and Rosenberg were among the first who worked on the opening of the 'black box' of technology. Dominant design thinking is rooted in the observation that technological progress is based on trial and error. When a new product class emerges, the technology's inherent potential and its anticipated users' needs are unknown. Experimentation and market introductions of designs are ways to reduce uncertainty, next to the involvement of users in the design process (Thomke & von Hippel, 2002).

Abernathy and Utterback (1978) and Abernathy (1978) introduced the concept of dominant designs. Their initial understanding of a dominant design entails that it marks the turning point at which an industry transitions from unique products to mass-production manufacturing. This transition follows several steps (Abernathy & Utterback, 1978, p. 2):

- Fluid pattern. In this phase, many small firms compete by introducing their product designs to the market. Firms compete at the design level, meaning that firms experiment with the product's form and characteristics. Creating a design with broad appeal offers the possibility to meet the needs of a wide range of consumers.
- Transitional stage. A design amasses a substantial market share and becomes the dominant design. The focus of competition moves from the design level to the subsystem level.

- Specific pattern. Following the selection of the dominant design, competitors are forced to imitate this dominant configuration. New developments concentrate on incremental innovation. Innovations become cumulative, and competition shifts from product differentiation to pricing.

These steps are visible in the emergence of the pneumatic-tire safety bicycle as the dominant design (superseding the safety bicycle with solid tires) (Dowell & Swaminathan, 2006). Before the pneumatic-tire safety bike emerged, cycling was a niche activity, and only few firms offered bicycles. But the emergence of the pneumatic-tire safety bike introduced cycling to the masses and resulted in an inrush of companies. The safety bike overcame the drawbacks of the solid-tire bicycle and offered light running and more comfort based on pneumatic tires. With increasing demand, an inflow of producers brought prices down, further fueling demand. At the same time, increasing cost pressure on producers led many firms to withdraw from the business (Dowell & Swaminathan, 2000). Improvements in subsystems accompanied this process. Initially, pneumatic tires were disputed due to safety concerns arising from frequent ruptures (Bijker et al., 1987). Improvements in subsystems such as pneumatic tires or chain drives eventually meant that this design outcompeted other designs on most aspects relevant to users. After selecting the pneumatic-tire bicycle as the dominant design, these improvements helped to further manifest its position relative to other designs.

The example of the safety bicycle also highlights the focus of dominant designs on subsystems. Dominant designs are usually conceptualized at the product level based on a set of subsystems. It is the "weight of many innovations that tilted the economic balance in favor of one approach" (Abernathy (1978), as cited in Christensen et al., 1998, p. 210). Various researchers followed this conceptualization of the dominant design as the best synthesis or package of existing innovations that dominate others (e.g., Christensen et al., 1998; Christensen & Bower, 1996; Teece, 1986; Tushman & Anderson, 1986).

Abernathy and Utterback's (1978) original description of the dominant design entailed that a dominant design emerges once per product class. Anderson and Tushman (1990) break with this idea by introducing a cyclic or temporal component to dominant design thinking, called the *technology cycle*. Instead of being selected for good, dominant designs are merely a stage in a continuous process characterized by variation, selection, and retention of features. It entails that technological discontinuities initiate eras of ferment with high variation. These are somewhat chaotic phases in which actors try to build up a system around alternative new technologies. At the same time, these technologies do compete with each other and the previous dominant technology. In this phase, the number of technology variations in a product class increases. The era of ferment comes to an end when a new dominant design is selected. Dominant design selection marks the start of a period of incremental change, which continues until another technological discontinuity disrupts the status quo.

Whether or not dominant designs emerge once per product class or cyclically, the emergence of a dominant design has implications for firms. Empirical studies have focused on dominant designs concerning entry and exit patterns (Baum et al., 1995; Khazam & Mowery, 1994; Suarez & Utterback, 1995; Utterback & Suárez, 1993), and entry regarding specific stages of the technology cycle (Christensen et al., 1998). Strategy scholars were interested in strategies for creating dominant designs (Suarez, 2004).

2.2.2. Platforms

Research on dominant designs was already well on its way when research on platforms emerged. Scholars from economics and engineering have developed the literature on platforms in parallel. We discuss the resulting two streams of literature separately. First, the economic stream began early in this millennium. Industrial economy scholars have started paying attention to platforms, conceptualized as *two-sided markets* (Rochet & Tirole, 2003), *multi-sided markets* (Rysman, 2009), or *multi-sided platforms* (Evans, 2003). Platforms are viewed as particular kinds of markets that intermediate and facilitate transactions between different groups of users, called sides that, without the platform, would not be able to interact and transact as smoothly and efficiently as via the platform. For instance, Rochet and Tirole (2003) capture two-sided markets in a theoretical model as a mixture of network economics and multi-product pricing that stresses cross-elasticities.

Network effects that arise between the different sides of the platform are at the core of this literature (Armstrong, 2006; Evans, 2003; Rochet & Tirole, 2003, 2006). The premise is that users value a platform more the larger its number of users is. Next to direct (or same-side) network effects, indirect network effects drive two-sided markets. These occur if “the benefit to users in at least one group (side A) depends on the number of other users in the other group (side B). An indirect network effect arises if there are cross-group network effects in both directions (from A to B and from B to A) and side B’s participation decision depends on the number of participants on side A so that the benefit to a user on side B depends (indirectly) on the number of users on side A” (Hagiu & Wright, 2011, p. 5).

For instance, a technology platform such as Google Android with a more extensive installed base than its competitors will increase incentives for developers of apps to develop for this platform. This increase in complements would then help attract more users to the platform. Together, both mechanisms can cause the emergence and prevalence of a dominant platform to the platform leader's advantage (Bonardi & Durand, 2003).[1]

Models of platform competition from the economic perspective on platforms are driven by the adoption of the platform by different sides, fueled by network effects (Gawer, 2014). As the value offered by the platform mainly stems from the access of the sides to each other, getting "both sides on board" becomes an important goal (Rochet & Tirole, 2003, p. 990), while avoiding the "chicken and egg-problem" (Caillaud & Jullien, 2003). The chicken and egg problem entails that a platform should have amassed sellers to attract buyers. But sellers will only populate the platform if they expect buyers. Many contributions in this literature suggest that these problems be addressed through pricing that may involve subsidizing one side to attract the other (Armstrong, 2006; Rochet & Tirole, 2003, 2006).

Meanwhile, the engineering perspective on platforms has been shaped by organizational theorists studying platforms as technological architectures that help to manage complexities (Gawer, 2014). Wheelwright and Clark (1992) were the first to explicitly mention the term platform, referring to products that address core customers' wants but are adaptable by adding, substituting, or removing features. According to Meyer and Lehnard (1997), a platform consists of elements and interfaces common to a family of products. The distributed development of components and recombinant innovation rests on modular design (Henderson & Clark, 1990), a common feature of engineering platforms (Baldwin & Woodard, 2009). This perspective's broader theme became the systematic reusing of components, facilitating economies of scope in production and innovation. Following this stream of literature, platforms are conceptualized as consisting of a stable chore and a more variable periphery, assuming an overarching design hierarchy (Baldwin & Woodard, 2009).

This view's core is the systematic reuse of components that enables economies of scope and scale – highlighting the facilitation of innovation as a key function of platforms (Gawer, 2014). Economies of scope in production entail that the

1 Dominant platforms are also dubbed focal platforms (Halaburda & Yehezkel, 2019) or established platforms (Suarez & Kirtley, 2012).

joint production of outputs is cheaper than producing each output separately (Teece, 1980). Gawer (2014) suggests expanding the economies of scope to entail innovation, meaning that it is cheaper to innovate jointly than to pursue these innovations separately.

Empirical research studied platforms across firms in supply chains (e.g., Brusoni, 2005; Huang et al., 2005; MacDuffie, 2013) but also in more extensive networks of firms that are not linked through supply chains, called innovation ecosystems or platform ecosystems (e.g., Adner & Kapoor, 2010; Boudreau, 2010; Nambisan & Sawhney, 2011). Reviewing both streams, Gawer (2014, p. 1239) suggested an overarching definition, characterizing platforms as “evolving organizations or metaorganizations1 that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery.

2.3. Methodology

To compare dominant designs and platforms, we:
(1) selected papers that are representative of their respective field,
(2) developed a review framework, and
(3) qualitatively coded the papers based on this framework.

2.3.1. Paper selection

We created a sample of studies by searching for dominant designs and platforms (including synonyms) on ISI Web of Science. To identify studies that belong to the field's core, we proceeded with the top 500 most-cited papers. We checked the resulting papers for substantial fit, removing purely technical papers and those that only treat platforms and dominant designs in passing. Since an absolute citation measure has downsides (e.g., it favors older papers and does not account for different citation patterns across disciplines and time (Coryn, 2006)), we supplemented the sample with papers in the Web of Science 'highly cited paper' category. The 'highly cited' indicator takes different citation rates by field and paper age into account (Clarivate, 2018), addressing some of the problems of citation numbers as a quality proxy. We create citation, co-citation, and bibliographic coupling maps based on this sample, with the software VOSviewer (www.vosviewer.com) to select key papers.

2.3.2. Review framework

A review framework is necessary to aid the disentangling of the research fields surrounding dominant designs and platforms (Ginsberg & Venkatraman, 1985). We developed a review framework to analyze and distinguish between dominant designs and platforms conceptually. It consists of two major parts: *positioning* (Figure 2-1, top) and *distinguishing features* (Figure 2-1, bottom). We now discuss both in more detail.

Distinguishing features form the framework's core and are based on a cause-mechanism-output framework, inspired by similar studies that have used this structure to define concepts (Ginsberg & Venkatraman, 1985; Simsek, 2009; Zahra et al., 2006). It contains the aspects *cause*, *mechanism*, *contrast*, *complementary aspects*, and *outcome*.

Each of these aspects can be used (alone or in combination) to define a concept. For example, a natural disaster is defined as "a sudden and terrible event in nature (such as a hurricane, tornado, or flood) that usually results in serious damage and many deaths" (Merriam-Webster, 2020). Here, the outcome is destruction and death, and the cause is a terrible event in nature. This definition draws on the aspects *cause* and *output* but does not draw on the aspects *mechanism*, *contrast*, or *complementary aspects*, so these are left void. *Complementary aspects* and *contrast* may require more explanation. Definition by *complementary aspects* refers to the specification of a concept's complementary components. For example, communication appliances can be defined as appliances that require an infrastructure. Clarification by *contrast* relates to discriminant validity, which ensures that one construct can be empirically distinguished from similar constructs and that aspects unrelated to the construct can be indicated (Bacharach, 1989). A definition of an ecosystem draws hereon, which is "a set of actors with varying degrees of multilateral, nongeneric complementarities that are not fully hierarchically controlled" (Jacobides et al., 2018, p. 2264). Here, the ecosystem contrasts with other sets of actors by specifying that it is not fully hierarchically controlled.

What we summarize under *positioning* is related to the boundaries based on assumptions that constrain theory (Bacharach, 1989). It is implicitly evident that contextual factors (e.g., McIntyre & Srinivasan, 2017) and disciplinary backgrounds (e.g., Gawer, 2014; Jacobides et al., 2018) are used to structure reviews. Therefore, we divide *positioning* into *perspective, discipline,* and *context* (see Figure 2-1).

A research paper's perspective is judged based on the following aspects: *problem owner* of the research problem, *unit of analysis*, and *level of anal*ysis. The level of analysis concerns the level or granularity of the research, whereas the unit of analysis refers to the entity or actor studied (Yurdusev, 1993). Level and unit of analysis are sometimes intimately related. The unit of analysis can, for example, refer to project teams, companies (including a range of project teams and departments), supply chains (including a range of companies), or industries (including a range of supply chains). In that case, level and unit of analysis vary together. However, the unit and level of analysis can also vary apart from each other. For instance, the unit of analysis can refer to either suppliers or customers, both of which can be analyzed at the level of a market. Both unit and level of analysis are used in other frameworks to structure literature reviews, e.g., (Astley & Van de Ven, 1983). The context refers to the research setting, such as industry, geography, and timeframe. It also covers what we call *start situation*, for example, the availability of different designs, each of which could be selected as the dominant design.

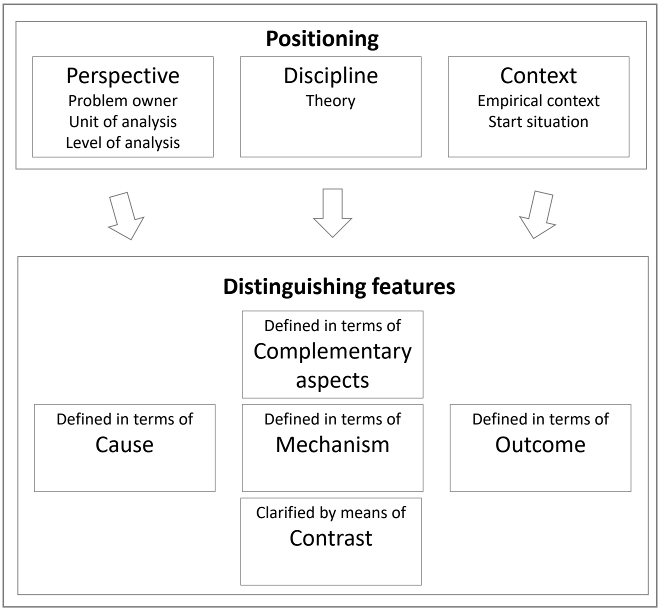

Figure 2-1. Review framework.

2.3.3. Analysis

We analyzed 27 relevant papers based on the framework qualitatively. As a first step, the first and third authors assigned papers to the streams of dominant designs and platforms. Cases of disagreement were solved via discussion. The analysis of *distinguishing features* started by analyzing definitions of the key concepts of *dominant designs* and *platforms*. We looked at the remainder of the paper only after extracting information from the definitions (if present).

To judge a paper's *positioning*, we used the following guidelines. A research paper's perspective is judged based on the problem owner of the research problem, the unit of analysis, and the level of analysis. The problem owner and the role are inferred from the practical implications presented in the paper. Often, the disciplinary background is explicitly mentioned, for example, in Gawer's (2014) review covering the engineering and economics perspective on platforms, as already mentioned in the abstract. In other cases, we preferably infer this information from the theory used in the article due to the field's interdisciplinary nature. For instance, we judge the disciplinary background of the study on ecosystem theory by Jacobides et al. (2018) as engineering management and economics. This is based on frequently citing literature on industry platforms that originates from engineering (management) and its foundation in complementarity theory.

2.4. Results

Analyzing definitions of dominant designs and platforms in representative papers showed that their commonalities and differences surface in both main parts of the framework. We present their commonalities and differences in terms of distinguishing features and positioning.

2.4.1. Analysis of distinguishing features

Analysis of causes. The stream of dominant designs has yet to settle on what causes its phenomenon to emerge. Nevertheless, various causes have been mentioned, such as installed base and radical innovation. According to Abernathy and Utterback (1978), users are assumed to play a major role in selecting a dominant design as their understanding of performance requirements is more intimate, leading them to make 'suggestions' for the following version of the innovation. As this research is framed from the perspective of firms (and seemingly dissociate from consumers), suggestions by users likely take the form of purchase decisions. Amassing users then depends on the design's appeal to a broad group of users. Rather than being the best design, Constant (1980) maintains that the dominant design was the design with the best performance across a wide variety of applications. For instance, the DC-3 airplane did not become the dominant design because it was the aircraft that traveled the fastest, had the most extended range, or was the largest (Abernathy & Utterback, 1978). Instead, it was the most economical large, reasonably fast airplane with a long range.

From the perspective of consecutive dominant designs, radical innovation plays a vital role as a cause. Radical innovations break with current designs and practices and trigger an era of ferment (Abernathy & Clark, 1985; Romanelli & Tushman, 1994; Tushman & Anderson, 1986). Anderson and Tushman (1990) add that radical innovation and the many resulting designs trigger manufacturers, customers, suppliers, and regulators' efforts to decrease uncertainty associated with the variation. Furthermore, Anderson and Tushman (1990) mention market demand, market power by leading producers, and first-mover advantage as potential causes of a dominant design. Various economic and organizational factors, such as the possession of collateral assets, industry regulation, government intervention, or managerial strategic action, may also play a role (Suarez & Utterback, 1995).

In contrast, many seminal papers offer no cause that triggers the emergence of a platform (Adner & Kapoor, 2010; Gawer & Cusumano, 2014; McIntyre & Srinivasan, 2017; Rochet & Tirole, 2003). Gawer's (2014) review suggests complexity as a condition for modularity for engineering platforms. Hence, complexity could be seen as a condition for platforms to arise. The economics perspective on (multi-sided) platforms assumes the pre-existence of different sides with a need for interaction that the platform facilitates in the form of a conduit, presumably lowering transaction costs. Although different from the economics perspective, recent advances in ecosystem theory suggest that ecosystems emerge in response to a "need for coordination that cannot be dealt with in markets", enabled by a modular design (Jacobides et al., 2018, p. 2260). These examples, however, create the impression of necessary conditions rather than sufficient conditions for platform emergence, which fits with the observation that platforms come into existence based on managerial action (Gawer & Cusumano, 2014).

Key distinction: Both streams have yet to settle on what causes their phenomenon to emerge. Radical innovation is only mentioned regarding dominant designs. Contrarily, platforms do not simply emerge without firm-level agency (Gawer & Cusumano, 2014). That means that firms deliberately create platforms. In contrast, dominant designs emerge in the market because of the collective action of many firms and other actors. In both streams, complexity plays a role. Modularity as a condition is mentioned only in platform research.

Analysis of mechanisms. The general nature of the dominant design selection process is described as emergent from demand-driven competition (Anderson & Tushman, 1990; Chaturvedi & Prescott, 2020; Henderson & Clark, 1990), evolutionary (Chen et al., 2017), and may occur in situations with strong path dependency (Schilling, 1998).[2] It can be a unique (Abernathy, 1978), or recurring and ongoing process (Anderson & Tushman, 1990). Increasing returns, technological factors, and other factors can play a role.

Schilling (1998) posits that increasing returns to adoption play a role in dominant design selection. Increasing returns are composed of *learning effects* (refining technology, learning accumulates around a specific trajectory) and network effects. Network effects can be part of dominant design selection (e.g., Frenken et al., 1999) but need not be present (Gallagher, 2007). A design can be selected as the dominant design simply because it is the better product, scoring higher on the price-performance ratio.

2 Abernathy and Utterback (1978) give no information about the mechanism's operational mode in their original conceptualization.

Regarding technological factors, Suarez and Utterback (1995) emphasize that technological factors alone may not suffice to explain dominant design selection, as the dominant design is not necessarily the design with the highest technological performance. Rather than technology alone, the price-performance ratio can drive dominant design selection in products, processes, or components (Gallagher, 2007), such as in the example of the DC-3 airplane (Abernathy & Utterback, 1978). Strategic action can also influence dominant design emergence, such as technology appropriability (R. Srinivasan et al., 2006) and licensing decisions. Last, other mechanisms include pressure for compatibility and government regulation (Schilling, 1998).

Economies of scope relate to both dominant designs and platforms. Economies of scope are present when the joint production of goods is cheaper than the individual production (Teece, 1980). Dominant designs can emerge due to economies of scope (Constant, 1980). Importantly, economies of scope can also arise from use across different applications. Here, economies of scope arise as the design can be used across many applications (scope), leading to production at greater scale. Production in larger numbers may create enough traction in the market to eventually select the design as the dominant design.

Once a dominant design has been selected, the persistent architecture that it embodies leads to the codification of knowledge on core components (Dosi, 1988). Different versions of products can then be efficiently developed and produced due to economies of scope. Common core components organized according to a common core architecture may lead to an increasing variety in performance characteristics.

In platforms, economies of scope relate to providing tools and resources or reusing components. Economies of scope are an often-mentioned feature that can be placed between dominance-related mechanisms and internal coordination mechanisms (e.g., Boudreau, 2012; Gawer, 2014; Tiwana et al., 2010). The systematic reuse of components allows for economies of scope in production as reusing components enables higher quantities per component. Gawer (2014) suggests extending economies of scope to innovation, entailing that innovating on products A and B together is lower cost than innovating separately.

Platforms know mechanisms on several levels. One group of mechanisms relates to the dominance of platforms. Fascinated by the prospect of monopoly profits, much research addressed how to achieve platform dominance. Van Alstyne et al.

(2016) write that network effects drive platforms' power and success. Dominance aside, platforms (and their ecosystems) have been contrasted based on internal coordination mechanisms. Gawer (2014) calls this coordination mechanism *ecosystem governance*, which is based on pricing in multi-sided platforms, and based competition management in ecosystems (Gawer & Cusumano, 2014). In comparison with other network forms, Jacobides et al. (2018) stress that ecosystems are not fully hierarchically controlled, meaning that ecosystems must rely on control mechanisms other than a managerial hierarchy. The characteristic that the collective investment cannot be recovered or redeployed elsewhere binds ecosystems together.

Key distinctions. The analysis shows that, in the field of platforms, two types of mechanisms are analyzed: Mechanisms leading to the dominance of platforms and, on the other hand, internal coordination mechanisms. Platforms and dominant designs, hence, relate differently to the notion of dominance. Platforms can also be non-dominant, such as in Facebook's early days when it competed with Myspace. Competition between platforms need not lead to a dominant platform (e.g., several platforms exist in the video game console market), and platforms can also pursue differentiation rather than dominance strategies (Cennamo, 2021). Here lies a key difference with a dominant design which "is simply one among many different 'design approaches'" (Gallagher, 2007, p. 272) in the absence of dominance.

Furthermore, the mechanisms behind dominant design selection are often described as demand-driven, evolutionary, or not described at all. This contrasts with research platforms where mechanisms have received much attention. With dominant designs, coordination occurs by settling on a dominant design, meaning by choice of technology alone. Besides, dominant design selection mechanisms cover different periods – selection can be unique, recurring, or ongoing, whereas platforms' mechanisms potentially lead to the prevalence of one dominant platform. The idea that different platforms may take their turns in being dominant is not described.

Analysis of outcomes and complementary aspects. Many studies define dominant designs as an outcome, such as the institutionalization of product features (Chaturvedi & Prescott, 2020) that manifests as the dominance of a particular design (Khazam & Mowery, 1994). Abernathy and Utterback (1978) describe innovation patterns ajar empirical observations in the semiconductors, aircraft, electronics, and automotive industries. The development of a dominant design is seen as "the shift from radical to evolutionary product innovation" (Abernathy & Utterback, 1978, p. 6). This means that concluding dominant design development entails reaching a state of evolutionary product innovation.

This early concept of a dominant design is common with many other studies. Some characterize a dominant design as reducing variation and uncertainty in a product class (Anderson & Tushman, 1990) or the shift of technology development at the component and process level (Christensen et al., 1998). Another frequently mentioned outcome is economies of scale by enforcing standardization (Anderson & Tushman, 1990; Suarez & Utterback, 1995). This causal chain, however, is not shared by all studies – even though still defined as the outcome, Henderson and Clark (1990) see a dominant design as emergent from the opportunity to obtain economies of scale (referencing David (1985) and Arthur (1989)).

Constant (1980) defines a dominant design as stabilizing architectural knowledge, which then becomes encoded and implicit. Architectural knowledge concerns the links between components rather than the components themselves (Henderson & Clark, 1990, p. 11). An architectural innovation alters how a product's components are related to each other without affecting the knowledge underlying the components (Henderson & Clark, 1990, p. 10). The idea of architectural knowledge takes a central place in later studies, such as Christensen et al. (1998), who operationalize dominant designs based on architectural configurations, or Gallagher (2007, p. 374), who portrays dominant designs as "persistent architectures." The emergence of such a persistent architecture is usually accompanied by a convergence of design attributes (Gallagher, 2007).

Whereas dominant designs are often defined as an outcome, platform research frequently draws on both outcome and complementary aspects to define the central concept. A notable definition in this respect is the one by Van Alstyne et al. (2016), who explicitly mention platform owner, platform provider, producers, and consumers as the constitutive agents of a platform, and that platforms have an ecosystem. Papers that address the outcome in their definition of platforms mention the resulting network of producers and consumers (Van Alstyne et al., 2016), the stimulation of value co-creation (McIntyre & Srinivasan, 2017; Tiwana et al., 2010), intermediation (Rochet & Tirole, 2003), and economies of scale respectively scope (Boudreau, 2012). Jacobides et al. (2018) describe the existence of an ecosystem as obviating the need for custom contractual agreements with each partner.

Key distinction: The concept of core and peripheral systems that implies modularity is typical of dominant designs and platforms. While most definitions across dominant designs and platforms draw on outcomes, there is a subtle difference regarding their recognition. In contrast to platforms, dominant designs can only be recognized in retrospect based on subjective guidelines (Gallagher, 2007). This counts for earlier definitions (based on a shift from radical to incremental innovation) and newer ones based on architecture.

Further, platforms and dominant designs differ in responding to diverging consumer needs. As Constant (1980) explicated in his description of the jet-powered airplane, dominant designs are designs with the best performance across a variety of applications, although not optimal in specific applications. Dominant designs are inherently suitable to many use cases but not necessarily customizable. For instance, an airplane design can be used across several ranges, for passenger travel and freight, depending on whether seats are installed. Innovation platforms, on the other hand, allow for customization, such as in the case of smartphone operating systems, that can be equipped with apps according to the individual user's needs.

2.4.2. Positioning

In contrast to distinguishing features, positioning is about contextual aspects of studies that do not necessarily surface in the definitions. The analysis showed that most studies across both fields address managers as problem owners but with a different focus. Much platform research is written from a platform leader's or owner's viewpoint. Where research in the domain of platforms emphasizes agency by the platform owner, research in the domain of dominant designs does so in response to dynamics at the industry or product class (e.g., Anderson & Tushman, 1990; Gallagher, 2007; Henderson & Clark, 1990; Suarez & Utterback, 1995). While dominant design research knows agency in response to industry-level dynamics (such as the selection of a dominant design), the dominant design itself emerges and is not directly linked to agency.

Parts of this may be explainable by the evolutionary focus of many early dominant design scholars (e.g., Abernathy & Utterback, 1978; Tushman & Anderson, 1986), as argued in Section 2.2.1. The ambition to shed light on the interaction between technology and the economy is reflected in the research designs. As a start situation, many studies assume the existence of several alternative competing technological designs out of which a dominant design is selected (e.g., Anderson & Tushman, 1990; Gallagher, 2007; Suarez & Utterback, 1995), triggered by radical innovation (Anderson & Tushman, 1990; Gallagher, 2007; Henderson & Clark, 1990). The technological architecture is often studied with the production process (Abernathy & Utterback, 1978) or in combination with the firm (Chen et al., 2017; Christensen et al., 1998; Suarez & Utterback, 1995).

Although both fields focus on technological innovation, the specific technologies studied differ. Research on dominant designs is mostly based on high-tech, such as semiconductors or automotive. Platform research is mostly based on ICT, such as mobile apps, PC software, or video games. Part of this is explainable in the lagged development of the fields – many studies on dominant designs were published before the widespread diffusion of the internet and computers.

Key distinction: Both fields have a focus on technological innovation. Dominant design research studies a technological design against the background of its product class or industry. Platform studies focus mostly on actors (mostly the platform leader and complementors) within a platform ecosystem. Empirically, both streams rely on high-tech – dominant design research is based in contexts such as semiconductors or automotive, whereas platforms research primarily draws on ICT contexts.

2.5. Discussion

Comparing dominant designs and platforms based on the cause-mechanism-output framework revealed differences and commonalties. Dominant designs are understood as prevalent architectures that define a set of core design concepts, and platforms are seen as meta-organizations that facilitate economies of scale and scope based on a modular core technological architecture and more peripheral systems. Table 2-2 presents the results of this study in condensed form.

The fields have several aspects in common. First, both dominant designs and platforms are modular systems structured around core and peripheral systems. Regarding dominant designs, this already surfaces in early studies that define dominant designs at the product level based on a set of subsystems (Christensen et al., 1998). For instance, an automobile (product/ system) is composed of propulsion, drive train, chassis, brakes, or steering (subsystems). In the case of an internal combustion engine, the subsystem propulsion contains the components pistons, valves, crankshaft, and connection rods, among others. (Sub)systems are more at the core when their change affects more other subsystems and are regarded as more peripheral when their change affects fewer other subsystems. (Murmann & Frenken, 2006). With platforms, the stable core is what constitutes the platform (e.g., Apple's iOS operating system) (Baldwin & Woodard, 2009), and the periphery is organized around the platform (e.g., third-party apps developed for Apple's iOS operating system).

A commonality between dominant designs and platforms is that they both occur at several levels within a technological system. More modern conceptualizations of dominant designs see them as nested technological systems composed of one or more levels of subsystems and components (Baldwin & Clark, 1997; Henderson & Clark, 1990; Murmann & Frenken, 2006). Dominant designs have been studied both at the system level (e.g., automobiles (Abernathy & Utterback, 1978)) and subsystem level of a technological system (e.g., internal combustion engines (Abernathy, 1978). Similarly, platforms can occur at several levels, as platforms within platforms (Tiwana, 2013). For instance, Google introduced its browser Chrome as an app, then transformed it into a platform by adding apps for Chrome, and ultimately turned it into its own operating system (Chrome OS).

Table 2-2. Commonalities and differences between dominant designs and platforms.

	Dominant Designs	**Platforms**
Definition	Prevalent architectures that define a set of core design concepts	Meta organizations facilitating economies of scale and scope, modular architecture
Discipline	Evolutionary economics, economics, innovation management	Engineering management, strategic management, network economics
Problem owner	Manager	Platform leader, manager
Unit of Analysis	Technological design architecture	Meta-organization, platform, ecosystem
Level of analysis	Industry, product class	Ecosystem, product family, central value proposition
Context	High-tech manufacturing, ICT	ICT, consumer electronics
Start situation	Alternative or competing technological design	*Unspecified*
Cause	Market demand, market power by leading producers, first mover advantage, possession of collateral assets, industry regulation, government intervention, managerial strategic action	*Largely unspecified*
Mechanism	Emergent, demand-driven competition, sometimes network effects, learning effects, economies of scope	(Indirect) network effects, pricing, ecosystem governance, asset specificity
Clarification by contrast	Not necessarily technologically superior, mostly non-proprietary	Ecosystems: not fully hierarchically controlled
Complementary aspects	Production, maintenance, and repair equipment, enforce or embody standards, composed of core and periphery	Modular architecture, composed of core and periphery, complementary products and services that utilize the core
Outcome	Variety reduction, uncertainty reduction, economies of scale, shift to component-level innovation	Value co-creation, intermediation, economies of scale and scope

There are commonalities and differences in how dominant designs and platforms relate to innovation. Their structure and the distinction between core and periphery have similar innovation implications. Both are structured modularly, with complexity contained in modules that interact via interfaces (Baldwin & Clark, 2000). This allows for mix-and-match innovation by recombining modules (Garud & Kumaraswamy, 1995) and modular innovation (Henderson & Clark, 1990). Changing subsystems that are more at the core has cascading effects on more peripheral subsystems. At the same time, changing them is more complicated. The more the core changes, the more radical and system-wide the impact is.

Modifying the core also relates to how platform leaders drive platform-wide innovation. For instance, platform leaders encourage innovation by integrating functionality that is provided at several instances in the periphery into the platform core (Parker et al., 2016), or by updating hardware and increasing processing and graphical power at the introduction of a new generation of video game consoles (R. S. Lee, 2012).

While both platforms and dominant designs relate to economies of scope, they do so in different ways. Dominant designs can facilitate economies of scope based on reasonable performance across a range of applications (scope) that leads to production at a greater scale (Constant, 1980). After selecting a dominant design, product varieties increase by modifying peripheral components. Platforms, however, and enabling users to tailor the platform to their specific needs by drawing on unique combinations of complements (Garud et al., 2008), such as in the case of smartphone apps that one can install as desired.

Further, dominant designs and platforms differ in their causes and underlying mechanisms. First, the most significant difference lies in how these phenomena come into being: dominant designs emerge, while platforms result from managerial action. Platforms know a central actor, called platform leader or platform owner. Little is known about what causes platforms to emerge, except that platforms do not emerge without managerial action. In contrast, dominant designs are largely non-proprietary and emerge due to the joint actions of many firms. Dominant designs often emerge in response to radical innovation and complete an era of ferment. In that respect, it remains a challenge to recognize dominant designs ex-ante (Gallagher, 2007).

Independent of their causes, some contexts are more prone to forming platforms (Parker et al., 2016):

- Information-intensive industries, such as media and telecom, have seen the rise of many platforms.
- Industries with non-scalable, expensive, and mostly human gatekeepers, such as publishing and retailers, have formed a viable context for platforms such as Etsy and Amazon that allow producers or artist to market their goods.
- Highly-fragmented industries have provided opportunities for platforms to aggregate offerings of many small complementors in one place (e.g., Airbnb).
- Industries high in information asymmetries, such as used car sales, allowed platforms to aggregate offerings and create a level playing field by making detailed information available to all parties (e.g., Autoscout24).

Other industries have typically been less fertile for platforms. Industries with high regulatory control (e.g., healthcare, banking), high failure costs (e.g., matching a patient with the wrong doctor), and resource-intensive and less information-intensive industries (e.g., mining, oil and gas) have seen fewer platforms emerge (Parker et al., 2016). Nevertheless, this is starting to change as Big Tech platforms such as Google or Amazon have entered industries such as healthcare or education that previously had lagged (Ozalp et al., 2022), blurring the picture of where platforms tend to become active.

Dominant design and platform research differ in the mechanisms that are at play. Dominant designs know one primary mechanism, the selection process. The baseline is that a dominant design emerges out of demand-driven competition in a set of related yet different application contexts, each of which sets slightly different requirements (the dominant design of an airplane is used in vastly different ranges and for passenger and freight transport). Platform research can be divided into two types of mechanisms: mechanisms leading to platform dominance, and platform-internal coordination mechanisms. Dominance-related mechanisms are a mixture of direct and indirect network effects. Coordination mechanisms can be subsumed under governance outside of managerial hierarchies. While network effects are central to platforms, they play a different role in dominant designs. Network effects can drive dominant design selection, but it can also be driven by order-of-magnitude advances in the price-performance ratio (Gallagher, 2007).

Next to diverse kinds of mechanisms, it is also evident that the fields differ in the duration or timespan of mechanisms. Based on the technology cycle, dominant design thinking acknowledges the come and go of successive dominant designs. This cyclical nature is foreign to platform thinking which frequently is interested in reaching and maintaining one platform's dominance. At the same time, the more cross-sectional actor-centric perspective is alien to platform literature. The dominant design perspective is longitudinal, whereas the platform perspective is more snapshot-like.

The degree of external innovation in a platform shapes the similarity between dominant designs and platforms, see Section 2.2.2. Opposed to the platform literature, the dominant design literature does not have a strong stance on interface openness. Where a modular design and a structure consisting of a core and a periphery are features shared by most platforms, the degree of openness differs across types of platforms (Gawer, 2014). Engineering platforms (e.g., Meyer & Lehnerd, 1997) serve as the basis for product families, such as Black & Decker's platform for power tools (Simpson et al., 2006). Here, an electric motor with variable stack length but fixed axial diameter kept housing dimensions common and allowed Black & Decker to produce derivative products at lower cost and greater speed.

Like dominant designs, engineering platforms define the architecture of products, and the stability of core subsystems allows for product varieties by changing peripheral subsystems. Engineering platforms rely on mostly closed interfaces, as opposed to more open platforms, such as supply chain or industry platforms. Supply chain platforms form a middle ground between product families and industry platforms. They enable drawing on the capabilities of parties coordinated via a platform. Supply-chain platforms have interfaces that are selectively open to supply-chain partners.

In contrast to dominant designs is the explicit focus of platforms on external innovation found in industry platforms, especially digital platforms. Industry platforms rely on complementary products to cater to heterogeneous user demands (L. Sun et al., 2016). At the very least, platforms facilitate interaction between suppliers of goods and services (complements) offered by complementors, entailing that value creation occurs increasingly externally (Parker et al., 2017). How open or closed interfaces are influences the degree to which external innovation is possible (West, 2003). While these platforms still rely on a modular design and core and peripheral systems, the scope of the product varieties is no longer fully controlled by the platform leader. Digitalism further questions the assumption of a stable core as the core is evolving (Saarikko, 2016). It makes platforms generative, meaning one cannot foresee which modules will be added in the future (Boudreau, 2012).

Last, the empirical contexts, as well as units and levels of analysis, explain some differences between the fields. The studied empirical phenomenon is not exactly the same. Dominant design research focuses mainly on standalone complex product architectures in high-tech industries such as semiconductors or automotive. In contrast, platform research applies a more systemic perspective, predominantly based on ICT. This is not to blame dominant design scholars – many central studies in this field were authored long before the widespread adoption of computers, let alone the internet (see Table 2-2).

2.5.1. Reflections on the comparison of concepts

Using the framework led us to draw two lessons relating to its application and applicability. Using the framework showed that it is appropriate to interpret its components more loosely. The framework's core features are cause, mechanism, contrast, complementary aspects, and outcome. Cause, mechanism, and outcome may suggest a causal relationship between cause and outcome. Although quite intuitive, using the framework showed that some events precede the outcome but more closely resemble antecedents than causes.

Second, the proposed framework may only help compare specific types of definitions. It may not help in situations where the meaning and relevance of these components change over time and depend on the context (Ortt et al., 2020). Likely, it is more promising to describe highly contextual definitions in terms of f*amily resemblances* (Wittgenstein, 1953) because simply combining the attributes of all individual cases usually does not help overcome their particularity. Like one can characterize a family by traits that some of its members share (though not necessarily all), one can describe a concept by traits that together define it but do not necessarily surface in all individual cases.

Responsible innovation is such a concept (Ortt et al., 2020). What we perceive as responsible changes even for one technological system in one context. For instance, in the United States, 19th-century wind power (used to provide drinking water to cattle) was deemed responsible for reasons other than wind power 100 years later (used to generate electricity). Hence, comparing concepts based on our approach is unlikely to work in contexts best described by family resemblances. It may unnecessarily bring particularities of individual definitions to the foreground from which family resemblances were used to abstract.

2.5.2. Future research

At the same time, these differences offer potential complementarities. We see promising research opportunities at the intersection of the long-term evolutionary perspective with the cross-sectional, actor-centric view of platform research. The cyclical perspective related to the technology cycle that is so common in dominant design research may lead to new insights in the domain of platforms.

First, a cyclical view on platform dominance is not immanent in the literature. As Evans and Schmalensee (2016) note, it may be hard to imagine that currently very competitive platforms such as Google or Facebook are subjected to a cyclical pattern and may be eventually overturned. Nevertheless, anecdotal evidence suggests that this is possible and that platform dominance can be at least successive (e.g., Myspace outcompeted Friendster and later lost to Facebook). Future research could address when the succession of dominant platforms occurs and what triggers the succession of dominant platforms.

The technology cycle suggests that technology is the driver of the cyclic pattern. Changes in technology could have different implications on different levels of analysis, *such as industry, platform, or focal product*. We see several directions for future research in this regard.

- On the industry level, dynamics between several platforms and a focal technology are under-explored. An exception is a study on how complementarities between several platforms enabled the growth of the additive manufacturing industry (Kwak et al., 2018).
- On the platform level, the example of Facebook outcompeting Myspace illustrates how technology drives platform competition. In part, Facebook's performance is attributed to technological advances based on openness to external developers (Gillette, 2011). Myspace stretched its resources thin when it tried to develop all new features in-house, resulting in a buggy performance. Unlike Myspace, Facebook's opening in 2006 enabled it to draw on external developers capable of extending its functionality (Parker et al., 2016). Future research could explore dynamics based on platform-enabling or platform-providing technologies. For instance, *are platforms based on pre-paradigmatic enabling technologies such as blockchain more or less fragile than their counterparts based on paradigmatic technologies*? Distributed platforms relying on blockchain technology may threaten today's platforms (Trabucchi & Buganza, 2021).

- On the focal product level, multi-sided markets may depend on the technology cycle of the focal product that is transacted on their platform. For instance, used car sale platforms such as mobile.de or autotrader.com may depend on the transition to powertrains other than internal combustion, with implications for platform design and management.

Another direction for future research relates to the comparability of concepts. Juxtaposing different structural metaphors (Gillespie, 2010) makes sense when complex technological innovation behaves comparably. We expect dominant designs and platforms to share some key characteristics, although the fields have had their bloom in different decades. Bayus (1994) finds no evidence supporting shrinking product life cycles or systematically accelerating diffusion rates (Bayus, 1992). Neither has the length of the pre-diffusion phase considerably changed (Ortt, 2010a). Future studies that compare concepts may face the following questions: *Which insights from research on one concept apply to the other*? *When are these insights transferrable (how much overlap is necessary)*? *If so, in which direction are insights transferrable (from old to new, new to old)*?

In comparing dominant designs to platforms, we have focused on platforms in their pure form. However, Cusumano (2022) notes that many Platforms, such as Amazon's marketplace and Apple's iOS and AppStore, combine several types of platforms – these are often multisided-transaction markets and innovation platforms (Cusumano, 2022). Apple, for instance, runs an innovation platform (Apple iOS) and several multi-sided transaction platforms (Apple's AppStore, iTunes). Furthermore, many successful platforms combine platform and non-platform businesses. To date, though, the literature has focussed on platform strategy and management, but little is known about the workings of combined platform and non-platform businesses, or the combination of several platform types.

2.6. Conclusion

This chapter investigated the systematic commonalities and differences between dominant designs and platforms. The contributions are twofold: First, we have developed a framework tailored to comparing concepts. It combines aspects from several prior approaches into one framework. Using the framework showed that it serves as a helpful protocol for reading and analyzing papers. The multitude of attributes delivers much material for the review but requires the authors to choose which material to present. It provides structure during the review process, making it more transparent without being too constrained. Second, we applied the framework to compare the concepts of dominant designs and platforms. We elaborated on the differences and potential complementarities between dominant designs and platforms, presented as future research directions. This review adds to a growing literature that intends to take stock, structure, and consolidate recent advances in management research (Chen et al., 2017; Gawer, 2014; Jacobides et al., 2018; McIntyre & Srinivasan, 2017; 2006) and the comparison of structural metaphors (Gallagher, 2007; Shipilov & Burelli, 2020). This is valuable to scholars and practitioners alike as it facilitates access to the literature and helps bridge the divide between practitioners and scholars.

This study is not without limitations. Clarifying concepts based on theoretical or scientific literature and defining them as precisely as possible is, by nature, a positivist endeavor. Based on recent calls for more synthesis in management research (Haley et al., 2022), we believe this is necessary and valuable to theory and practice. Interpretivist approaches (Schaffer, 2016) may help understand the situated use of concepts and may complement studies similar to ours.

As some treat dominant designs and de-facto standards as synonyms (e.g., Anderson & Tushman, 1990; Besen & Farrell, 1994; Schilling, 1998), we relied on past research (Gallagher, 2007; 2006) to distinguish between the two concepts. Nevertheless, the synonymous use of dominant designs and standards may have interfered with the boundaries of this study. Moreover, comparing dominant designs and platforms requires identifying the fields' core publications which we have done based on the number of citations as a (dis)qualifier. Relying on an absolute measure of relevance (absolute number of citations) puts older contributions at an advantage over most recent ones. We addressed some of this bias by considering all studies that ISI Web of Science classified as highly cited, which has led to the inclusion of various more recent studies and a relatively balanced distribution of the included study over time (by publication year).

Chapter 3

Factors for Additive Manufacturing Technology Selection

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Abstract

The paper addresses the most important factors for the selection of additive manufacturing (AM) technology as a method of production of metal parts. AM creates objects by adding material layer-by-layer based on 3D models. At present, interest in AM is high as it is hoped that AM contributes to the competitiveness of Western manufacturing industries. A literature study is conducted to identify the factors that affect the selection of AM technology. Expert interviews and the Best Worst Method are used to prioritize these factors based on relative factor weights. We find that technology, demand, environment and supply-related factors are categorized, and further mapped to offer a holistic picture of AM technology selection. According to expert assessments, market demand was ranked highest, although market demand is currently lacking. The composition and size of the expert panel and the framing of some of the factors in light of previous literature cause validity limitations. Further research is encouraged to differentiate the selection factors for different AM implementation projects. The paper presents a more complete framework of factors for innovation selection in general and the selection of AM technology in specific. This framework can serve as a basis for future studies on technology selection in the (additive) manufacturing sector and beyond. In addition to AM-specific factor weights, the paper explains why specific factors are important, reducing uncertainty for managers that have to choose between alternative manufacturing technologies.

3.1. Introduction

In early 2020, General Electric unveiled its new jet engine, GE9X, which includes several additively manufactured metal parts (Kellner, 2020). The applications of Additive manufacturing (AM), which creates objects by adding material layer-by-layer based on 3D models, are no longer limited to prototyping as it is also used for the production of functional parts (Atzeni & Salmi, 2012). And yet, news about General Electric using additively manufactured functional parts in its new jet engine still creates a stir in the AM community and beyond. Inspired by AM's unique capabilities, policymakers and the public have shown increased interest in AM. For instance, the European Commission sees AM as a promising technology with great economic potential.

Nevertheless, the diffusion of AM practical applications is lagging behind expectations, and additively manufactured components continue to be the exception rather than the norm. Currently, metal AM accounts only for a tiny fraction of the global manufacturing market, less than 0.1 %, to be precise, according to a market report by 3DHubs (2019, p. 8). Given these figures, it seems pressing to study the underlying factors that influence the selection of AM technology in the manufacturing technology market. These factors may help to explain why AM technology was selected as the method of production instead of several other possible alternatives, and thereby help the AM sector move towards large-scale implementation.

Only sparse research focuses on factors for the selection of innovative AM technology (Yeh & Chen, 2018). Whilst some studies explore challenges and drivers related to the implementation of AM technology (Dwivedi et al., 2017; Martinsuo & Luomaranta, 2018; Mellor et al., 2014), few studies focus on AM technology selection among alternative production methods, or prioritize such factors. Some exceptions include studies conducted in Taiwan (Yeh & Chen, 2018), the US and UK (Hasan et al., 2019; Schniederjans, 2017; Schniederjans & Yalcin, 2018), and India (Marak et al., 2019). Europe, as the second biggest AM market after the US according to a 2019 AMFG report, has not yet been studied in this respect. By including literature related to technology dominance, technology diffusion, AM adoption, technology acceptance, and business models, we offer a more encompassing framework for AM technology selection. The goal is to identify factors for the selection of AM technology as the method of production and to prioritize these factors using expert interviews. The information from the interviews is analyzed using the best worst method (BWM). The main research question is: "*What are the most important factors for the selection of AM technology in the European context according to experts*?" We will focus on additive manufacturing of metal parts rather than polymer, concrete or other materials.

The literature study results in a framework of 39 factors for innovation selection in general and the selection of metal AM technology in specific. Prioritizing these factors for the case of metal AM in Europe clearly shows that the demand for AM products in the market, relative technological performance, and the business model behind AM are the most important. Interestingly, market demand ranks highest even though there is currently a lack thereof, as pointed out by interviewees. The prioritization of factors informs both theory and practice as it adds to the literature on the antecedents of AM selection and reduces uncertainty for managers that cannot address all factors simultaneously.

3.2. Literature review

3.2.1. Overview on metal additive manufacturing
AM utilizing metals is a relatively innovative manufacturing technology that currently comprises five mainstream self-standing technological solutions (Zhang et al., 2017): Powder Bed and Inkjet 3D Printing (3DP), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Direct Metal Deposition (DMD), and Electron Beam AM (EBAM).

Each of these solutions have their own specialties, but for the purpose of this study (selection of AM technology), these applications are assessed under the umbrella term of metallic AM. Metallic AM can be combined with other manufacturing technologies to create more efficient and complex manufacturing possibilities (Gibson, 2017). Martinsuo and Luomaranta (2018) argue that metallic AM can best be viewed as a systemic innovation that requires complementary innovations in other manufacturing, business, and supply chain processes as well as cooperation with other companies in the focal company's supply chain. Therefore, AM is introducing a new paradigm for manufacturing industries with the possibility to disrupt companies' contemporary business logics (Weller et al., 2015).

When producing end-usable parts or components, the following process chain is usually followed. AM always requires a suitable 3D model, the expertise of a product designer (functionality of the design), and an AM expert to optimize the design for production with AM (Luomaranta & Martinsuo, 2020). This differs from traditional subtractive manufacturing where a digital model is not always necessary. AM also requires specific machines and specific raw materials, usually powdered metals (Khajavi et al., 2014). Operating AM machines requires specific skillsets from the operating personnel (Murmura & Bravi, 2018). After manufacturing, objects need to be post-processed (Khajavi et al., 2014) and quality checked before being assembled as a component into a product or before using the AM object as an end product. AM brings the following benefits: no specific tooling is needed, reducing production time and expense, small product batches are economically feasible, products can be custom-made and product designs can be changed quickly and easily, product designs can be more complex, less waste is generated, and shorter and more agile supply chains with low inventory needs can be used (Holmström et al., 2010).

3.2.2. Selecting and adopting additive manufacturing technology

Previous research has studied factors for the selection and adoption of AM technology from various perspectives, including but not limited to metal AM. Table 3-1 groups such studies according to the factors that are discussed in these studies. Many papers study factors related to AM technology as a technological innovation. Frequently reoccurring are factors such as cost, material and energy consumption, as well as aspects of the design and manufacturing process. The group demand-related includes different factors studied from the perspective of actors that select AM technology. Often mentioned are experience with and knowledge of AM, the size of the company that selects AM technology, and the general demand for AM technology. Factors that influence AM selection at the aggregate level (and for several types of materials including metal, polymers, and so on) are summarized under environmental factors, including the availability of standards, geographical location, and the influence of multinationals. Yet other papers study AM in the context of a supply chain, stressing the alignment and integration of efforts.

Table 3-1. Overview of factors for the selection of AM technologies (not limited to metal AM).

Category	Factor	Study
Technology-related	• AM manufacturing process optimization	Jin, He et al. (2017)
	• Optimization of material consumption in extrusion processes	Jin, Du et al. (2017)
	• Cost and technological limitations	Dwivedi et al. (2017)
	• Integration of the digital process chain via one standard	Bonnard et al. (2018)
	• Flexibility and where it is needed	Ding (2018)
	• Capacity utilization (time, material, component lifetime), design adaptation, energy saving	Baumers, Dickens, et al. (2016)
	• Quality, production time, material consumption	Achillas et al. (2015, 2017)
	• Environmental impact, cost	Le Bourhis et al. (2013)
	• Product properties such as complexity and volume	Baumers, Tuck, et al. (2016)
	• Costs of manufacturing, safety stock	Knofius et al. (2016)
	• Energy consumption as a driver of AM profitability	Niaki et al. (2019)
	• Complementary innovations in the supply chain,	Martinsuo and Luomaranta (2018)

Table 3-1. Continued.

Category	Factor	Study
Demand-related	• Awareness of key issues in the customer's processes and technical solutions	Ding (2018)
	• Availability of training opportunities and investments to implement AM	Murmura and Bravi (2018)
	• Experience with and knowledge of AM	Kianian et al. (2016), Murmura and Bravi (2018), Niaki and Nonino (2017)
	• Small size of the focal company	Kianian et al. (2016)
	• Demand rate	Knofius et al. (2016).
	• Type of transition from conventional manufacturing to AM, company size, aim AM is used for	Niaki and Nonino (2017)
	• Demand, the company's manufacturing strategy	Khajavi et al. (2014)
	• Focal company's customers, customer sensitivity to price, delivery lead time	Muir and Haddud (2018)
Environment-related	• Availability of industry standards	Martinsuo and Luomaranta (2018), Hannibal and Knight (2018)
	• Role of AM in global manufacturing strategies of multinationals	Laplume *et al.* (2016)
	• Geographical location	Durach et al. (2017)
	• Customers' perception of brand, aesthetics, and authenticity	Hannibal and Knight (2018)
	• Environment	Le Bourhis et al. (2013)
Supply-related	• Support from the supply chain	Martinsuo and Luomaranta (2018)
	• Supply risk	Muir and Haddud (2018)
	• Supply chain flexibility as a mediator of the relation between AM and supply chain performance	Delic and Eyers (2020)
	• Supply chain integration	Niaki and Nonino (2017)

Although these studies establish more and less important factors based on their individual contexts, it is difficult to compare the importance of factors across studies precisely because of this richness in contexts and foci. A much smaller group of studies addresses this problem by compiling lists of factors and prioritizing these. Table 3-2 presents an overview of the six studies that have studied the relative importance of various factors across several AM technologies.

Table 3-2. Overviews of empirical studies that prioritize factors for the selection of various AM technologies.

Source	Method and derivation of factors	Context
Schniederjans (2017)	Survey, statistical analysis; diffusion of innovation theory (DOI), theory of technology adoption and usage	270 top-management representatives from US manufacturing firms
Schniederjans and Yalcin (2018)	Structured interviews, non-parametric statistical analysis; 16 factors from the five most mainstream innovation adoption theories	63 top-managers from US manufacturing firms
Yeh and Chen (2018)	Group decision analytic hierarchy process; non-systematic AM literature review fitted into technology-organizational-environment-cost framework	18 upper management-level experts, Taiwanese manufacturing industry
Hasan *et al*. (2019)	Delphi study; factors for mass adoption of AM in conventional manufacturing processes according to participants	Eight participants from the US and UK, both from academia and industry
Marak et al. (2019)	Survey, statistical analysis, DOI theory	92 Indian firms
Niaki et al. (2019)	BWM analysis, factors collected in a qualitative survey	88 companies across 22 countries (survey), 12 AM experts (BWM)

	Least important factors	Most important factors
	• Trialability • Observability • Social influence	• Relative advantage • Compatibility • Facilitating conditions • Performance expectancy
	• Complexity, effort expectancy • Perceived behavioral control • Perceived ease of use • Facilitating conditions • Trialability • Mimetic pressures, observability	• Performance expectancy • Relative advantage • Perceived usefulness • Compatibility • Social influence • Coercive pressures
	• Government policy • Top management support • Organizational readiness • Technology infrastructure	• Cost (material, machine, labor) • Technology (relative advantage) • Environment (partners)
	• Process automation • Market demand • Public acceptance • Manufacturing speed	• AM-adapted technical support and services • Cost of products, production, and post-processing • Machine tolerances, process stability, part-to-part variability • Availability of quality assurance protocols • Availability of materials, material property data, and print parameters • Increasing acceptance by large companies
	• Compatibility • Observability	• Relative advantage • Trialability • Ease of use
	• Environmental and social benefits • Customer expectation • Technology adaptability • Business and market expectation	• AM enabling creativity and innovation • Design complexity and customization • Low-volume production • Quick and economical prototyping • Cost and time savings

Although these studies draw on different theoretical frameworks and empirical contexts, all find that, in a broader sense, relative (technological) advantage is an important factor, though with differences in detailedness. However, the studies also disagree on several factors: trialability, social influences, facilitating conditions, and compatibility are mentioned both amongst the most and least important factors. Table 3-2 clearly shows that more than half of the studies draw on the US as a research context.

Further, [1] comparing studies that study factors for AM selection in general (Table 3-1) and studies that prioritize factors for AM selection (Table 3-2) shows that these two groups of studies use different factors. Studies in Table 3-1 mention factors that are partly very specific and may be idiosyncratic to AM, whereas studies on the prioritization of factors in Table 3-2 frequently draw on perceived innovation attributes from the technology acceptance literature. Perceived innovation attributes can be used in contexts where the requirements for technology selection do not (yet) follow from practice, as the study may concern potential users only. This, for instance, is the case in Yeh and Chen (2018), who consult manufacturing industry experts with roles in production, marketing, and R&D, but without specifying whether these experts do have actual experience with AM. Similarly, Schniederjans (2017) and Marak et al. (2019), and Schniederjans and Yalcin (2018) relied on mostly non-AM users in their studies.

3.2.3. Literature study on factors for the selection of AM technology[2]

In addition to the AM-specific literature in Table 3-1 and Table 3-2, we also referred to seminal work on standard dominance (van de Kaa et al., 2011), technology diffusion (Ortt, 2010b), business models (e.g., Demil & Lecocq, 2010; Joyce & Paquin, 2016), and technology acceptance (Davis, 1989). To obtain a complete set of factors for the selection of AM technologies, a literature search on ISI Web of Science was conducted using keywords related to acceptance, adoption, diffusion, innovation (with an asterisk, e.g., accept*) in combination with additive manufacturing or synonyms thereof. After removing purely technical or conceptual articles, this led to the inclusion of 47 articles in the final study.

1 This paragraph is not included in the paper as published in Journal of Manufacturing Technology Management.

2 The literature study was conducted as a team-effort within the IAMRRI project.

The literature study produced a list of 168 factors across eleven categories, though with much overlap and partly excessive level of detail. Hence, we removed duplicates, condensed excessively detailed factors into overarching concepts, and deleted barriers that were also formulated as factors. For example, the factor *capital requirement* was deleted, as it is very similar to *relative price/ cost/ effort*. The level of detail was reduced by combining *quality, material consumption, production time, and user-friendliness* into *relative technological performance*. The barrier *unavailability of skilled operators* was deleted, as it is also captured in the factor *sufficient education and skills development*. We concluded with 39 factors grouped across several stakeholders, the innovation itself, and the environment in which the innovation is selected, following the structure in Table 3-1.

We distinguish between *demand-side innovator* and *supply-side innovator*. *Demand-side innovator* refers to the customer as it ‘demands' innovations in the market. The customer could demand either AM machines or products and services based on AM. We refer to it as innovator to acknowledge that the introduction of a new technology represents an innovative activity for the developer of the technology as well as for the first-time user. In our situation, the demand-side innovator is the manufacturing company that adopts and implements AM technologies into its production process and develops new products and services based on it. *Supply-side innovator* refers to the actor that introduces an innovation in the market. In our situation, the supply-side innovator is the company that develops and produces AM machines to cater to the needs of the demand-side innovator. The *innovation itself* refers to the innovation that is introduced in the market by the supply-side innovator and that is adopted by the demand-side innovator. In our situation, the innovation is the AM machine or technology. We assume that the demand-side innovator has an *innovation support strategy* that describes efforts to implement the innovation into its existing production lines successfully. *Other stakeholders* refers to all other actors that influence this process, such as regulators and standardization organizations. All these activities take place against the background of *environmental-level factors*, such as the degree of market uncertainty. The category *business model* comprises factors that describe properties of business models in AM across different actors. Table 3-3 presents detailed descriptions of the factors.

Table 3-3. Factors for the selection of AM technologies from the perspective of innovation and technology adoption.

Factor	Definition
Innovator characteristics (demand-side)	
Customer level of education	Ability of the customer to utilize the innovation (Dedehayir et al., 2017).
Customer resources	Current financial condition of the customer who demands AM machines or products and services based on AM (Willard & Cooper, 1985).
Market demand	Customers' current and forecasted demand (Dedehayir et al., 2017).
Customer installed base (previous, current, potential)	Number of units in which the innovation was in use (previous), is in use (current), or will potentially be in use (potential) (Greenstein, 1993).
Intended frequency of use	Rate at which the product is planned to be used (Steenhuis & Pretorius, 2016).
Innovation characteristics (innovation itself)	
Relative technological performance	Comparison of the product's characteristics to other alternatives' characteristics (Schumpeter, 1934), for example, in terms of reliability, defect rate, or ease of use (Baumers, Tuck, et al., 2016).
Compatibility	Refers to whether two interrelated entities are compatible, whether older generations of a product are compatible with newer ones, also in terms of capabilities and radicalness of innovation (de Vries, 1999).
Flexibility	Incremental costs of adapting the innovation to new customer needs, developments, etc. (van de Kaa et al., 2011).
Perceived risk	Perceived likelihood that something will fail, and the perceived seriousness of the consequences if it does fail (Garbarino & Strahilevitz, 2004).
Relative price/ cost/ effort	Cost of acquiring the innovation, including capital requirement, cost of taking it into use, and training cost (Baumers, Dickens, et al., 2016).
Complementary goods and services	Availability of goods and services that are consumed together with the innovation (e.g., metal powders) (Teece, 1986).
Innovator characteristics (supply-side)	
Financial strength	Financial means that are at the disposal of organization to support the innovation, both current and prospective financial means (Willard & Cooper, 1985).
Brand reputation and credibility	Trust in the brand, benefits for society, and potential threats (Corkindale & Belder, 2009).

Table 3-3. Continued.

Factor	Definition
Operational supremacy	Innovator's effectiveness in exploiting its resources relative to the effectiveness of the competitors (Schilling, 2002).
Learning orientation	Innovators capacity to acquire skills and absorb information but also to increase its absorptive capacity (Agarwal et al., 2004).
Efficiency of production process	Characteristics of the production process, e.g., in terms of necessary ancillary process steps, build time, or energy consumption (Baumers, Tuck, et al., 2016).
Enabling infrastructure, technology, or production method	Necessary infrastructure for the innovation to unfurl its utility, e.g., high-power grid for charging stations for electric cars (Ortt, 2017).
Innovation support strategy	
Pricing strategy, price structure	"All actions taken to create market share through strategically pricing the products in which the format has been implemented" (van de Kaa et al., 2011, p. 1404).
Appropriability strategy (IPR)	Efforts to protect the innovation against imitation by competitors (J.-R. Lee et al., 1995).
Timing of entry	Strategic choice of a first market introduction of the innovation (van de Kaa et al., 2011).
Marketing communications	Communication with customers to manage expectations, e.g., by using strategic pre-announcements, including sense of mission, lobbying activities, or communicability (Shapiro & Varian, 1998).
Distribution strategy	Usage of the distribution system for strategic purposes (Willard & Cooper, 1985).
Commitment (supply-side innovator)	Attention an innovation gets from the actors involved, in terms of support, usually in times of low returns on investment (Willard & Cooper, 1985).
Network formation and coordination strategy	Future direction and plan of action for forming and coordinating a network (Ortt, 2010b).
Other stakeholders	
Big Fish	Actors who can exert influence on the market through their buying power (Suarez & Utterback, 1995).
Regulator	Public sector officials who specify regulations for a geographic area, for example, pertaining to liability (Suarez & Utterback, 1995).
Standardization organization	Public sector agencies or networks that develop and publish standards, such as IEEE or ISO (Wu et al., 2018).
Judiciary	Legal system that interprets and applies laws as a means to solve conflicts (van de Kaa et al., 2011).

Table 3-3. Continued.

Factor	Definition
Insurance company	Companies that spread risk among insurance policyholders (Rothman, 1980).
Environmental-level factors	
Bandwagon effect	Users choosing the same solution that others already have chosen for a similar problem (de Vries, 1999).
Market uncertainty	Customers hesitant to adopt when level of uncertainty is too high, e.g., rate of change, number of options available or unforeseen (micro) events including international political conflicts (van de Kaa et al., 2011).
Switching costs	Cost of switching between competing technologies or innovations, including resistance to change (Suarez, 2004).
Availability of rules and standards	Rules and standards available to promote the use of a technology (Ortt, 2010b).
Job opportunities	Perceived attractiveness of an industry as seen by job-seekers, relative to other industries (Joyce & Paquin, 2016).
Sufficient education and skills development	Opportunities to upgrade the skills of workers according to needs of the AM industry (Kianian et al., 2015).
Dissemination of AM in society	Communication about AM as a production method in society. Higher dissemination increases familiarity with the technology (Steenhuis & Pretorius, 2016).
Business model	
Imitability, scalability, and integrability	Extent to which the innovation/business model can be imitated, whether there is a significant cost and disadvantage for another organization to duplicate the innovation/business model, whether it can respond to increases in demand, and whether it can be integrated with the whole value chain (Demil & Lecocq, 2010)
Failure to identify actor or stakeholders	Inability to identify all actors and stakeholders in the business ecosystem (Joyce & Paquin, 2016).
Failure to consider influencing factors	Lack of awareness of trends such as potential technology substitution and inability to adjust the business model accordingly (Chesbrough, 2010).

3.3. Methodology

3.3.1. Best worst method

AM technology selection represents a multi-criteria decision-making problem. The methodology used to analyze the relevant factors and determine their corresponding weight is the BWM (Rezaei, 2015, 2016). The BWM stands out with relatively few comparisons compared to other methods such as Analytic Hierarchy Process (AHP), whilst still delivering highly reliable weighs (Rezaei, 2015).

A MCDM problem usually takes the following form:

$$A = \begin{matrix} & \begin{matrix} c_1 & c_2 & \cdots & c_n \end{matrix} \\ \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} & \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{bmatrix} \end{matrix} \quad (3\text{-}1)$$

where $\{c_1,c_2,\ldots,c_n\}$ is a set of criteria, $\{a_1,a_2,\ldots,a_m\}$ is a set of possible alternatives, and $\{Pij\}$ is the score of alternative i on criterion j. For the choice of a most promising alternative, an alternative with the highest overall value needs to be determined. Therefore, weights are attached to the criteria, denoted as $\{w_1,w_2,\ldots,w_n\}$, for which $w_j \geq 0$ and $\sum w_j = 1$. The following term establishes the value of alternative i, denoted as Vi:

$$V_i = \sum_{j=1}^{n} w_j p_{ij} \quad (3\text{-}2)$$

The BWM is based on pairwise comparison to derive the factor weights. As its name suggests, the decision maker needs to identify the best and the worst among the criteria, which will be compared to the remaining criteria in the next step. To determine the weights of the criteria, a maximin problem is formulated and solved. A consistency ratio indicates the reliability of the decision maker's choices in the BWM.

The linear BWM can be completed in five steps (Rezaei, 2015, 2016):

1. A set of decision-making criteria (factors) $\{c_1, c_2, \ldots, c_n\}$ needs to be determined (see Table 3-3).
2. The best (e.g., most desirable or important) and the worst (e.g., least desirable or important) factor need to be identified.
3. The preference of the best criterion over all other criteria needs to be indicated using numbers from 1 to 9, where 1 indicates equal importance and 9 indicates most different importance. This results in the Best-to-Others vector:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn},) \tag{3-3}$$

   a_{Bi} indicates the preference of the best criterion *B* over criterion *j*.

4. The preference of all criteria with respect to the worst criterion need to be determined using numbers from 1 to 9. Again, 1 indicates equal importance and 9 indicates most different importance. This results in the Other-to-Worst vector:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW},) \tag{3-4}$$

   a_{jW} indicates the preference of the criterion j over the worst criterion *W*.

5. Lastly, the optimal weights $(w^*_1, w^*_2, \ldots, w^*_n)$ need to be derived. This can be done by minimizing the maximum absolute differences, considering that weights must not be negative and that the sum of all weights must be equal to 1. This results in the following minmax model:

$$minimax_j = \left\{ \left| \frac{w_B}{w_J} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \tag{3-5}$$

$$s.t. \tag{3-6}$$

$$\sum_j w_j = 1 \tag{3-7}$$

$$w_j \geq 0, for\ all\ j \tag{3-8}$$

The minimax model is then transformed:

$$Min \xi \tag{3-9}$$

$$s.t. \tag{3-10}$$

$$\left| \frac{w_B}{w_J} - a_{Bj} \right| \leq \xi, for\ all\ j \tag{3-11}$$

$$\left|\frac{w_J}{w_W} - a_{jW}\right| \leq \xi, for\ all\ j \quad (3\text{-}12)$$

$$\sum_j w_j = 1 \quad (3\text{-}13)$$

$$w_j \geq 0, for\ all\ j \quad (3\text{-}14)$$

The optimal weights and the reliability of the weights ξ^* (consistency of the comparisons) are obtained by solving this equation. The closer ξ^* is to zero, the higher the consistency and thus, the reliability of the comparisons. The highest-scoring alternative can be selected by comparing the alternatives with respect to their overall values as determined in equation (3-2), whilst higher values are more desirable.

3.3.2. Data collection

The questionnaires were distributed to AM experts from various European countries. To qualify as experts, we required comprehensive knowledge of AM. Our sample of nine experts can be seen as a transdisciplinary team along the innovation value chain from both academia and the industry, all of whom are involved in studying and creating AM technologies. The data was collected in May 2019. Table 3-4 gives an overview of their backgrounds.

The first step of the BWM is to determine a set of decision criteria (factors) divided into categories (see Table 3-3). To compare the factors, we used a two-tiered approach: The steps described above were followed to determine the factor weights (by comparing factors within categories) and category weights (by comparing the categories). Multiplying factor weights and category weights leads to *global weights*.

To ensure the reliability of the study, the participants were given definitions of the factors. Instructions and the opportunity to ask questions were offered during a webinar. After completion, the participants were asked to rank the importance of the factors based on intuition and gut feeling, and to elaborate on their choice in a few sentences. Some of the experts were interviewed for further elaboration of their decision and asked to reflect on the results of the study.

Table 3-4. Overview of interviewed experts.

Expert	Background	Expertise (except for AM technologies)	Function and Organization
1	Industry	3D reconstruction engineer	Engineer, private company
2	Academia	Material science	Researcher, university
3	Academia	Academic entrepreneurship	Lecturer/ assistant professor, university
4	Academia	Industrial management	Researcher, university
5	Industry	Management	Manager, private company
6	Academia	Innovation management and entrepreneurship	Associate professor, university
7	Industry	Material science	Engineer/ manager, private company
8	Industry, Academia	Material science	Professor, university, private company
9	Academia	Technology foresight	Researcher, research and technology organization

3.4. Results

3.4.1. Relative factor weights

Table 3-5 shows that the most important factors in the context are market demand (0.064), relative technological performance (0.064), imitability, scalability, integrability (0.064), failure to identify actors/ stakeholders (0.061), and commitment (0.049).

Table 3-6 presents the consistency ratios for the comparison presented in Table 3-5. Out of the 72 comparisons, only three show a ξ^* of larger than 0,2 (highest ξ^*: 0,392), whilst 43 comparisons have a ξ^* of below 0,1 – concluding that the comparisons are consistent (Rezaei, 2015). The highest ξ^* of 0,392 affects the results of expert 8 regarding the comparison of innovator characteristics.[3] None of these factors turned out to be among the highest-ranking factors, regardless of whether expert 8 was included in the final results. We hence conclude that the high ξ^* of this comparison did not qualitatively affect the results.

3.4.2. Robustness of the results

The BWM itself cannot consolidate the resulting weights of different decision-makers, so results are typically aggregated by calculating average weights (Mohammadi and Rezaei, 2019). We test for the potential influence of outliers on the top five most important factors by excluding individual experts from the sample one at a time, an approach known as 'leave-one-out' and common in economics (e.g., Caballero et al., 2004). After calculating the average global weights, we compared the top five most important factors with respect to the inclusion of the same factors in the top five. This test showed that the top five most important factors are identical in five of the nine reduced samples (though with different rankings). In the other four cases, only one factor was different, and this difference did not correlate with the background of the experts (industry vs. academia), showing that the addition of further experts to our sample would not likely alter the results significantly.

3 This and the following two sentences are not included in the paper as published in Journal of Manufacturing Technology Management.

Table 3-5. Relative factor weights for the selection of metal AM.

Factor/ category description	**Global weights per expert**		
	1	2	3
Innovator characteristics (demand-side)	**0.107**	**0.333**	**0.213**
Customer level of education	0.017	0.083	0.032
Customer resources	0.025	0.041	0.049
Market demand	0.044	0.141	0.085
Customer installed base (previous, current, potential)	0.008	0.055	0.032
Intended frequency of use	0.013	0.013	0.015
Innovation characteristics (innovation itself)	**0.085**	**0.139**	**0.213**
Relative technological performance	0.004	0.057	0.018
Compatibility	0.019	0.011	0.065
Flexibility	0.010	0.026	0.065
Perceived risk	0.008	0.004	0.011
Relative price, cost, effort	0.032	0.016	0.036
Complementary goods and services	0.013	0.025	0.018
Innovator characteristics (supply-side)	**0.142**	**0.028**	**0.213**
Financial strength	0.031	0.003	0.065
Brand reputation and credibility	0.007	0.002	0.036
Operational supremacy	0.013	0.001	0.015
Learning orientation	0.021	0.013	0.036
Efficiency of production process	0.016	0.002	0.024
Enabling infrastructure/ technology/ production method	0.054	0.029	0.024
Innovation support strategy	**0.351**	**0.083**	**0.121**
Pricing strategy, price structure	0.075	0.006	0.016
Appropriability strategy (IPR)	0.030	0.002	0.024
Timing of entry	0.038	0.009	0.024
Marketing communications	0.025	0.029	0.040
Distribution strategy	0.011	0.007	0.004
Commitment (supply-side innovator)	0.050	0.050	0.020
Network formation and coordination strategy	0.121	0.018	0.008
Other stakeholders	**0.071**	**0.139**	**0.081**
Big fish	0.012	0.073	0.026
Regulator	0.030	0.030	0.026
Standardization organizations	0.018	0.018	0.015
Judiciary	0.009	0.011	0.010
Insurance company	0.003	0.006	0.004

Global weights per expert (Continued)						Average local weights	Average global weights	Rank
4	5	6	7	8	9			
0.249	**0.092**	**0.079**	**0.193**	**0.209**	**0.155**		**0.181**	
0.098	0.047	0.004	0.064	0.075	0.007	0.249	0.047	6
0.042	0.011	0.007	0.026	0.019	0.077	0.189	0.033	12
0.070	0.019	0.035	0.074	0.083	0.024	0.344	0.064	1
0.014	0.009	0.011	0.019	0.024	0.031	0.123	0.023	21
0.025	0.005	0.022	0.010	0.008	0.016	0.095	0.014	28
0.249	**0.215**	**0.368**	**0.310**	**0.353**	**0.155**		**0.232**	
0.094	0.079	0.120	0.109	0.077	0.014	0.092	0.064	2
0.012	0.034	0.048	0.063	0.077	0.024	0.153	0.039	10
0.023	0.025	0.015	0.063	0.125	0.024	0.153	0.042	9
0.023	0.020	0.039	0.021	0.031	0.004	0.026	0.018	24
0.058	0.050	0.097	0.042	0.031	0.036	0.230	0.044	7
0.039	0.007	0.048	0.013	0.012	0.053	0.346	0.025	17
0.249	**0.154**	**0.119**	**0.129**	**0.139**	**0.103**		**0.142**	
0.047	0.036	0.011	0.015	0.033	0.016	0.187	0.029	15
0.047	0.006	0.019	0.021	0.022	0.024	0.137	0.020	23
0.012	0.018	0.028	0.015	0.008	0.040	0.129	0.017	26
0.082	0.015	0.004	0.006	0.033	0.004	0.174	0.024	19
0.031	0.054	0.014	0.021	0.033	0.010	0.155	0.023	20
0.018	0.022	0.051	0.055	0.011	0.013	0.217	0.031	13
0.035	**0.336**	**0.095**	**0.077**	**0.105**	**0.155**		**0.151**	
0.004	0.059	0.003	0.016	0.003	0.040	0.138	0.025	18
0.006	0.040	0.008	0.008	0.010	0.004	0.102	0.015	27
0.006	0.123	0.010	0.006	0.014	0.025	0.159	0.028	16
0.010	0.011	0.007	0.026	0.021	0.025	0.203	0.021	22
0.001	0.023	0.012	0.011	0.008	0.025	0.085	0.011	30
0.031	0.028	0.061	0.036	0.113	0.056	0.141	0.049	5
0.004	0.054	0.038	0.003	0.014	0.012	0.173	0.030	14
0.073	**0.058**	**0.068**	**0.034**	**0.041**	**0.155**		**0.080**	
0.019	0.033	0.033	0.016	0.004	0.084	0.385	0.033	11
0.019	0.008	0.008	0.006	0.015	0.007	0.231	0.017	25
0.019	0.007	0.010	0.006	0.007	0.026	0.180	0.014	29
0.011	0.006	0.014	0.002	0.004	0.017	0.116	0.009	31
0.004	0.003	0.003	0.003	0.011	0.020	0.088	0.007	35

Table 3-5. Continued.

Factor/ category description	Global weights per expert		
	1	2	3
Environmental-level factors	**0.030**	**0.069**	**0.037**
Bandwagon effect	0.006	0.014	0.003
Market uncertainty	0.004	0.005	0.005
Switching cost	0.011	0.009	0.013
Availability of rules and standards	0.003	0.002	0.005
Job opportunities	0.001	0.007	0.001
Sufficient education and skills development	0.003	0.007	0.003
Dissemination of AM in society	0.002	0.006	0.005
Business model	**0.213**	**0.208**	**0.121**
Imitability, scalability, integrability	0.120	0.034	0.020
Failure to identify actors/ stakeholders	0.027	0.161	0.035
Failure to consider influential factors	0.067	0.013	0.066

Table 3-6. Consistency ratios for the comparisons.

Consistency ratio	Expert		
	1	2	3
ξ^* categories	0.076	0.083	0.029
ξ^* Innovator characteristics (demand-side)	0.057	0.071	0.055
ξ^* Innovation characteristics (innovation itself)	0.081	0.151	0.039
ξ^* Innovator characteristics (supply-side)	0.063	0.137	0.034
ξ^* Innovation support strategy	0.085	0.086	0.065
ξ^* Other stakeholders	0.077	0.131	0.044
ξ^* Environmental-level factors	0.066	0.154	0.077
ξ^* Business model	0.063	0.211	0.042

Global weights per expert (Continued)						Average local weights	Average global weights	Rank
4	5	6	7	8	9			
0.048	**0.030**	**0.032**	**0.064**	**0.084**	**0.022**		**0.046**	
0.005	0.003	0.007	0.004	0.002	0.013	0.208	0.006	36
0.014	0.003	0.004	0.008	0.006	0.001	0.121	0.006	38
0.005	0.002	0.011	0.008	0.004	0.002	0.178	0.007	33
0.014	0.001	0.003	0.021	0.009	0.003	0.137	0.007	34
0.002	0.010	0.001	0.002	0.012	0.002	0.097	0.004	39
0.003	0.004	0.002	0.012	0.028	0.002	0.132	0.007	32
0.003	0.007	0.005	0.004	0.019	0.003	0.127	0.006	37
0.097	**0.115**	**0.238**	**0.193**	**0.070**	**0.256**		**0.168**	
0.016	0.019	0.024	0.123	0.006	0.209	0.319	0.064	3
0.052	0.034	0.163	0.050	0.008	0.023	0.353	0.061	4
0.028	0.062	0.052	0.019	0.056	0.023	0.329	0.043	8

Expert (Continued)					
4	5	6	7	8	9
0.042	0.124	0.108	0.076	0.066	0.054
0.112	0.103	0.126	0.072	0.104	0.109
0.087	0.104	0.201	0.053	0.083	0.114
0.047	0.118	0.117	0.090	0.392	0.082
0.066	0.111	0.127	0.077	0.080	0.057
0.029	0.135	0.121	0.088	0.150	0.118
0.044	0.100	0.097	0.060	0.111	0.092
0.042	0.042	0.183	0.140	0.133	0.000

3.4.3. Interpretation of factor weights

Market demand, the highest-ranking factor of this study, refers to current and forecasted market demand. Currently, AM technologies cater to the demands of various small market niches, and AM companies have to engage in customer education to stimulate demand (Martinsuo & Luomaranta, 2018). It would certainly be easier for AM companies if there was a better understanding of the technology in the market and if they could cater to a strong demand. After the data collection and when the results where known, discussions with expert 4 highlighted the dichotomy with respect to demand for AM, how can customer demand be currently lacking and yet be the most important factor? AM is successfully catering to the needs of various niches, but on the other hand, the demand for AM is not high enough to enable the transition to large-scale production, which is still limited to few companies and applications (Ortt, 2017).

It is important to understand the situation that demand is the most important factor, yet demand is still limited. For major innovations, this is more often the case. At first, there is most often only a small segment of users that knows the innovation, can value its benefits, can work with its initial limitations because the technology is not yet fully mature, and has a need that is intense enough to overcome all barriers that come with an emerging technology. One of those barriers that a major innovation may initially suffer from is the lack of standards or a dominant design. As a dominant design for AM technology has not yet been selected (Steenhuis & Pretorius, 2016), demand might be held back by different expectations in the market regarding the form and functionality of AM technologies. Tauber (1974), almost fifty years ago, described that market research discourages major innovations because the small niche of users that need the innovation urgently is not large enough to emerge in a random sample exploring the market need for that innovation.

Relative technological performance compares the technological performance of the focal technology to other alternatives. As AM is struggling with part-to-part and machine-to-machine variability (Martinsuo & Luomaranta, 2018), it is no surprise to find this factor amongst the highest-ranked. Contemporary metal parts production technologies, such as casting, are well developed, and hence it is possible to produce parts with extremely low variability in specification. AM technologies are newer and perform very well in creating custom products, yet often suffer from higher variability in specification when used to produce larger numbers of parts. In practice, a relatively high proportion of AM-manufactured parts are condemned for further use. This factor was also mentioned to be the most important factor in the intuitive choice. Discussing the results, one respondent noted that *relative technological performance* leads to a unique selling point, competitiveness, higher value of products, or to lower cost. Respondent 5 argues that it is associated with higher earnings before interest and tax. Higher-performing AM technology may, for example, reduce the amount of necessary post-processing of the parts and thereby increase profitability.

Regarding the business model factors (*imitability, scalability, integrability,* and *failure to identify actors/ stakeholders*), expert 2 noted that business models are the interface between products, markets, and customers. The competitiveness of AM technology depends on the value it offers. As it often is more expensive than other manufacturing techniques, firms rely on AM to leverage some of its unique characteristics, rather than just replacing an existing process (Rayna & Striukova, 2016). Production of final parts with AM loosens the link between product and production site, as any AM machine that fulfills the manufacturing requirements may become a complementary asset (ibid.) Taken together, new forms of value creation, products, and service offerings likely feed into new business models.

Commitment is the support actors give to an innovation. Currently, AM has a small market share in the overall manufacturing market, and many actors lack knowledge of AM and support from the supply chain (Martinsuo & Luomaranta, 2018; Murmura & Bravi, 2018). By supporting AM, for example, by engaging in customer education (ranked 6th), demand for AM could be increased, ultimately benefiting the selection of AM.

3.5. Discussion

3.5.1. The main factors and how they can be assessed in practice

The results suggest that the selection of metal AM technologies depends most on market demand and on their relative technological performance. Given that there are significant advantages attached to applying AM as a novel manufacturing technique, one would expect market demand for this technology to be high. In addition, as that factor is the most important for the selection of AM, one would expect AM to be the dominant metal manufacturing technology. However, counterintuitively, this is not the case and the question is why this is not the case.

First, in practice, assessing *market demand* and *relative technological performanc*e is not straightforward. AM is an emerging technology that is mainly applied in specific market niches instead of being a mainstream and dominant manufacturing technology (Ortt, 2017). A pattern of development and diffusion in which emerging technologies are first developed and applied in specific market niches, before a standard version of the technology emerges and is applied in mainstream markets, is well documented in theory (Geels, 2002; Tushman & Rosenkopf, 1992) and practice (Ortt, 2010b). Examples of such market niches for AM are prototyping and local production of specific spare parts (Ortt, 2016). The consequences of AM application in different market niches are significant. The demands differ per niche, and AM performance can be seen as fundamentally different per niche (although the focus of this study, metal AM, is already a niche within AM).

Alternative technologies of AM differ per market niche, and hence the relative performance of AM compared to alternative technologies also differs per niche. Moreover, the performance requirements are significantly different in such early market niches in which AM is applied. Similarly, the factor *relative technological performance* is also well-reflected in Martinsuo and Luomaranta's (2018) work as they find numerous challenges that fall under this factor, showing that the performance of AM technology is idiosyncratic to the specific context. The consequences of applying AM in subsequent market niches are also significant for other market factors of this study. The degree of *imitability, scalability, and integrability* (ranked third), and the *failure to identify actors and stakeholders* (ranked fourth), may markedly differ for subsequent market niches.

Cost, compatibility, and regulation may become increasingly important when AM grows to be a mainstream manufacturing technology. For market niches such as prototyping, however, AM is a cheap and fast technology compared to the old way of creating prototypes. A similar conclusion is possible for the use of AM in creating dental prostheses or specialized spare machine parts on location. In general, AM may be more expensive than contemporary manufacturing technologies, but for the niches in which AM is first applied, that is not the case.

3.5.2. Comparison to studies with other results

The importance of *relative technological performance* is in line with recent work by Martinsuo and Luomaranta (2018) and Schniederjans (2017), who find that technology-related adoption challenges are the third most mentioned and that relative technological advantage is a significant driver of managers' intention to adopt AM. Comparable conclusions are reached in the other studies in Table 3-2 (Hasan et al., 2019; Marak et al., 2019; Schniederjans & Yalcin, 2018; Yeh & Chen, 2018). The results provide evidence for Suarez's proposition (2004) that technological characteristics play an important role in the early phases of the technology selection process. Martinsuo and Luomaranta (2018) report that subcontractors are especially exposed to market demand as they cannot invest until they have orders.

Yeh and Chen (2018) find that *cost* and *environment* are the most important factors for the selection of AM in the Taiwanese manufacturing industry. Le Bourhis et al. (2013), Dwivedi et al. (2017), Martinsuo and Luomaranta (2018), and Niaki et al. (2019) also consider *cost* to be an important factor and mention that if costs are too high, they could create a barrier. In our study, *relative cost, price, effort* is represented in the top 10, but with a significantly lower weight compared to the top three factors. This might be due to differences in the empirical context of studies related to geography and technology (e.g., metal AM versus AM in general). Yeh and Chen (2018) analyze AM as a whole rather than metal AM specifically. Le Bourhis *et al*. (2013) assess the environmental impact of AM, and Dwivedi *et al*. (2017) analyze barriers to adoption in the Indian automotive sector. Schniederjans and Yalcin (2018) find that *compatibility* is a high-ranking factor, contrasting the results of this study, as compatibility is ranked 10th with a weight of roughly half of the highest-ranking factor. This could be due to the differences in the definition of compatibility. Schniederjans and Yalcin (2018) define it as an "innovation's consistency with existing values, past experiences and needs" (p. 515), whereas the definition in this study is more focused on technical compatibility (see Table 3-3). Environmental factors such as *availability of rules and standards*, or *market uncertainty* have similarly low weights as in other studies. In Yeh and Chen (2018) and Le Bourhis et al. (2013), factors related to competitiveness, market trends, or policy had relatively low rankings, as were comparable factors in our study (e.g., *regulator*, *standardization organization*, *big fish*). Candi and Beltagui (2019) are an exception, suggesting that technological uncertainty moderates both innovation performance and business impact of AM. This means that high technological uncertainty likely amplifies advantages of AM such as no need for tooling or affordable customization that also relate to high-ranking factors such as *relative technological performance* (Khajavi et al., 2014).

The property of the BWM that the sum of the relative weights is equal to 1 has implications for the factor weights: the more factors in a BWM, the lower the average relative weight (see equation (3-7)). This is relevant when varying numbers of factors are compared per category, and it might explain to some extent why the factors in the category business model (only three factors compared to five to seven factors in the other categories) have high global weights. Nevertheless, this is only half of the story, as global weights are derived by multiplying category weights with local weights. Other BWM studies have not discussed the influence of a varying number of factors per sub-category. For example, in a study on the selection of bioethanol facility locations in Iran, three of the five highest-ranking factors stem from the smallest categories, ranging between two and five factors (Kheybari et al., 2019). In contrast, this is not the case in a study on standards for business-to-government data exchange (van de Kaa et al., 2018) or in the study on the selection of thermochemical conversion technology for biomass (van de Kaa et al., 2017).

3.6. Conclusion

This paper sought to answer the question "What are the most important factors for the selection of AM technology in the European context according to experts?" We conducted a literature study on relevant factors for AM technology selection, resulting in 39 factors. AM-specific literature together with seminal work on standard dominance, technology acceptance, business models, and innovation diffusion was analyzed to develop a more robust framework. The 39 factors were prioritized in the context of metal AM by a group of European AM experts using the BWM method, followed by semi-structured interviews. This revealed new, other than cost-related priorities and increased the understanding of the factor prioritization. The four highest-ranking factors are: 1) market demand, 2) relative technological performance, 3) imitability, scalability, integrability, and 4) failure to identify actors/ stakeholders.

3.6.1. Theoretical contributions

The set of 39 factors contributes towards a more holistic view of technology selection compared to existing frameworks and could serve as a starting point for future studies on the selection of metal AM technology in specific but also technology selection in general. The factor prioritization for metal AM showed that the broad literature study across literature streams was beneficial, as none of the streams would have covered all factors on its own. The factors *commitment*, and *relative technological performance* originate from the literature on standard dominance (van de Kaa et al., 2011), technology diffusion (Ortt, 2010b), and AM adoption (e.g., Martinsuo and Luomaranta, 2018; Yeh and Chen, 2018), whereas the business model-related factors were solely mentioned in the AM adoption respectively business model literature (Demil & Lecocq, 2010; Joyce & Paquin, 2016). *Market demand* was solely mentioned in the AM adoption literature. Although the individual domains are powerful on their own, this indicates that a broad literature study is worth the effort. Relatedly, the current study can be seen as a response to a call for more multi-perspective research (Narayanan & Chen, 2012). The paper also offers explanations of why the factors are important based on literature and discussions with experts. In this respect, this study adds to a small but growing literature on prioritizing factors for AM adoption.

Further, this study also contributes to the MCDM and BWM methodology literature. The applicability of the BWM has already been confirmed in various studies that compared relatively few factors. Only one other study applied the BWM to an equally high number of factors. Malek and Desai (2019) derived relative weights for 39 barriers to sustainable manufacturing in Indian SMEs. The high consistency ratios of their study and the current study show that the BWM is well applicable to the comparison of more criteria based on a two-tiered system of category comparisons and criteria comparisons. Furthermore, we show how the 'leave-one-out' approach that is common in economics can serve as a robustness measure for a ranking of factors in BWM studies.

3.6.2. Practical contributions

Firms face uncertainty when choosing between alternative manufacturing technologies. The framework of factors proposed in this paper may reduce this uncertainty. Although there are some case-specific aspects to this comprehensive framework, it may be applicable to technology selection in general with only minor adjustments. The prioritization of factors for metal AM provides a starting point for organizations with limited resources that cannot address all factors simultaneously. For firms who want to enter the AM market, the most important factors might provide guidance in understanding the industry.

The results highlight the importance of the business model component with respect to AM technology, reflecting the network nature of the problem. AM companies should actively engage in market and network development as there is no big market they can easily address. In situations such as the writing of a business plan, the proposed framework may serve as a starting point or inventory of areas to address. Furthermore, this study analyses factors at a more abstract level as opposed to studies exploring few factors in more depth, highlights the complementary role of both study designs. More aggregate-level studies may help to place studies with a narrower scope in context, where the narrower-scoped studies add more detail by zooming in on specific factors.

3.6.3. Limitations and future research

This study is based on expert opinions from a sample of nine European experts. Although the results of this study proved robust, future research could replicate the findings in other contexts and based on different experts. Further research could also study specific factors in depth and identify managerial strategies to address factors that were identified as most important. When studying factors for technology adoption, one faces the dilemma of level of detail versus clarity. Too many factors are difficult to compare meaningfully, whereas using very broad factors could reduce the utility.

We have already discussed that the evaluation of the factors may depend on the actual market niche. Similarly, future studies could assess the factors according to three categories of actors that in their own way adopt AM-technologies or the result thereof. In a simplified value chain, Steenhuis et al. (2020) distinguish machine manufacturers that adopt the AM concept and produce AM machines, manufacturers adopting AM technology as part of their production process, and customers who adopt products created by AM technology. These represent three categories of actors that almost inevitably use different criteria to decide about adoption of AM-technology or AM-products because of their position in the supply chain and because of their difference in knowledge. In some way, the case of AM-technology shows that diffusion takes place by subsequent groups of actors in a chain.

Furthermore, future research could verify, based on hypothesis testing, whether the high-ranking factors of this study indeed correlate with or lead to the selection of AM technology. The current study focused on the selection of AM technology versus other manufacturing technologies. Future studies could focus on the selection of a dominant design for AM technology, as Steenhuis and Pretorius (2016) noted that a dominant design for AM technology has not yet been selected. Finally, future research could address how market factors such as market demand and relative technological performance (and the other high-ranking factors) not only differ in value but also in weight when they are assessed over time in different market niches.

Chapter 4

Complementor Participation in Platforms: Evidence from the 7th and 8th Generation of Video Game Consoles

This paper is co-authored with Geerten van de Kaa, Mark de Reuver, Amir Poyaan Afghari and Ranjan Prajapati. Earlier versions of this paper were presented at the 2020 Academy of Management meeting, the 2020 International Association for Management of Technology conference, and published as: Sobota, V. C. M., van de Kaa, G, de Reuver, M, Prajapati, R Complementor participation in platforms: Evidence from the 7th and 8th generations of video game consoles. *Proceedings of the 55th Hawaii International Conference on System Sciences*. Hawaii International Conference on System Sciences. https://doi.org/10.24251/HICSS.2022.810

Abstract

This chapter analyses strategies for platform owners to increase complementor participation on the platform. Specifically, it investigates how the dimensions breadth of content offerings, boundary resources, and exclusive content relate to complementor participation in platform-based ecosystems. We hypothesize that higher levels of each of these drivers increase the platform's attractiveness to future complementors and increase complementor participation. Based on negative binomial fixed effects regressions in the context of video game consoles, we find that breadth of content offerings and boundary resources, but not exclusive content, are positively related to complementor participation. The results have implications for the orchestration of platform ecosystems.

4.1. Introduction

Platform-based ecosystems have recently received increasing attention for describing competitive environments (Jacobides et al., 2018). Here, we define platforms as meta-organizations that federate and coordinate innovating and competing actors, facilitate economies of scale and scope, and entail a modular architecture (Gawer, 2014). When the complementarities between platform and complements are non-generic, ecosystems can emerge with the platform at the center (Jacobides et al., 2018). An ecosystem contains the platform leader, the providers of complementary goods (complementors, cop), and users (Ceccagnoli et al., 2012; Gawer & Cusumano, 2008). For example, in this study's context, video game consoles are platform-based ecosystems for which third-party game developers produce games that end users consume. Together, these actors form an ecosystem. When users decide whether to buy into either of the two, they often consider the number and quality of the available complementary products (complements, hereafter) next to the platform's characteristics. This effect is known as indirect network effects (Katz & Shapiro, 1985) and highlights the importance of complementors for the platform's overall success.

The participation of complementors on platforms and the availability of complements cannot be taken for granted (McIntyre & Srinivasan, 2017). Recent studies investigate drivers for platform adoption that can be sources of competitive advantage for complementors and hence strengthen the platform's position. Such drivers include, for instance, the platform's installed base composition in terms of early and late adopters (Rietveld & Eggers, 2018). Others have singled out factors expected to influence complementor participation and lie within the platform's sphere of influence. Such factors include moves by the platform owner, such as protection against external threats by the platform owner (Bagheri et al., 2016) or platform entry into the complementor space (Wen & Zhu, 2019). Others have studied resources such as technological advances across generations (Ozalp et al., 2018) or the provision of tools and regulations that serve as an interface between platform owners and complementors (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Petrik & Herzwurm, 2020). Again others have studied content-related aspects such as the breadth of content offerings (Broekhuizen et al., 2021) or content only published on the focal platform (Cennamo & Santaló, 2013; Corts & Lederman, 2009; A. Srinivasan & Venkatraman, 2010).

Three of these particularly relate to the positioning of a platform towards its complementors. These are the breadth of content offerings, the provision of tools and regulations that serve as an interface between platform owners and complementors (called boundary resources), and content that is only available on the focal platform (called exclusive content). These aspects are related as each is controlled by the platform and relates to the platform's positioning towards complementors and differentiation vis-à-vis competing platforms.

These factors are complementary as they capture different aspects of platform competition. Breadth of content offerings and exclusive content relate to indirect network effects. It also reflects choices regarding technological performance, such as Wii's move towards simple and intuitive gaming instead of high-end performance (Huse, 2010). Boundary resources relate to the modularity and expandability of the platform and to sharing technological capabilities. All three factors also relate to technology strategy.

Although the availability of boundary resources is known to relate to complementor participation positively, it still needs to be clarified how it relates to complementor participation when studied in concert with the other two factors. This matters as our understanding of coexisting complementor strategies and their influence on ecosystem outcomes need to be improved (Cenamor & Frishammar, 2021). This chapter addresses the following question: *How do these three factors affect complementor participation*?

We empirically study boundary resources jointly with the breadth of content offerings and exclusive content and examine how they affect complementor participation. The use of longitudinal data highlights the process aspect of our research. We study these issues based on longitudinal data on the seventh and eighth generations of video game consoles. This ecosystem consists of the game console (e.g., Sony PlayStation) with its platform leader (Sony in this example), video games (complements) that are compatible with this specific game console, and the users of video game consoles. The video game industry is dynamic and hence ideal for understanding complementor-platform dynamics. Several studies (e.g., Cennamo & Santaló, 2009; Rietveld et al., 2019) have used this setting based on its prototypical resemblance to platform ecosystems. Indirect network effects, short product cycles, and intense competition between and within generations characterize the video console industry (Clements & Ohashi, 2005).

We show how three factors inherent and unique to platform-based ecosystems affect the participation of complementors, which is essential for the ecosystem innovation process. The results show that breadth of content offerings and boundary resources, but not exclusive content, are positively related to complementor participation. This study sheds light on the dynamics of platform management by putting *federation* (Gawer, 2014) central, which in this case is the attraction of complementors. This is relevant as "...neither the existence nor the process of federation of complementors into a collective can be taken for granted ..." (Gawer, 2014, p. 1245). This study contributes to the literature on ecosystem orchestration (Gawer, 2014; Rietveld & Schilling, 2020), platform openness in general (Broekhuizen et al., 2021), and boundary resources in particular (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013) by studying three factors that affect complementors' intention to stay with a platform.

The chapter is structured as follows. Section 4.2 defines platforms and discusses peculiarities of contexts where platforms are technological infrastructures for complement development. Section 4.3 introduces the context of the study, video game consoles. Section 4.4 develops hypotheses on how exclusive content, boundary resources, and breadth of content offerings affect complementor participation. Section 4.5 presents the data of this study, the variables, and the estimation method. Section 4.6 presents the findings. Section 4.7 discusses the findings and contributions and concludes with directions for future research.

4.2. Theoretical background: complementor participation in platforms

In many industries, platform-based business models are a way to reduce complexity by sharing modules, components, and other assets (Halman et al., 2003; Scholten & Scholten, 2012) and by co-creating value outside the firm's boundaries (Parker et al., 2017). In some cases, a platform's existence leads to a platform ecosystem's emergence. Platform-based ecosystems differ from platforms in that complementarities between complements and platform are non-generic (Jacobides et al., 2018). Non-generic complementarities entail that, to partake, complementors have to commit by making investments that cannot be redeployed elsewhere. By joining the platform ecosystem, complementors can access the platform's end users. Complementary goods and services are primarily developed for the platform and increase the core platform's value (McIntyre & Srinivasan, 2017).

What is referred to as the platform consists of the platform owner and platform provider. In this study's context, the platform owner (e.g., Sony) develops and markets a platform (video game console, e.g., PlayStation). Complementors develop video games compatible with one platform (exclusive content) or multiple platforms (non-exclusive content). Users can use more than one platform (console), and complementors can develop for more than one platform, so the populations of potential users and complementors can overlap.

Several types of platforms have in common that the value of a platform to its users is dependent on indirect network effects, which refer to the incremental increase in value to users that originates from the number and quality of products and services on another side of the market. Theoretically, three different patterns are possible: A monotonic pattern would imply that each additional complement increases the platform's value to users. More likely, though, are decreasing returns where the additional value stemming from addition complements decreases. Lastly, a critical value of complements may exist above which users experience no additional benefits (Liebowitz & Margolis, 1999).

Its objective differs in contexts where the platform is not just a marketplace (Panico & Cennamo, 2020). If a platform offers the technological infrastructure for developing complementary innovations, it is vital to align complementor incentives with the platform ecosystem's objective (Cennamo & Santaló, 2019; Jacobides et al., 2018; Rietveld et al., 2019). Platforms facilitate economies of scope, defined as reducing costs by developing two products jointly instead of separately (Gawer, 2014). This can be achieved by following a modular approach to platform design (Baldwin & Clark, 2004). The architecture of a platform includes more stable components at its core and more variable components in its periphery (Baldwin & Woodard, 2009). In the case of video games, for example, the console is at the platform's core while the complements (video games) are at the periphery. For the most part, this stream views platforms as stable components at the core upon which innovation occurs on modules by using stable interfaces (Gawer, 2014) – an assumption questioned by digitalism, which has made interfaces more fluid (de Reuver et al., 2018; Eaton et al., 2015).

Modularity reduces complexity by splitting systems into components arranged according to a standardized architecture and connected via standardized interfaces. This modular architecture makes platforms suitable for facilitating innovation (Gawer, 2014), which aligns with modularity theory (Baldwin & Clark, 2000; Schilling, 2000). In this respect, modularity also facilitates innovation by reducing the scope of information designers have to work with, enabling more specialization and the division of innovative tasks (Garud & Kumaraswamy, 1995). Interfaces are crucial for modularity and innovation as they simultaneously divide and connect innovative activities (Baldwin & Clark, 2000).

To draw on the knowledge and capabilities of external innovations and to enable independent experimentation, platforms can publish boundary resources, which are the tools and regulations that mediate access to the platform's core (Ghazawneh & Henfridsson, 2013). Platform providers influence the degree of openness through boundary resources. In other words, boundary resources enable platform owners to shift design capabilities to complementors (von Hippel & Katz, 2002). Boundary resources make it easier to develop diverse complements for end users, thus combining economies of scale with product differentiation and creating incentives for complementors (Ghazawneh & Henfridsson, 2013). Boundary resources are hence a facet of platform openness (Chesbrough, 2002).

Openness covers both the technological dimension (e.g., accessibility of interfaces) and the organizational dimension (e.g., conditions to use the interfaces) (Nikayin et al., 2013). Open standards are a means to achieve technical openness (West, 2003, 2017). Organizational openness can be controlled via rules and contracts that determine whether and to what extent complementors can participate in the platform (Nikayin et al., 2013). In the video game console industry, exclusive content is a facet of organizational openness. It refers to releasing a complement only on one platform based on a contractual agreement between the platform owner and the complementor (Corts & Lederman, 2009). At its core, exclusive content based on contractual agreements restricts multihoming.

An open strategy can help platform firms decrease the cost of developing future products by reducing the amount of redesign necessary for future product generations (Martin & Ishii, 2002). Giving complementors access to the platform increases their adoption rates and leads to more diverse and innovative complement offerings (Ondrus et al., 2015). However, these benefits are dependent on the specific open platform strategy. To shed light on potential complementor strategies, we first discuss three factors for complementor participation.

4.3. Empirical context: video game consoles

The video game console industry is an ideal setting to understand complementor-platform dynamics. Several studies (Cennamo & Santaló, 2009; e.g., Rietveld et al., 2019) have used this setting to show the typical characteristics of platform ecosystems. Video game consoles constitute the platform. They are stationary devices connected to a monitor or television and are handled via an ergonomic controller. Console-based gaming creates a much more immersive experience than touchscreen-based gaming on handheld devices or mobile phones (Wiegand et al., 2022). Although the game FIFA is available for video game consoles (e.g., PlayStation 3 and 4), handheld devices (PlayStation Vita), and mobile phones (iPhone), we focus on competition between video game consoles because these offer similarly immersive gameplay.

Traditionally, the hardware specifications of consoles remain unchanged during their lifetime. However, introducing a new generation is an opportunity to update hardware, and increase processing and graphical power. Technological changes in the industry have led to eight generations of incompatible video game consoles, with new generations being introduced roughly every five years (A. Srinivasan & Venkatraman, 2010). Three main platform providers (console manufacturers, in this case) have been active in the industry in the recent past (R. S. Lee, 2012): Nintendo, Sony, and Microsoft. This study covers video game consoles of two generations (seventh and eighth generation), namely Nintendo's consoles Wii and the WiiU, Sony's PlayStation 3 and PlayStation 4, and Microsoft's Xbox360 and Xbox One.

Although competition has been fierce in each generation, this has not led to one dominant console. Moreover, the success of a platform in this industry heavily depends on the platform owner's ability to attract complementors (video game developers) who produce high-quality content (video games) for the respective platform (game console). Consequently, consumers carefully consider each console's game quality and diversity in their purchasing decision.

Three incompatible consoles competed in the seventh and eighth generations of video game consoles. Incompatibility entails that complements (video games) developed for one platform (video game console) will not readily run on another platform. Users can adopt either of the platforms, or choose to multihome (buy more than one platform), involving the extra cost of purchasing another video game console. Similarly, when developing games, complementors can decide to develop a game for one platform exclusively or to multihome by developing the game for more than one platform. However, offering the game on more than one platform entails that the game has to be *ported* to the other platform, involving high costs. Most games are available for more than one platform in a generation of video game consoles (Vjestica, 2022)

4.4. Hypothesis development

4.4.1. Breadth of content offerings

Consumer demands are often heterogeneous, and platforms can address these demands by expanding to different categories. When deliberating whether to develop a complement for a specific platform, a complementor may consider the value users derive from the marginal complement (Liebowitz & Margolis, 1999), and the number of available complements. The patterns mentioned above regarding the return on additional complements are likely at work in parallel across various categories.

For example, early smartphone apps were mostly productivity-related tools such as calculators, address books, and notepads. Today, smartphone apps cover all conceivable areas, including health (e.g., nutrition trackers), automotive (e.g., CarPlay), and many more. Hence, expanding the opportunities for complementors to reach into different categories allows the platform to increase the strength of indirect network effects. Individual users may rely on particular likes and dislikes, creating a unique combination of frequented game title markets. Variety-seeking teenagers, for instance, often use specific video games extensively for several weeks and trade them for a new game without ever returning to it (Gallagher & West, 2009). Giving complementors horizontal access to different markets allows them to differentiate their products and specialize, thereby decreasing competition compared to a platform focused on a narrower set of markets and avoiding crowding situations. We define the breadth of content offerings as the variety of categories a platform represents via complements. Breadth refers to the number of categories (as opposed to depth, which is the number of items per category) (Broekhuizen et al., 2021).

Complementors intending to enter a category might be more inclined to do on a console that already offers complements in a specific game title category. Otherwise, the complementor would need to pioneer the genre on that platform, likely involving extra marketing costs. Hence, the breadth of content offerings, or the number of categories a platform is represented in, increases entry options for complementors without having to pioneer the game category on that platform. That might give the focal console an advantage over competing consoles with representation in fewer categories. Similarly, having complement offerings in more different categories might attract a larger variety of complementors compared to a platform with representation in fewer categories. Boudreau (2012) supports this argument with evidence from the context of mobile handheld devices. He found an increase in hardware complements when platforms gave access to many complementors from various industries to the platform. Hence:

Hypothesis (H1): *Breadth of content offerings has a positive effect on complementor participation in a platform*.

4.4.2. Boundary resources

Relying on complementors poses the challenge of designing the technology so that complementors can access the core technology without exposing too much. In the case of video games, the right tools and resources allow game developers to develop high-quality games that take advantage of the console's unique architecture, enabling a rich experience for end users. Developing a game involves significant investments of effort and time – here is where game engines come to the rescue for game developers.

The literature on boundary resources focuses on the perspective of platform owners (Bianco et al., 2014; Eaton et al., 2015; Ghazawneh & Henfridsson, 2013). Boundary resources have mainly been studied in terms of APIs and Software Development Kits to involve complementors (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Schreieck et al., 2016). They are essential for managing the tension between securing control of the platform infrastructure and maintaining its generativity (Eaton et al., 2015; Mukhopadhyay et al., 2016). Platform owners can exert control via boundary resources by introducing new ones or modifying existing ones (Karhu et al., 2018). Ghazawneh and Henfridsson (2013) introduced the concept of self-resourcing, referring to the development of additional boundary resources by complementors themselves in response to perceived limitations of existing boundary resources. In this respect, boundary resources feature "feedback mechanisms and mutual shaping" (Ghazawneh & Henfridsson, 2013, p. 178). New boundary resources can be initiated by both the platform owner and complementors so that the platform owner's role can be reactive and proactive. The use of some boundary resources may also be mandatory. Still, most boundary resources are optional, and their use depends on the preference and design choices of complementors in their pursuit to serve their clients (Ghazawneh & Henfridsson, 2013).

A better assortment of boundary resources may allow complementors to focus more on game design and creative tasks instead of developing core technologies and making a platform more interesting for complementors. Boundary resources can also be seen as modules that facilitate economies of scope. Regarding complements for Apple's iOS platform, Ghazawneh and Henfridsson (2013) found that the number of applications on the platform increased with every new boundary resource introduced. This suggests that boundary resources may be essential to attract complementors to the platform, as captured in our second hypothesis.

Hypothesis (H2): *The availability of boundary resources has a positive effect on complementor participation in a platform*.

4.4.3. Exclusive content

Platform owners differentiated their product offerings from rivals through exclusive high-quality or premium content (Carrillo & Tan, 2021; Hagiu & Lee, 2011). Exclusive content refers to complements only available on the focal platform (Corts & Lederman, 2009). Exclusive content can be obtained either by internally developing games based on an integrated game developer, based on a complementor's decision to offer the complement on only one platform, or via exclusive agreements with complementors. Whether to pursue exclusive contracts with complementors is a strategic trade-off for both platform and complementors.

From the *platform owner's* perspective, exclusive contracts with complementors are a way to secure unique content for end users and to enjoy the benefits of indirect network effects. When used as a strategic tool, exclusivity usually comes in exchange for a lump-sum payment or an attractive licensing fee. The platform owner must compare the prospective benefits gained from exclusive content against the cost of reducing licensing fees or lump-sum payments (Corts & Lederman, 2009). Forced exclusivity is rare in the video game industry (R. S. Lee, 2012).

From the *complementor* perspective, whether to join a platform depends on the installed base of the focal and competing platforms. The complementors' incentive to license their product to a platform is dependent on the market's potential that they can reach through the platform's installed base (Cennamo & Santaló, 2009). In this situation, with similar market shares, complementors tend to multihome to spread the fixed costs of development over several platforms (Corts & Lederman, 2009). However, multihoming is not for free as variable costs are necessary to make a complement compatible with another platform. Given the extra cost, a complementor can also choose to offer a game on one platform only.

How much exclusive content is offered on a platform has implications for complementors. It may attract future complementors for the following reasons. Exclusive content is often of higher quality than non-exclusive content. Cennamo, Ozalp, and Kretschmer (2018) show that the quality of complements drops if complementors decide to produce simultaneously for different and technologically complex platforms. Fully leveraging the technological capabilities of a platform requires managing an increasing number of interdependencies that result in technological complexity. In the context of video game consoles, this technological complexity dependents, for instance, on the number of specialized and interdependent processors. Optimally allocating tasks to processors is challenging for developers (Horowitz, 2013). More exclusive games hence signal higher-quality content to future complementors.

Further, exclusive content can incentivize users to join a lagging platform over an incumbent platform (R. S. Lee, 2013). Without exclusive contracts, high-quality software would be released on the incumbent platform based on the prospects of selling to a larger installed base. Often, top-ranking exclusive games are the ones that sell consoles (Binken & Stremersch, 2009). Additionally, complement availability on other platforms may reduce the indirect network effects stemming from this complement (Gil & Warzynski, 2010) as it reduces the differentiation of the platform (Coughlan, 2004; R. S. Lee, 2013). Seeing that most games are multihoming games (non-exclusive games) (Vjestica, 2022), a higher share of exclusive games on the focal platform increases its attractiveness to future complementors. Hence:

Hypothesis (H3): *Exclusive content has a positive influence on complementor participation in a platform*.

4.5. Data and methods

4.5.1. Data and sample

We created a panel from multiple sources. We obtained quarterly global sales data from VGChartz. This industry research firm compiled a game database covering over 40,000 titles and 1.5 million data points, spanning two generations of consoles and game titles (seventh and eighth generation, 2005-2015). It also documents every game title's release year, publisher, developer, genre, and the platform on which it was released. We validated the data by cross-checking with Mobygames.com, which has been consulted for information on game titles by other studies (Corts & Lederman, 2009). The Internet Game Database (IGDB) provides information on game engines available for each console (including release dates), validated by cross-checking with online news and press releases. In summary, the dataset comprises six video game consoles (platforms) and two generations, during which 2199 game titles were released.

4.5.2. Measures

Regarding the dependent variable, we conceptualize indirect network effects as complementor participation, which we define as the count of unique game developers on platform i in quarter t. We refer to unique game developers to imply that a game developer with more than one game for a platform is counted only once, irrespective of the number of games by that game developer on the specific platform.

Regarding independent variables, we measure the *breadth of content offerings* as the proportion of game genres produced for platform i in quarter $t - 1$ over the total existing game genres in quarter $t - 1$. A specific genre represents a user group that is characterized by distinct demands. Here, genres serve as a proxy for markets, and the availability of a game title by platform i in a specific genre is seen as catering to this market. The more genres a platform covers, the more accessible it is to different markets from the complementor perspective. We operationalize the *availability of boundary resources* as a count of game engines available for platform i in quarter $t - 1$. Game engines are software tools to equip game developers with features to support core game development areas such as audio, video, physics, or animation. We measure *exclusive content* as the proportion of exclusive game titles produced on platform i in quarter $t - 1$ to total exclusive game titles for all platforms in quarter $t - 1$. An exclusive game title is available only on the focal platform and never on the rival platforms during the period of observation. Hence, exclusive content is the platform's ability to negotiate exclusive contracts with game developers, as also used by Cennamo and Santaló (2009) to study the effect of exclusivity on hardware demand.

We define exclusive content and breadth of content offerings as proportions because we expect complementors to weigh exclusive content on a particular platform compared to other platforms. Similarly, we expect them to compare portfolios of served game genres across platforms rather than the absolute number. With boundary resources, it is more likely that complementors are on the look for specific game engines rather than taking a portfolio perspective.

We control for *installed base* as unit sales of console i in quarter $t - 1$, as it influences indirect network effects and the intention of complementors to develop games for a platform. Although one may intuitively use a cumulative measure for installed base, prior research has shown that cumulative measures may overstate network effects (Nair et al., 2004; Rietveld & Eggers, 2018). The logic is that users are primarily active in the time right after the purchase and may become inactive later on. We use the natural logarithm of installed base to reduce the skewness (for use in first-stage estimations). The video game industry shows a strong seasonal pattern as many new games and consoles are released in the last quarter of the year. Therefore, we use a dummy (*seasonality*) to control for the last quarter of the year.

Whenever a new generation of a platform is released, consumers are drawn to the new and technologically superior platform. This decreases complementors' support for the older version of that platform as the direct network effects tend to decrease with the introduction of newer generations. As in Srinivasan and Venkatraman (2010), we use a dummy variable (*generation dummy*) for the period in which both a newer and an older generation of a platform coexist.

4.5.3. Estimation method

As discussed above, we seek to estimate whether breadth of content offerings, boundary resources, and exclusive content are related to the number of complementors that offer complements for a specific platform. As the dependent variable (complementors) is a non-negative integer, we opt for a count model. We chose the fixed effects specification. It is suitable for addressing panel data caused by several years of observations.

The most common count model, the Poisson model, expresses the probability that platform *i* has y_{it} complementors in period *t* in the following way (Hausman et al., 1984):

$$P(y_{it}) = \frac{Exp\ (-\lambda_{it})\lambda_{it}^{y_{it}}}{y_{it}!} \tag{4-1}$$

$P(y_{it})$ expresses the probability of platform *i* having y_i complementors in period *t*. λ_{it} is the mean of the Poisson distribution. It equals the expected number of additional complementors per time period and platform, $E[y_{it}]$. The relationship between the Poisson parameter and the explanatory variables is most commonly expressed in a log-linear way:

$$\lambda_{it} = Exp(\boldsymbol{\beta X_{it}} + \boldsymbol{\beta_0}) \tag{4-2}$$

where β and β_0 are estimable paramaters, and X_{it} are explanatory variables including the year of observation –whose parameter grants the fixed effect in this model. The Poisson distribution requires that the variance and the mean are equal (J. Sun & Zhao, 2013), which does not hold based on our dependent variable complementor participation (the variance is more than 10 times the mean). In this case, a negative binomial (NB) distribution may be a better fit.[1] The NB distribution is derived by adding an error term to the mean function:

$$\lambda_{it} = Exp(\boldsymbol{\beta X_i} + \boldsymbol{\beta_0} + \varepsilon_{it}) \tag{4-3}$$

With $Exp(\varepsilon_{it})$ being a gamma-distributed with the mean equal to 1 and variance α^2, and allowing the variance to differ from the mean:

$$VAR[y_{it}] = E[y_{it}]\big[1 + \alpha E[y_{it}]\big] = E[y_{it}] + \alpha E[y_{it}]^2 \tag{4-4}$$

We use the maximum likelihood estimator (MLE) to estimate the above model (Washington et al., 2020):

1 Both Akaike's information criterion (AIC) and Bayesian information criterion (BIC) suggest that the negative binomial model fits best, comparing the Poisson model with fixed effects, the NB model, and the NB model with fixed effects and suppressed constant.

$$l = \prod_{i=1}^{N}\prod_{t=1}^{T} P(y_{it}) = \prod_{i=1}^{N}\prod_{t=1}^{T} \frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y_i\right)}{\Gamma\left(\frac{1}{\alpha}\right) y_i!} \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{1/\alpha} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{\lambda_i} \quad (4\text{-}5)$$

Where Γ(.) is a gamma function.

We evaluate the goodness-of-fit of different models based on the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) (Washington et al., 2020):

$$AIC = -2LL + 2P \quad (4\text{-}6)$$

$$BIC = -2LL + PLog(N) \quad (4\text{-}7)$$

LL is the log-likelihood at convergence of the estimated model, *P* is the number of estimated parameters, and *N* is the sample size. The model with lower AIC and BIC is usually preferred over other models.

Theoretically, the causation could also be opposite to what we hypothesize (from boundary resources to complementors) as game engines (these underlie the variable boundary resources) could belong to the very game developers who are the complementors. This would mean that boundary resources are driven by the number of complementors. The other independent variables (breadth of content offerings and exclusive content) could also be driven by the dependent variable. If we were studying a situation with only two platforms, all the variation would be explained by exclusive games since non-exclusive games are available on both platforms. This is less the case in a three-way competition, but an exclusive game, as we define it, increases complementor participation if this is the only game offered by this complementor. Similar concerns may apply to breadth of content offerings. The serving of a genre manifests as the platform having a game on offer in that genre. In the case of high breadth (many categories) and low depth (few games per category), our dependent variable could also affect the breadth of content offerings. We use a lag of each independent variable as we are interested in their effect on future complementors.

Network effects are a central theme in platform research, entailing that the number of users and the number of complementors (via the number of complements) are mutually dependent. In our case, the platform's present users (installed base) attract new complementors. These new complementors likely attract new users via the complements they offer, and so forth. This feedback loop presents a source of endogeneity (Semadeni et al., 2014) that we address with a two-step estimation approach and the inclusion of an exogenous variable (*exchange rate*).

We follow past research that addresses endogeneity resulting from installed based on the costs of consoles (Clements & Ohashi, 2005). We instrument installed base via the cost of a console based on the exchange rate between the country of production and the US$. The logic is that production costs are likely to affect retail prices,[2] which is likely the case for several reasons. The profits in the industry are generated from software sales and royalties rather than hardware sales (R. S. Lee, 2012). Consoles are often sold at prices that equal production costs or even at a loss to spur income from software sales and royalties. Hence, one can expect the exchange rate with the country of production to affect prices and, ultimately, hardware demand. There should be no reverse effect of video game production on exchange rates, and one can expect that exchange rates influence complementor participation only via console sales, but not directly. We obtained information on exchange rates from fxtop.com and used quarterly averages.

The two-step approach is not readily implemented in Stata with the negative binomial fixed effects model. Hence, we run the two steps manually, with the disadvantage that the standard errors of the first stage are not corrected. Details regarding first-stage estimations can be found in the appendix.

4.5.4. Descriptive statistics

We computed pairwise correlations for all variables in the model, see Table 4-1. At first, we included platform age in the model but dropped based on high correlations with installed base (0.941). Most correlations are below 0.5 (magnitudes), except for correlations between breadth of content offerings and complementor participation (0.570), exclusive content and breadth of content offerings (0.529), installed base and breadth of content offerings (0.705), and the generation dummy and installed base (0.531). Appendix A contains within-panel correlations.

2 The data is not limited to the United States. Nevertheless, the exchange rate between the country of production and the US$ likely indicates the exchange rates with major markets for video game consoles. Further, the exchange rates only vary between platforms to the extent that the platforms are produced in different countries. Most of the consoles in the seventh and eighth generations of video game consoles were produced by Foxconn. In cases where we could find the manufacture but not the specific production location, we assumed that the platform was produced in the country in which the biggest production site of the manufacturer is located.

Table 4-1. Pairwise correlations.

Variable	1.	2.	3.	4.	5.	6.	7.
1. Complementors	1.000						
2. Breadth of content offerings	0.570	1.000					
3. Boundary resources	0.055	0.274	1.000				
4. Exclusive content	0.387	0.529	-0.282	1.000			
5. Installed base	0.444	0.705	0.121	0.366	1.000		
6. Generation dummy	-0.380	-0.488	0.135	-0.232	0.531	1.000	
7. Seasonality	0.413	0.010	0.030	0.013	0.060	0.087	1.000
8. Exchange rate	-0.131	-0.268	-0.305	-0.082	-0.167	0.016	0.006

Note. The correlations refer to installed based after logarithmic transformation.

Table 4-2 contains summary statistics. The panel contains 139 observations across six platforms (PS3, Xbox 360, Wii, Wii U, PS4, and Xbox One) with an average of 23.2 time periods per platform (the data is recorded quarterly).

Table 4-2. Descriptive statistics.

Variable		Mean	Std. dev.	Min	Max
Complementors	overall	21.683	17.477	0	107
	between		6.400	8.250	24.750
	within		16.823	-3.067	103.934
Breadth of content offerings	overall	0.646	0.250	0	1
	between		0.108	0.464	0.747
	within		0.228	0.103	1.103
Boundary resources	overall	19.050	7.901	7	30
	between		7.702	8.333	25.375
	within		3.673	5.255	24.255
Exclusive content	overall	0.281	0.237	0	1
	between		0.098	0.102	0.407
	within		0.222	-0.126	1.048
Installed base	overall	14.221	1.045	10.840	16.271
	between		0.489	13.457	14.970
	within		0.998	10.946	16.378
Generation dummy	overall	0.223	0.418	0	1
	between		0.160	0	0.361
	within		0.399	-0.138	0.992
Seasonality	overall	0.252	0.436	0	1
	between		0.003	0.250	0.256
	within		0.436	-0.005	1.002
Exchange rate	overall	0.122	0.054	0.029	0.164
	between		0.051	0.032	0.161
	within		0.008	0.0971	0.136

Note. The data contain 139 observations across six platforms, averaging 23.2 observations per platform. Next to the global mean ($\bar{\bar{x}}$), the summary statistic decomposes the variable X_{it} into between ($\bar{x}_i$) and within ($x_{it} - \bar{x}_i + \bar{\bar{x}}$), adding the global mean back in to make the results comparable (StataCorp, 2017). The statistics refer to installed based after logarithmic transformation.

4.6. Results

4.6.1. Main Results

We present the results in Table 4-3. We rely on conditional fixed-effects negative binomial regressions. In all models, complementor participation is the dependent variable. We hypothesized that exclusive content, boundary resources, and breadth of content offerings are all positively related to complementor participation. We find partial evidence for this in model 1 of Table 4-3.

The highly significant coefficient of 0.043 supports the hypothesis that the availability of boundary resources positively relates to complementor participation. Similarly, breadth of content offerings' highly significant coefficient of 1.452 supports the hypothesis that it positively relates to complementor participation. However, exclusive content is not positively associated with complementor participation, seeing that its coefficient is insignificant ($p = 0.513$).

We compute the variance inflation factors (VIFs) to address potential multicollinearity concerns. The highest VIF (3.03) regards breadth of content offerings in model 1. As breadth of content offerings strongly correlates with exclusive content, installed base, and generation dummy, we excluded breadth of content offerings in model 2 of Table 4-3. Although this results in some changes to exclusive content's coefficient (increase in magnitude), the results remain inconclusive regarding the respective hypothesis.

The controls for the presence of a new generation (generation dummy) and the control for seasonality are both highly significant. The coefficient of generation dummy is negative, indicating that the presence of a new generation decreases complementor participation, which we expected as both users will at some point cease opting for older-generation consoles, and game sales will decrease. Seasonality is positive, indicating that more new complementors join a platform in the last quarter of the year, probably to profit from the high-selling Christmas season.

To summarize, boundary resources and breadth of content offerings are both positively related to complementor participation. However, exclusive content is unrelated to complementor participation, contrary to our predictions. There may be overlapping dynamics between breadth of content offerings and exclusive content. Breadth of content offerings captures how many genres of games a platform is represented with at least one game, relative to all available genres.

Exclusive content could both deepen offerings in specific genres, as well as establish new genres. Breadth of content offerings would remain the same in the former case but increase in the latter case. While the variables capture different dynamics, some of the dynamics may overlap when aggregated. Taken together, we can accept H1 (related to breadth of content offerings) and H2 (related to boundary resources) but not H3 (related to exclusive content).

Table 4-3. Second-stage regression results (fist-stage reported in Table 4-7).

Variables	**Model (1)**	**Model (2)**
	Negative binomial fixed effects regression Dependent variable: complementors	
Installed base	0.010	0.049***
	(0.020)	(0.018)
Generation dummy	-0.812***	-0.633***
	(0.131)	(0.146)
Seasonality	0.635***	0.674***
	(0.074)	(0.078)
Exclusive content	-0.138	-0.373*
	(0.211)	(0.210)
Boundary resources	0.043***	
	(0.009)	
Breadth of content offerings	1.452***	1.661***
	(0.285)	(0.304)
Log-pseudolikelihood	-439.502	-449.707
AIC / BIC	891.003 / 908.610	909.414 / 924.087
Observations	139	139
Number of platforms	6	6

Note. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4-4. Variance inflation factors.

Variable	**Model (1)**	**Model (2)**
Installed base	1.90	1.82
Generation dummy	1.93	1.80
Seasonality	1.04	1.04
Exclusive content	2.04	1.40
Boundary resources	1.85	
Breadth of content offerings	3.03	1.79

Note. Variance inflation factors computed for models 1 and 2 of Table 4-3.

4.6.2. Robustness and comparison with other studies

Our findings regarding boundary resources are in line with previous research. Ghazawneh and Henfridsson (2013) attribute a prominent role to boundary resources, as confirmed by our results. Additional data analysis supports this point. We created an additional dataset with game engines, release dates, and the platforms for which the game engines were available. Correlating the availability of game engines per platform shows high correlations for PS3, PS4, XOne, and X360, and low to low negative correlations between the former platforms and Wii / WiiU (see Table 4-5). The effect of boundary resources seems contingent on whether the platform pursues a high-end or variety strategy. This suggests that boundary resources are used strategically. In the 7th generation of video game consoles, Wii is an outlier as it targets more casual gamers with a larger variety of less high-end games. With this strategy, Wii is distinguished from the other platforms as it requires less sophisticated game engines. The uncorrelated release dates between Wii and other platforms indicate that Wii follows a different boundary resource strategy.

Table 4-5. Correlation of boundary resource releases by platform.

Variable	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. PS3_Gen7	1.000					
2. PS4_Gen8	0.069	1.000				
3. X360_Gen7	0.408	0.311	1.000			
4. XOne_Gen8	0.101	0.785	0.385	1.000		
5. Wii_Gen7	0.105	-0.234	0.043	-0.149	1.000	
6. WiiU_Gen8	-0.043	0.006	0.175	0.000	0.061	1.000

We are not aware of studies that relate exclusive content to complementor participation. As Lee (2013) finds that the absence of exclusive contracts may reinforce an incumbent's leading position, one would expect exclusive content to increase the attractiveness of a platform to a complementor, compared to a platform with less exclusive content. However, without a leading platform or with differentiated platforms (such as Wii), exclusive content may not be as crucial in attracting future complementors. Further, the effects of exclusive content on complementor participation may surface more at the level of individual games that attract users rather than at the portfolio level. This may explain the mixed results concerning exclusive content.

Findings regarding breadth of content offerings are in line with studies that highlight the importance of a diversified complement portfolio. Breadth of content offerings reflects a variety of complement offerings and is vital in attracting users to the platform ecosystem (Boudreau & Jeppesen, 2015; McIntyre et al., 2020). Next to access to a diverse user base, a platform's variety in complements may indicate opportunities for complementors to expand their offerings on the same platform. Becoming familiar with the technological particularities of the platform is an investment for complementors. The prospect of reusing platform resources allows complementors to focus on their unique capabilities (Tiwana, 2013), as platforms can increase their portfolio to genres on the same platform (Barlow et al., 2019). Complementors can reuse resources even more so when leveraging their experience with a specific platform in identifying underserved and attractive niches (Ozalp & Kretschmer, 2019).

However, some studies question a strictly positive relationship between breadth of content offerings and complementors. In mature platforms, competition is intense, and identifying uncovered niches may be difficult, and the complementors may be put off innovating by the presence of their kind (Boudreau, 2012). This suggests that breadth of content offerings should seize to increase complementor participation beyond a certain point.

4.7. Discussion and conclusion

We examined how breadth of content offerings, boundary resources, and exclusive content affect complementor participation. We hypothesized that each positively influences complementor participation. We examined the relationships in video game consoles' seventh and eighth generations. The results show that breadth of content offerings and boundary resources, but not exclusive content, are positively related to complementor participation.

The three factors for complementor participation are related to several streams in platform literature. Boundary resources, tools, and regulations that serve as an interface between platform owners and complementors (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Petrik & Herzwurm, 2020), relate to the literature on access openness, i.e., decreasing the cost of complement development (Benlian et al., 2015). We contribute to the measurement and dimensionality of platform openness by suggesting measures for the breadth of content offerings and boundary resources – something scholars still need to agree on (Broekhuizen et al., 2021). Previous approaches to studying boundary resources were primarily qualitative (Ghazawneh & Henfridsson, 2013; Karhu et al., 2018). Exclusive content (Cennamo & Santaló, 2013; Corts & Lederman, 2009; A. Srinivasan & Venkatraman, 2010) relates to platform openness in the classical sense as a restriction to multihome (Eisenmann et al., 2009). It also relates to platform differentiation as a form of content curation. Breadth of content offerings and exclusive content relate to different kinds of network effects. All three factors also relate to technology strategy. Breadth of content offerings reflects choices regarding technological performance. This study contributes by testing these factors' effect on complementor participation, which has rarely been studied to date (Broekhuizen et al., 2021).

This study also contributes to the growing literature on how the hub of a platform federates and orchestrates an ecosystem of complementors (Rietveld & Schilling, 2020). Gawer (2014) calls for research on the drivers and consequences of changes in platform openness. Further, several studies propose relationships between platform openness and various organizational outcomes, such as market growth (Boudreau, 2010), coordination (de Reuver et al., 2015), or value capture and value creation (Parker et al., 2017; West, 2003). The choice of our dependent variable adds to the literature by focusing on what Gawer (2014) describes as a *federation*, which may be loosely defined as the gathering or joining together of actors into a larger organization. Our framework points to the formation of networks of complementors as a source of competitive advantage (Shipilov & Gawer, 2019). In the absence of managerial hierarchy or authority, as in platform-based ecosystems, the federation of innovative agents is one of the initial steps in nurturing an ecosystem. In other words, complements can only become available once complementors have decided to commit to the platform.

From a practical perspective, the results can guide managers on how to increase complementor participation in their platform. In practice, relations with complementors require nourishing and cherishing. Potential complementors are less abundant than often assumed (McGowan & Hienerth, 2022), stressing the importance of complementor strategies. By studying how to influence the number of complementors instead of the number of complements, our study helps practitioners create and maintain a diverse ecosystem of complementors. Our results suggest that breadth of content offerings and boundary resources are relevant in attracting future complementors.

Several limitations apply. Generalizability may be affected by the industry and platform-specific dynamics concerning complementor relations and exclusive content. In contrast to the video game industry, do more or less entirely without exclusive content. For instance, exclusive content is rare in mobile operating systems such as Android or iOS, and multihoming is common among developers (Hyrynsalmi et al., 2016). A potential explanation is that multihoming is inconvenient for users, and most would find it cumbersome to carry more than one phone. Not so in game consoles - although multihoming is expensive (the cost of an additional console), it is, in principle, workable as video game consoles are not portable devices. Hence, Exclusive content can only play a role in attracting future complementors to the extent that it is essential in the platform market.

The importance of boundary resources in attracting complementors may depend on the type and capabilities of complementors. Relatively few complementors characterize video game console platforms. For instance, the maximum number of complementors in our data is 107. The high cost involved with video game development[3] suggests high investments and capabilities of complementors. The found relationship may hold in other contexts with few but sophisticated complementors, such as healthcare data-sharing platforms.

3 There is a dedicated entry on Wikipedia listing video games that cost more than $50 Million to develop: https://en.wikipedia.org/wiki/List_of_most_expensive_video_games_to_develop

Breadth of content offerings is perhaps the most generic of the three dimensions in that it captures the variety of content offerings on the genre level. We expect the relationship between breadth of content offerings and complementor participation to hold in situations where few platforms compete. Identity-based strategies may involve a more focused platform scope in contexts with more platforms. The consequence may be that the relationship between breadth of content offerings and complementor participation is positive only to a certain level.

The dimensions for complementor participation we have studied are not exhaustive. While focusing on complementor dynamics, our data reflect video gaming platforms and interconnected ecosystems. We study whether different factors for complementor participation are related to new complementors (game developers) joining the platform. From the model's perspective, a complementor can join one of the covered platforms, several, or none. However, the model only reflects these options, not the many other options beyond video console gaming that complementors face in practice. Although previous research has shown that competition mainly occurs between gaming devices of similar immersion (Wiegand et al., 2022), future research could incorporate these aspects by covering several types of platforms (consoles, handheld devices, PCs).

Moreover, endogeneity could be further reduced by including additional instruments for installed base, and instrumenting the independent variables. We are not aware of promising instruments for breadth of content offerings. Previous studies have instrumented exclusive content based on exclusive content in the previous console generation (Cennamo & Santaló, 2013). Data availability prevented using this instrument as this would come with the loss of one generation of video game consoles in the current data set. Previous approaches to instrumenting boundary resources (based on average boundary resource levels (Zapadka, 2022)) are likely not independent of the current study's frame of boundary resources.

We see promising research directions in studying the attraction of especially productive, successful, or innovative complementors in addition to our measure of general complementor participation. It seems that the literature on complements evolves in two camps, one studying complementors (e.g., Choia et al., 2017; Schaarschmidt et al., 2018), the other studying complements (Cenamor & Frishammar, 2021; e.g., Eaton et al., 2015). Future research could explore the relationship between the two measures of ecosystem activity. Future studies could consider differences in quality, affordance, or usefulness of boundary resources. For example, Petrik and Herzwurm (2020) study boundary resource quality concerning complementor satisfaction, which might help consider quality differences. Ghazawneh and Henfridsson (2013) conceptualize boundary resources as serving two distinct purposes. It may be worthwhile to differentiate between boundary resources for sourcing (control-related) and resourcing (scope, diversity) (Ghazawneh & Henfridsson, 2013). Similarly, our measure of boundary resources counts all published boundary resources but remains inconclusive about their actual use by complementors. Due to the industry's nature, it is not easy to obtain information about game engines that were used by complementors to develop game titles.

Further, Cennamo, Ozalp, and Kretschmer (2018) find that multihoming complements have lower-quality performance on technologically complex platforms. Exploiting the opportunities of higher-performance and technologically more complex platforms requires more platform-specific investment that is difficult to port to different platforms. Cennamo et al. (2018) also show that complex consoles have more complements in the top 10 compared to simpler platforms. These exclusive games at the top of the rankings likely sell platforms (Binken & Stremersch, 2009). Future studies could investigate the interdependencies between platform technology and exclusive content in attracting future complementors.

Appendix A (Chapter 4)

Table 4-6 shows correlations that take the panel structure of the data into account. Breadth of content offerings is strongly positively correlated with complementors in most platforms except for Wii U (not correlated) and Xbox One (moderately correlated). The picture is mixed for boundary resources – in some platforms, it is strongly positively correlated with complementors (PlayStation4 and Xbox One). In others, it is almost uncorrelated (PlayStation 3, Wii, Xbox 360), and in one platform, negatively correlated (Wii U). Concerning breadth of content offerings and boundary resources, it seems that the differences in correlations are to some extent related to the generation of the console. Once a console of a newer generation is present, fewer complementors will join the previous-generation platform. As the eighth generation did not yet have a successor at the time of data collection, this effect likely only applies to the seventh-generation platforms in the data.

A diverse picture arises for exclusive content. It is highly positively correlated with complementor participation in some platforms (Wii, PlayStation 4), slightly negatively correlated in others (Xbox 360, PlayStation 3), and hardly correlated in others (Wii U, Xbox One).

Table 4-7 contains first-stage regression results. We estimate the first stage with ordinary least squares and the fixed-effects specification. We started by regressing all independent variables and controls and one exogenous variable on installed base. We then retained only significant variables in the model. The model used for the predictions, hence, is the parsimonious model, including the exogenous variable (exchange rate), breadth of content offerings, generation dummy, and seasonality. The predictions for installed base are then included in the second stage of the model.

Table 4-6. Within-panel correlations.

a) **PlayStation 3**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.520	1.000					
3. Boundary resources	-0.003	0.274	1.000				
4. Exclusive content	-0.239	0.086	0.629	1.000			
5. Installed base	0.295	0.462	-0.187	-0.345	1.000		
6. Generation dummy	-0.354	-0.047	0.571	0.521	0.490	1.000	
7. Seasonality	0.555	0.145	0.097	0.128	0.071	0.111	1.000
8. Exchange rate	0.030	0.321	0.570	0.546	0.254	0.073	-0.036

b) **Wii**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.697	1.000					
3. Boundary resources	0.100	-0.130	1.000				
4. Exclusive content	0.761	0.940	-0.015	1.000			
5. Installed base	0.538	0.894	-0.130	0.874	1.000		
6. Generation dummy	-0.616	-0.843	0.182	-0.829	0.505	1.000	
7. Seasonality	0.424	-0.078	0.140	0.010	0.077	0.100	1.000
8. Exchange rate	-0.477	-0.737	0.547	-0.675	-0.646	0.713	0.073

c) **Xbox 360**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.423	1.000					
3. Boundary resources	-0.036	-0.481	1.000				
4. Exclusive content	-0.185	0.512	-0.732	1.000			
5. Installed base	0.386	0.636	-0.212	0.099	1.000		
6. Generation dummy	-0.470	-0.722	0.531	-0.368	0.492	1.000	
7. Seasonality	0.457	-0.037	0.055	-0.074	0.022	0.097	1.000
8. Exchange rate	-0.088	-0.465	0.980	-0.689	-0.196	0.523	0.032

d) **PlayStation 4**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.459	1.000					
3. Boundary resources	0.714	0.428	1.000				
4. Exclusive content	0.794	0.681	0.918	1.000			
5. Installed base	-0.204	-0.343	-0.257	-0.328	1.000		
6. Generation dummy[a]	.	.	.	.	.	.	
7. Seasonality	0.578	0.426	0.149	0.231	0.306	.	1.000
8. Exchange rate	-0.627	-0.443	-0.693	-0.738	0.163	.	-0.304

Table 4-6. Continued.

e) **Wii U**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.001	1.000					
3. Boundary resources	-0.337	-0.582	1.000				
4. Exclusive content	0.060	0.837	-0.762	1.000			
5. Installed base	-0.412	0.569	0.119	0.217	1.000		
6. Generation dummy[a]	.	.	.	.	.	.	
7. Seasonality	0.865	-0.253	0.000	-0.150	0.162	.	1.000
8. Exchange rate	0.024	0.388	-0.420	0.585	-0.025	.	-0.071
f) **Xbox One**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Complementors	1.000						
2. Breadth of content offerings	0.296	1.000					
3. Boundary resources	0.652	-0.009	1.000				
4. Exclusive content	0.164	0.623	0.132	1.000			
5. Installed base	0.500	0.614	-0.267	0.505	1.0000		
6. Generation dummy[a]	.	.	.	.	.	.	
7. Seasonality	0.724	0.525	0.149	0.424	0.244	.	1.000
8. Exchange rate	-0.534	-0.133	-0.693	-0.335	0.167	.	-0.304

Note. Within-correlations by platform. Tables a)-c) concern the 7th generation of video game consoles. Tables d)-f) concern the 8th generation. The correlations refer to installed based after logarithmic transformation. [a]At the time of the data collection, the 8th generation of video game consoles was the latest generation. Hence, the generation dummy is exclusively equal to zero for platforms of the 8th generation.

Table 4-7. First-stage regression results corresponding to Table 4-3.

Variables	**Model (1)**	**Model (2)**
	First-stage fixed-effects regression	
	Dependent variable: Ln installed base	
Exchange rate	17.45**	17.45**
	(7.037)	(7.037)
Breadth of content offerings	2.387***	2.387***
	(0.267)	(0.267)
Generation dummy	-1.121***	-1.121***
	(0.154)	(0.154)
Seasonality	-0.414***	-0.414***
	(0.110)	(0.110)
Constant	10.90***	10.90***
	(0.920)	(0.920)
Observations	139	139
R-squared	0.709	0.709
Number of platforms	6	6

Note. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4

Chapter 5

Optimal Distinctiveness:
The Role of Platform Size

This paper is co-authored with Roland J. Ortt, Geerten van de Kaa, and Cees van Beers. Earlier versions of this paper were presented at the R&D Management Conference 2022 and published as: Sobota, V.C.M., Ortt, R.J., van de Kaa, G., van Beers, C. (2023): Optimal distinctiveness: The role of platform size and identity. *Proceedings of the 56th Hawaii International Conference on System Sciences*. Hawaii International Conference on System Sciences.

Abstract

Recent theoretical advances hold that platforms comprise a second strategic dimension next to size, called distinctiveness, which describes the platform's technological and market scope. Letting go of platform size as the primary criterion for platform value opens the possibility for platforms to pursue differentiation strategies with a distinct market positioning. The concept of optimal distinctiveness (OD) implies that differentiation can be optimized to maximize performance. In this chapter, we draw on recent OD research in and outside of the field of platforms and elaborate on the role of platform size within the distinctiveness framework. We discuss platform size and distinctiveness in the context of OD and suggest propositions for future research. The chapter contributes to managing platforms and OD in platform markets by showing how a platform's distinctiveness strategy may depend on its size. We contribute to platform management across various platform sizes and to research on OD in platform markets.

5.1. Introduction

Platform leaders usually govern the surrounding ecosystems of developers of complementary products (complementors, hereafter) and users in that they strategically influence which kind of complementors and users they attract to their platform (Claussen et al., 2013). Two seemingly opposing competitive logics, which prioritize different aspects of value, have emerged, called *winner-take-all* (WTA) and *distinctiveness*[1] (Cennamo, 2021).

First, dominant platforms such as Google and Facebook have grown remarkably fast and thereby fueled the belief that building scale fast, growing installed base of users and content creators is a successful way to compete in such markets (Arthur, 1996). Such a strategy could facilitate a WTA outcome (Katz & Shapiro, 1994) and limit the remaining market space for competitors (Cennamo, 2021). This perspective is grounded in network economics theory (Armstrong, 2006; Caillaud & Jullien, 2003) and suggests that platform (network) size is the primary source of value. Positive feedback loops generated by direct and indirect network effects may lead to WTA competitive dynamics (E. Lee et al., 2006).

Second, recent theoretical advances hold that platforms can compete based on another aspect, called distinctiveness. Distinctiveness is concerned with the positioning of an enterprise vis-à-vis its environment (Zhao, 2022). Platform identity, another approach to platform value, allows platforms to pursue differentiation strategies with a distinct market positioning that stresses other sources of platform value than size. Recent research shows that platform owners make strategic decisions at odds with the WTA logic and resemble a distinctiveness or differentiation approach. It also allows a platform to persist next to bigger competitors. Platforms can attain market differentiation by distinct positioning (Bresnahan et al., 2014; Cennamo & Santaló, 2013), superior technological platform capabilities (Zhu & Iansiti, 2012), catering to specific user groups (Piskorski et al., 2008)or differentiated complementary product (complement, hereafter) and content offerings (Cennamo & Santaló, 2013).

How much to differentiate has long been on the mind of both academics and practitioners (Deephouse, 1999), seeing that distinct positioning comes with both benefits (competitive advantage) and costs (reduced legitimacy) (Deephouse,

1 Cennamo (2021) refers to this perspective *identity*. To disambiguate concerning organizational identity (that does not imply any specific strategy), we call this perspective on platform competition *distinctiveness*.

1999; Porter, 1980). Conformity results in legitimacy but leads to competition for resources and customers among similar companies (McNamara et al., 2003). A distinct positioning reduces competition (Porter, 1991), but comes at the loss of legitimacy. Hence, scholars addressed performance-maximizing levels of distinctiveness called *optimal distinctiveness* (OD) (e.g., Navis & Glynn, 2011; Zhao et al., 2018).

Research has questioned the unconditional WTA hypothesis (E. Lee et al., 2006) and suggested that strong-ties network effects outperform classical ones (Suarez, 2005). However, little is known about how the primary driver of value in the WTA framework, size, fits into the OD framework. More specifically, how OD is contingent on platform size is yet unknown. There is qualitative evidence that OD changes with platform size (Karanovic et al., 2020), as platform leaders with a distinctiveness strategy also have to attain a critical platform size (Eisenmann et al., 2006; Evans & Schmalensee, 2010). The critical size entails that below a certain number of users, complementors will not join the platform and vice versa. Hence, we ask: *How does platform size relate to optimal distinctiveness*?

This chapter explores the relationship between size, distinctiveness, and performance. We begin by conceptualizing distinctiveness in platforms at the complement level. We then review OD research that views OD as balancing conformity (as a source of legitimacy) and distinctiveness (as a source of competitive benefits). In Section 5.3, we first formulate the boundary conditions for the conceptual development. As OD essentially is about determining performance-maximizing levels of distinctiveness, we continue by discussing performance in the context of platforms and how it relates to the competitive logics *platform distinctiveness* and *platform size*. We infer that platform performance is a moving target, with changing constituents and weights over time. The second part of Section 5.3 proposes performance-maximizing levels of distinctiveness for small platforms. Section 5.4 concludes by summarizing the main argument and by discussing the scope of the argument.

This chapter contributes by integrating the primary driver of platform value in the WTA competitive logic, platform size, with OD research and the competitive logic based on platform distinctiveness. By conceptually developing how OD depends on platform size, we contribute to platform management across various platform sizes, and OD research in platform markets (Cennamo & Santaló, 2013; Taeuscher & Rothe, 2021). Although earlier research has accounted for size as part of network effects and feedback loops, the proposed relationships are not specified for different platform sizes. Further, recent distinctiveness research stresses that there is no stable level of OD (Zhao et al., 2017) and has turned to explain variance in the distinctiveness-performance relationship.

5.2. Conceptual background

5.2.1. Conceptualizing distinctiveness in platforms

We focus on the effect of distinctiveness strategies on performance in technology platforms. We define platforms as "meta-organizations that federate and coordinate constitutive agents who can innovate and compete; create value by generating and harnessing economies of scope in supply or/and in demand; and entail a modular technological architecture composed of a core and a periphery" (Gawer, 2014, p. 1239). The agents occupy one or more roles coordinated and federated in the platform. Usually, this is done by a platform owner or platform leader. The agents can compete with each other on the platform. For example, customers can see complementors and their offerings as competing alternatives, but agents can also indirectly benefit each other by fueling (indirect) network effects. An important agent is the platform owner, the focal firm that creates governance arrangements that participants in the periphery must follow if they wish to participate in the platform (Eisenmann et al., 2009). The platform provider supplies the interface for the platform (e.g., Android as a platform runs on smartphones by multiple producers).

Platforms can be seen as meta-organizations because platforms[2] create value by purposefully aligning loosely coupled actors that contribute complements and services towards a central value proposition (Jacobides et al., 2018). Platforms rely on complements to cater to heterogeneous user demands (L. Sun et al., 2016) and enable users to tailor the platform to their specific needs by drawing on unique combinations of complements (Garud et al., 2008). At the very least, platforms facilitate interaction between suppliers of goods and services (complements) offered by complementors. This can fuel positive direct and indirect network effects (Clements & Ohashi, 2005; Corts & Lederman, 2009). Involving complementors also entails that value creation increasingly occurs externally (Parker et al., 2017), as reflected in platforms' market capitalizations per employee, which often are many times higher than in non-platform firms.[3]

2 Under platforms, we subsume multi-sided platforms such as Craigslist and eBay, as well as platforms with higher-order complementarities such as iOS or Android.

3 https://blog.cfte.education/platform-based-financial-institutions-are-valued-over-10x-more-per-employee-than-traditional-fis/

A platform's identity can inform its distinctiveness strategy (see Figure 5-1). Organizational identity[4] is concerned with what others believe an organization to be, or what it claims to be (Ravasi et al., 2020), and its "members 'consensual understanding of 'who we are as an organization'" (Nag et al., 2007, p. 824). Next to their function as intermediaries, platforms also perform the role of gatekeepers by strategically influencing the type and quantity of complements and complementors they attract (Claussen et al., 2013). Although platforms may also offer complements themselves, we would not regard a business as a platform if it did not orchestrate and federate the offerings of independent complementors. Their market positioning hence strongly depends on the complements offered by independent complementors. Platforms can create a distinct market positioning by restricting access to a particular type of complementors (Cennamo & Santaló, 2013). For instance, the sponsors of video game platforms can restrict complementors to genres such as sports, thereby creating a distinct offering. Similar to other studies in the field (Cennamo & Santaló, 2013; Seamans & Zhu, 2014; Taeuscher & Rothe, 2021), we focus on distinctiveness in terms of the platform's market scope and scale (see Figure 5-1) (Cennamo, 2021).

By implication, platforms inherently deal with two types of distinctiveness. In the following, we focus on between-platform distinctiveness for several reasons. *Between*-distinctiveness compares the complement offerings of one platform relative to other platforms (Bu et al., 2021). Within-distinctiveness concerns the positioning of complements relative to other complements on the same platform. Platform owners drive complementors to offer various complements (Cusumano et al., 2019). Complementors then compete based on rankings of their complements (Boudreau & Jeppesen, 2015), which platform owners frequently update to maintain a high level of innovation (Claussen et al., 2013). As there is constant pressure for complements and complementors to get noticed, such as in the case of Apps, we assume that within-platform distinctiveness for complement offerings is mostly governed by complementor competition.

4 Organizational and platform identity need not be the same - in some cases, an organization may be the owner of several platforms and possess multiple identities (Georgallis & Lee, 2020), such as Apple, which owns both the AppStore and Apple iOS. On the other hand, when an organization owns only one platform, there may be no difference between the organizational identity and the platform identity. We assume that the organizational identity informs only one platform.

Figure 5-1. Distinctiveness in platforms.

5.2.2. Optimal distinctiveness theory

The bedrock of OD theory lies at the intersection of institutional theory and strategic management. Institutional theorists focus on why organizations are similar (Powell & DiMaggio, 1991) and model the conformity aspect in OD theory. Work by Deephouse (1996, 1999) suggests that organizations are driven towards conformity as they gain *legitimacy*.[5] Suchman (1995, p. 574) defines legitimacy as "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions." In this way, institutional theory sets the stage for optimal distinctiveness' conforming aspect. Institutional theory contributes the conforming aspect to OD thinking, with the underlying mechanism legitimacy.

Offering an opposing perspective to institutional theory's conforming aspect, strategic management scholars focused on differentiation as a source of value. Strategy scholars suggest differentiating by exploiting what is unique, distinctive, or valuable (Barney, 1991). Firms gain *competitive advantage* by crafting strategies that utilize environmental opportunities, respond to external threats, and utilize internal strengths (Peteraf & Barney, 2003) that are different from those of their competitors. Creating competitive advantage can also involve finding favorable market contexts (Porter, 1980), or developing valuable, rare, and inimitable resources and capabilities (Barney, 1991). Strategic management theory hence contributes the aspect of differentiation and its underlying mechanism competition to OD theory.

In combination, strategic management and institutional theory suggest that optimizing a distinct positioning concerning performance requires balancing differentiation (affecting competition) and conformity (affecting legitimacy), as illustrated in Figure 5-1. Many studies argue that both legitimacy and competition decrease with increasing distinctiveness.[6] Seeing that reduced competition benefits performance while reduced legitimacy is disadvantageous, the dilemma, then, is to determine how much to diverge from rivals to optimize performance.

5 There are similarities between legitimacy and reputation (Deephouse & Carter, 2005). However, legitimacy is about acceptance gained by conformity to regulative, normative, or cognitive norms that qualify the organization's existence. In contradistinction, reputation is more about relative comparisons between organizations on various attributes. While (financial) performance tends to improve reputation, it is not necessarily linked to legitimacy.

6 In the specific case of novelty-seeking audiences, this need not be the case. Täuscher, Bouncken, and Pesch (2021) argue that ventures can be legitimate just because and not despite their distinctive position in the eyes of novelty-seeking audiences. Their empirical work in the case of fund seeking on crowdfunding platforms confirms their prediction of a strictly positive relationship between distinctiveness and performance.

Research on distinctiveness has evolved in two camps. One camp holds that the distinctiveness logic requires firms to diverge enough to be perceived as distinct and to reduce competition, whereas differentiating too much foregoes revenues and scale economies from catering to the populous middle markets. It follows that moderately distinct positioning strikes a balance between these opposing forces (Deephouse, 1999), consequently ensuring optimal performance (Zhao et al., 2017). Various studies find evidence in support of this ∩-relationship between distinctiveness and performance (Deephouse, 1999; Roberts & Amit, 2003). This mechanism is shown schematically in Figure 5-2 (Haans, 2019). The dashed line in the left panel represents legitimacy, and the dotted line represents competition. Following the described logic, competition drops quicker than legitimacy. Assuming equal strength of the two factors, this model leads to the performance effect, as shown in the right part of Figure 5-2.

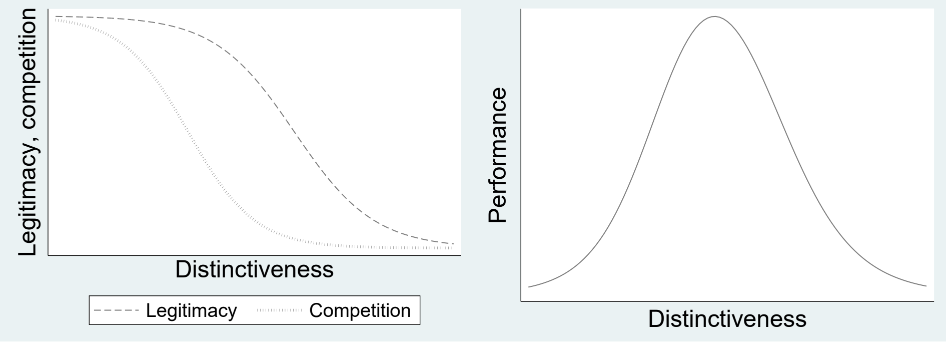

Figure 5-2. Distinctiveness and Performance: ∩-shaped (adapted from Haans, 2019, p. 8).

Despite its plausibility, other studies argue that distinctiveness may only be advantageous when brought to a high level. Modest distinctiveness may not suffice to reduce competition and simultaneously incur a deficit of focus and weak demand (Jennings et al., 2009; Zott & Amit, 2007). For example, Cennamo and Santaló (2013) find a U-shaped relationship between distinctiveness and market share in the contest of video game consoles. Performance is lowest for moderately distinct positions. Similarly, Jennings et al. (2009) find that law firms show the lowest productivity when deviating moderately from the industry norm for employment systems. High conformity or high deviation results in better productivity. Zott and Amit (2007) show that balancing efficient and novel business model designs reduces performance. In Figure 5-3, legitimacy (dashed line) diminishes quicker than competition (dotted line). The outcome is a U-shaped relationship between distinctiveness and performance, assuming equal strength of the two forces.

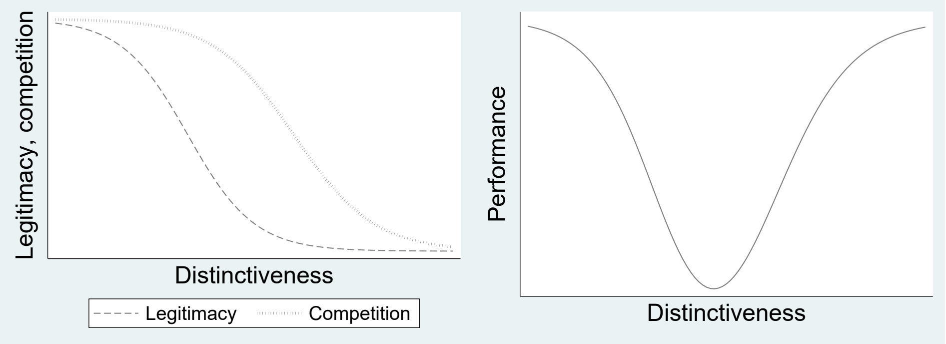

Figure 5-3. Distinctiveness and Performance: U*-shaped (adapted from Haans, 2019, p. 8).*

Haans (2019), however, suggests that these two camps should not be interpreted as inconsistent. There is agreement in studies that develop ∩- or U-shaped effects because both acknowledge the mechanisms of legitimacy and competition, as described above. Instead, combining Figure 5-2 and Figure 5-3 shows that the mechanism's shape depends on the relative strength of legitimacy and competition at each point in the curve. In Figure 5-2, competition falls as distinctiveness increases, and legitimacy decreases later, producing an ∩-shape. In comparison, in Figure 5-3, the decline in legitimacy precedes the decline in competition, resulting in a U-shape (Haans, 2019).

Though very insightful, this model assumes legitimacy and competition as prevailing mechanisms. Further, an additive effect requires the individual effects of legitimacy and competition to be similar in strength. All other confounding factors need to be taken care of. While this model has been used across domains, the precise shape of the mechanism may depend on the specific characteristics of platforms. For instance, once network effects protect the platform's position, the relative strength of legitimacy may dwindle. This may explain why some platforms turn to excessive value capture, such as squeezing the margins of complementors (Rietveld & Schilling, 2020).

5.3. Towards an optimal distinctiveness perspective on platform size

Our argument focuses on markets that permit the existence of various platforms next to each other, such as the MOOC market, donation platforms, crowdsourcing, or online labor platforms. Such markets usually show one or more of the following characteristics. Low *switching costs* (Eisenmann et al., 2006) allow users to use several specialist platforms with differentiated offerings rather than one generalist platform (Taeuscher & Rothe, 2021). *Local network effects* entail that the presence of specific users, such as relatives or friends, drives platform value more than the pure size of its installed base (E. Lee et al., 2006). With local network effects, users may choose a smaller platform over the leading one because, from their perspective, the smaller platform can still offer a more relevant installed base of users and complementors.

5.3.1. Platform performance and platform size

We conceptualize platform size as including the various sides of the platform to account for value-creating outside of the firm. We define *platform size* as including the relevant sides of a platform. In the following, we see size as relative. We define size in terms of the platform's number of users and complements. A small platform is small relative to other market participants and not dominant. A large platform is one of the bigger platforms, but not dominant. A dominant platform would be the biggest platform.

The optimal level of distinctiveness depends on which outcome is maximized (Durand & Haans, 2022). Parker, van Alstyne, and Choudary (2016) suggest that platform performance indicators may differ for start-up, growing, and mature platforms. By implication, the challenges for a platform change relative to its size:

- A start-up platform will most likely prioritize intermediation and minimize interaction failure until it has reached the critical mass of users and complementors (Parker et al., 2016). If participation levels do not meet the critical platform size (Evans & Schmalensee, 2010), direct and indirect network effects may be negative, and a downward spiral is set off. For instance, the platform 'WHY own it' aimed at facilitating the shared use of goods but never managed to attract sufficient people who offered goods, and demand far exceeded supply (Gloeckler, 2016). Until the critical platform size is reached, the number of users and complementors, which together constitute the size of the platform, successful intermediation, and the value gained by users and complementors, are crucial performance measures of platforms.

- When a platform has surpassed the critical mass of users and complementors, and when these derive sufficient value from the platform, it may shift its strategic focus. Monetization, the balance of sides (complementor to user ratio), and frequency and repetition of interaction become essential. For example, a platform may try to convert users into paying users by offering additional value at a cost. Balancing the relative size of a platform's sides can help avoid adverse network effects, such as in the case of driver downtime due to insufficient demand in the case of Uber.
- A platform that has achieved a self-sustaining business model can be seen as a mature platform. At this point, repeated and increasing activity on the platform may indicate platform performance next to standard business performance indicators such as profitability, revenues, and the like.

In light of constraints such as the critical value of participation in the platform, platform performance likely takes the form of a moving target, as the strategic goals of platforms are likely to change over time. However, as long as the platform has yet to reach the critical mass of users, increasing platform size will be a priority. Size may be a good indicator of performance as long as the critical size of the platform is not reached. However, after the platform has surpassed the critical size, other performance proxies may accompany or even replace size as proxies for performance, even in a platform that competes based on distinctiveness.

Observation 1: *If a platform has not (yet) reached the critical mass of users, size is an essential aspect of performance, independent of whether the platform strives for value based on size or distinctiveness*.

In the WTA framework, platform size drives the value that a platform creates. In such situations, the platform's performance strongly depends on size, which may justify using size as a proxy for performance. Recent distinctiveness studies used proxies for performance, such as market share in terms of installed base (Cennamo & Santaló, 2013; Zhao et al., 2018), online attention (Taeuscher & Rothe, 2021), and the number of downloads and reviews of apps (Barlow et al., 2019; van Angeren et al., 2022). Notably, most of these measures carry an aspect of platform size (number of users and downloads). Distinctiveness, and hence prioritizing other aspects of value over size, may lead to a smaller platform size (Piskorski et al., 2008), although it need not (Cennamo & Santaló, 2013). Studying distinct platforms may require other performance measures, such as profits or revenues, as in distinctiveness studies outside of the platform field (e.g., Haans, 2019), or relative performance measures, such as profitability.

The following examples highlight that conceptualizing performance narrowly as size may not be appropriate. The online dating platform eHarmony rejects membership for up to 20% of potential users to single out segments it does not wish to serve (Piskorski et al., 2008). This barrier towards participation leads to self-selection among potential users. Instead of accepting a broad user base, it screens potential users on many aspects, such as lifestyle, values, or personality. This information is then fed into the user platform and matching algorithm, amongst others, to enable matches based on long-term compatibility. Despite aggressive winner-take-all strategies, this focus has enabled eHarmony to convert three times more members into paying members than rival platforms.

Similarly, Apple handles a restrictive approval policy for app developers, which increases the burden and cost of innovation for complementors if they wish to develop for and connect to the users of their platform (Claussen et al., 2013). Such restrictive policies that increase affiliation costs for users and complement serve to induce platform-specific investments that cannot be easily redeployed elsewhere and ties participants to the platform's overall objective (Jacobides et al., 2018). They also show that maximum size may not be on every platform's agenda. Assessing platform performance purely based on size, then, falls short.

Observation 2: *We cannot assess the performance of small platforms if performance is universally proxied as size*.

5.3.2. Distinctiveness, platform size, and platform performance

As we have argued in the preceding section, platform performance has various aspects that change in relative importance as the platform reaches and surpasses the critical size. In the following, we use PERFORMANCE to indicate a weighted combination of performance aspects according to whether the platform has surpassed the critical mass.

With switching costs, platforms may benefit from offering both specialized and generic content, as users that consume specialist content may also demand generic content (Cennamo & Santaló, 2013). However, with low switching costs and the presence of large generalist platforms, conforming market positions are likely sufficiently served by the large platforms. In this context, small platforms may have to seek distinct market positions to be recognized next to larger competitors.

In the start-up phase of a platform's existence, distinctiveness and PERFORMANCE may be mutually constitutive (Karanovic et al., 2020). In this phase, achieving the critical mass of participation in the platform is a priority (Parker et al., 2016). Legitimacy may arise because of and not just despite distinctiveness, meaning that distinctiveness and legitimacy may be mutually enabling (Zhao et al., 2017), such as in the case of novelty-seeking audiences (Taeuscher et al., 2021). Distinctiveness may decrease cognitive legitimacy (an organization's comprehensibility), but it may improve its normative legitimacy. Normative legitimacy is an organization's perceived congruence with an audience's normative expectations (Suchman, 1995).

Platforms can translate their organizational identity into a distinctiveness strategy that fuels their initial growth. For example, in the market for stock photography, it is common for end users to buy stock photos from an intermediary that aggregates images from various artists and manages sales and licensing. One of the founding ideas behind Stocksy was to do justice to complementing artists offering stock photography by creating fair conditions. Based on this distinct positioning towards complementors, the complementing artists who joined first helped attract their sort via personal networks. In its early days, Stocksy selected complementing artists rigorously and capped intake to avoid competitive tensions between complementors (Karanovic et al., 2020).

Stocksy's distinctiveness strategy sets the platform apart from competitors (Karanovic et al., 2020). A small but high-quality selection of complementors drove its initial growth of both end-users and complementors. Positioning itself well outside the mainstream protected it from competition. Hence, for a small venture, the competitive benefits of standing out at highly distinct positions are likely more attractive than more moderate positions. Stocksy's distinct positioning, antithetical to mainstream stock photography companies, may have helped attract early complementors to the platform. A large platform may also be able to distance itself from a conforming market position, perhaps even more effectively so. But we predict that a small platform will have to rely on a distinct positioning to get noticed.

It is unlikely that small platforms will be able to reach combinations of legitimacy and competition that make it worthwhile to pursue conforming positions. At conforming positions, a small platform will have to compete based on similar attributes as a larger platform. Due to its size, it will not be able to offer a similar depth and breadth of both market and technical attributes. For this reason, mimicking competitive moves, network design, technology design, and complementor offerings has been chiefly associated with shoulder-to-shoulder-style WTA competition (Cennamo, 2021). Such strategizing will most likely be found in larger or dominant platforms. For this reason, conforming positions are least attractive to small platforms. Hence:

Proposition 1*: For small platforms, high levels of distinctiveness are optimal for PERFORMANCE*.

Whether moderate levels of distinctiveness benefit small platforms depends on how much competition is reduced. Research has shown that platforms operate in different markets (Livengood & Reger, 2010). How important individual markets are to the platform will differ. The platform may not respond to competitors not perceived to operate in markets close to the platform's identity. If a moderately distinct platform is perceived as sufficiently different by the main competitors, then moderate distinctiveness can offer sufficient protection to avoid fierce competition.

As argued above, small platforms conceivably build legitimacy at distinct positions. It is ambiguous whether moderately distinct positions will be distinct enough so that users perceive the small platform as such. On balance, we expect that moderately distinct positions are likely not significantly more attractive to small platforms than conforming positions.

Proposition 2*: For small platforms, moderate levels of distinctiveness are only marginally more beneficial to PERFORMANCE than conforming positions*.

5.4. Discussion and conclusion

In this chapter, we build on accounts that question the unconditional winner-take-all (WTA) approach (E. Lee et al., 2006) by suggesting that platforms, too, can pursue classical strategic options such as distinctiveness (Cennamo & Santaló, 2013). The WTA approach entails that size is (one of) the most crucial drivers of platform value. Optimal distinctiveness research suggests that distinctiveness has both costs and benefits and that performance-maximizing levels of distinctiveness can be determined. We contribute by integrating one of the most important variables from the WTA framework, size, into the distinctiveness framework. We argue that a platform's size has implications for its distinctiveness strategy by highlighting mechanisms through which this effect could manifest.

We have focused our exploration on markets in which several platforms can coexist. Such markets are usually characterized by, for instance, low switching costs (Eisenmann et al., 2006) or local network effects (E. Lee et al., 2006). Seeing that platforms can prioritize different aspects of platform value, such as platform identity or size (Cennamo, 2021), implies that platforms are likely to be of different sizes and that size plays a different role in evaluating platform performance. We argue that performance universally proxied as size would mean that we cannot assess performance in small platforms. The choice of performance measures also relates to different phases of platform development (Parker et al., 2016). We argue that, under the conditions mentioned above, it is optimal for a small platform to aim for high distinctiveness. We do so by suggesting propositions as a basis for future research. This research may guide managers by highlighting conditions under which high distinctiveness may optimize performance and discussing how this depends on the platform's size.

Some limitations apply. The conclusions may change when the platform's primary goal is to collect data that fuels other services rather than being a business that strives for profitability in its own right. For instance, Google launched Android mainly to drive its other services and platforms, such as Search and Google Maps, and distributed it freely. In that case, increasing platform size in terms of the number of users likely is the relevant performance measure across platform stages.

Further, this study assumes that platforms differentiate via their complement offerings. But there may be situations where the complement offerings are difficult to differentiate. For example, Fairbnb, a platform similar to Airbnb, essentially offers the same service. Although distinct in terms of complements (much lower choice of houses), this is unlikely to offer superior value to users. It likely offers value to its users based on its organizational identity rather than its complement offerings. Its organizational identity primarily lies in overcoming some of the social repercussions attributed to Airbnb (e.g., rising real estate prices or community fragmentation) based on its cooperative structure (reinvesting parts of their profits into local communities) and policies (e.g., one-house limit per user) (Fair Bnb Network società cooperativa, 2021).

Our work may be further expanded by considering optimal distinctiveness strategies for platforms other than small ones. Further, while we argue that the relevance of different performance aspects changes, future research could consider changes in the environment in which the platform competes. Organizations can also possess more than one platform, with different identities between platforms and potentially multiple identities per platform. Future research could explore how these conflicts affect distinctiveness strategies

Chapter 6

Conclusions and Reflections

This dissertation contains several chapters on participation in and performance of technology platforms. Platforms are widely considered one of the most influential organizational forms of our time. This dissertation studied how platform participation and platform performance are related to each other. This last chapter reflects on the dissertation as a whole. Its four sections reflect on the literature contributions and discuss practical implications, limitations, and directions for future research.

6.1. Contributions to the literature

This section discusses contributions in light of this dissertation's central theme, participation and performance. Second, it addresses contributions regarding the comparison of related scientific concepts in the social sciences.

Participation and performance of platforms

Participation and performance are two aspects that form a recurring theme in the chapters of this dissertation. In brief, Chapter 2 studies commonalities and differences between dominant designs and platforms, analyzing underlying causes, mechanisms, and outcomes. Chapters 3 and 4 address technology selection and complementor participation, two aspects of participation intrinsically linked to performance. Chapter 5 contrasts two logics of platform competition that differ in what extent they link performance to participation.

Chapter 2 compares dominant design and platform literature. These streams underlie technologies that have implications for participation and performance following from their structure. By performing reasonably well across application domains, a would-be dominant design can reach participation levels that manifest it as the dominant design. Increased participation, compared to other designs, leads to incremental innovation in the periphery of the design, continually improving its performance. In platforms, participation and performance are more closely related. There is a mutual relation between participation and performance, as based on network effects, participation is inherently linked to the performance of a platform.

In contrast to dominant designs, platforms also know different types of participation than just adoption. Different degrees of interface openness allow for the participation of different types of external parties. The more open platforms are, the more important external innovation becomes. Chapter 5 elaborates on the link between platform performance and platform participation. It examines performance-maximizing levels of distinctiveness in response to different levels of participation.

Technology selection in Chapter 3 refers to choosing a focal technology over alternatives. For a new technology to persist, participation is an essential aspect of performance. Chapter 3 identified many factors that influence technology selection. It draws on diverse kinds of literature, such as standard dominance, technology acceptance, business models, innovation diffusion, and context-specific literature on additive manufacturing adoption. Prioritizing these factors in the context of metal additive manufacturing based on expert opinions showed that market demand, relative technological performance, business-model-related factors, and commitment are the most critical factors. Individually and in combination, the essential factors also reveal what types of performance benefit participation (selection of the technology). In this case, it combines technological characteristics and how the technology is supported.

In addition, the literature search in Chapter 3 brought up new factors related to technology selection. It introduced factors related to education and skills development, and dissemination of the technology in society, that were not part of earlier frameworks. Other frameworks consider knowledge and learning on the part of the supply side, but knowledge dynamics concerning the demand side are not included.

Chapter 4 investigates how several drivers affect complementor participation. It addresses strategies that the platform owner can deploy to increase complementor participation in the platform. Although being a measure of participation for the main part, complementor participation directly links to the performance experience at the user level via the availability of complements and network effects. Three drivers of complementor participation within the platform's sphere of influence are particularly noteworthy: breadth of content offerings, boundary resources, and exclusive content.

The described relation between participation and performance is, to some extent, specific to platforms. It is useful to compare classical value chain contexts and platform contexts. Classical value chains describe chains or linear value flows through supply and demand relationships between actors. Depending on the perspective, inputs or outputs that offer some value are exchanged for money. On the other hand, platforms are characterized by a different, non-linear structure with the platform at the center and radially related sides.

Value chain situations can be analyzed on various points by breaking them up into dyadic supply and demand relationships: The part of the chain that is upstream is represented by the supply side, and the part downstream is represented by the demand side. Participation is simply the number of clients. Performance in such situations is usually assessed based on measures such as turnover or profit and results from turnover per client. Also, in these situations, participation and performance are distinct,[1] but their relationship is straightforward.

1 Depending on the type of market (e.g., lucrative niche vs mass market), the meaning of participant numbers differs.

Participation has a different role in platforms. The more complex dependencies underlying platforms cannot be understood by analyzing dyadic dependencies only. Different sides of a platform can vary regarding their price sensitivity. Such differences have led to pricing schemes in which the platform leader subsidizes side A at the expense of side B. The participation of side A (subsidized side) may be the reason for actors of side B (paying side) to join. This shows that, although conducive to overall platform performance, participation can be the measure of interest concerning the subsidized side. Looking at the dependency between the paying side and the platform only may suggest that it is sufficiently captured based on a transaction, but that disregards the role of side A's participation.

Commonalities and differences of structural metaphors

This dissertation contributes to a broader literature concerned with conceptual clarity within the domain of platforms and across related domains. Essentially, many management theories and frameworks often focus on concrete problems, such as overcoming diffusion barriers, establishing a technology in the market, or attracting complementors. However, too many angles and perspectives hamper using these tools. Management literature is often criticized for being fragmented and siloed. New streams and angles emerge continuously, often without replacing or integrating previous streams and angles. Such tendencies impede access to the literature.

Chapters 2 and 3 contribute by comparing structural metaphors, proposing a framework that can compare different kinds of literature, and synthesizing technology selection literature (e.g., Shipilov & Burelli, 2020; Shipilov & Gawer, 2019). Chapter 2 contributes to this literature by investigating the differences and commonalities between dominant designs and platforms. The literature on platforms is polycentric, and the specific relation of platforms to dominant designs depends on the type of platform under consideration. Characterized based on the nature of complementarities between different sides, the literature on platforms ranges from multisided markets to innovation platforms. The most substantial similarity between dominant designs and platforms occurs between innovation platforms and dominant designs: both are modular structures with core and peripheral systems, and facilitate economies of scale and scope. However, they do so in a slightly different way. A dominant design enables economies of scale and scope based on a design that does well across applications. An innovation platform does the same but focuses on customization by the user.

Chapter 3 adds an examination of factors that affect technology selection. The chapter draws on case-specific literature (metal additive manufacturing (AM)) and literature on technology selection in the broadest sense. It develops an overarching framework for technology selection. Studying additive manufacturing offers several contributions to the technology selection literature. Due to the differing properties of printed products, selecting AM over alternative production methods has consequences for producers (supply side) and users (demand side). Acknowledging the innovative efforts for both the demand and the supply side, Chapter 3 captured this dynamic in two categories of factors on demand-side and supply-side innovators. Prioritizing factors in the context of additive manufacturing shows that high-ranking factors stemmed from different kinds of literature. This specific combination of high-ranking factors would not have been identified by drawing on single frameworks only, as no single framework contains this combination of factors. In this sense, Chapter 3 demonstrated that combining frameworks provides a more comprehensive picture. In a way, Chapters 2 and 3 adopt different strategies to relate distinct streams of literature: Chapter 2 systematically compares two streams of literature, whereas Chapter 3 combines aspects from several literature streams.

6.2. Practical implications

This dissertation offers several contributions to practice relating to the synthesis of literature and the management of complementors.

Chapter 3 synthesized frameworks of factors that relate to technology selection. To support technology selection, it is crucial to identify areas that lie within one's influence. Knowing these areas allows managers and policymakers to focus efforts and use resources effectively. Often, those frameworks subtly differ in focus. For instance, they contain factors for becoming widely accepted or reaching large-scale diffusion. However, these focal differences are less relevant in practice when the foci can be subsumed under a common header, and when factors between the frameworks overlap. For instance:

- A design has to reach large-scale diffusion first to become widely accepted. This means that both foci can be seen as stages of technology selection. Large-scale diffusion can be seen as part of becoming widely accepted.
- Also, they are influenced by similar (categories of) factors. Specifically, both frameworks contain categories of factors on the technological system, with factors relating to technological performance, complementary products and services, or compatibility.

In such situations, distinct frameworks can unnecessarily hinder their use in practice, justifying their consolidation. Chapter 3 offers an encompassing framework that integrates several perspectives on technology selection.

Complementors management. This dissertation has several implications for the management of complementors. Complementors are important for a subcategory of products and services that function as systems and rely on external innovation to create the customer experience. Examples are video game consoles and games developed by complementors. For products or services with high stand-alone value, complementary products, and hence, the attraction of complementors, are less important. Examples are cars or cab rides. For the first category, the attraction of complementors matters as, ultimately, the user experience strongly depends on complementary products. The availability of complementary products and services surfaces in the framework of factors for technology selection presented in Chapter 3. With no particular focus on platforms, this can concern generic complements (such as gasoline for cars) as well as non-generic complements (such as metal powders for metal AM).

Chapter 4 addresses how to attract complementors in the context of platform ecosystems. It shows that boundary resources and breadth of content offerings are two levers that can be used for this purpose. Boundary resources can attract complementors by reducing the development costs for complementors. Breadth of content offerings gives complementors broader options in terms of content variety. Chapter 4 showed that exclusive content, on aggregate, is not related to complementor participation. However, this does not rule out that there is such an effect via specific exclusive titles. Chapter 5 highlights conditions under which high distinctiveness may optimize performance and discusses how this depends on the platform's size.

Contextualizing platform management. Organizations have different characteristics and objectives. Recommendations are relevant to the extent that they partially coincide with them. Chapter 5 addresses platform size as a characteristic of platforms. It suggests that performance-maximizing levels of distinctiveness depend on platform size. Making size explicit has several implications for platform management. First, formulating optimal distinctiveness (OD) strategies in response to platform size can help platform managers to navigate different phases of platform growth.

The practical implications of the WTA competitive logic are growing as fast as possible, for instance, by attracting venture capital that allows for aggressive strategizing. However, making size explicit in platform strategy and management could serve as an overture to different platform categories in terms of objective and size. For instance:

- There is anecdotal evidence of platform managers and owners preferring to remain independent of financiers. To those platform managers, recommendations to 'get big fast' are likely of little value. Slower growth and a smaller platform size are likely accepted in exchange for more autonomy. Formulating recommendations that reduce the necessity of external funding would benefit this platform manager type.
- There are types of platforms, such as cooperatively-owned platforms, where a financier-based growth approach is excluded by definition. Externally funded growth strategies defy the purpose of these platforms, and conventional wisdom is of limited applicability.
- There can also be reasons for complementors and users to aim for smaller platforms, such as the presence of specific audiences or complements, or based on the platform's congruence with normative expectations.

Implications for additive manufacturing. In the realm of AM, Chapter 3 showed that factors relating to demand, business models, and commitment are important. One can draw several implications from the relation between the factors. Considering the following:

- When viewed as a production method in the narrow sense, metal AM is likely more expensive than other methods.
- Using metal AM, or planning to use metal AM, has implications for the design. In metal constructions, where parts are joined by welding, more sophisticated designs can create extra costs by increasing the number of parts that need to be joined or by increasing the need for pre-processing. Optimizing a design could mean using more gradation in material thicknesses or adding openings in the material to save weight. In contrast, with AM, adding material is expensive. This means that sophisticated designs pay off, which has implications for the necessary design and engineering skills.

The different requirements for metal AM-based production mean that there can be an additional need for education and knowledge (see Chapter 3). Although prices will likely decrease in the future as technology improves, metal AM can be more expensive when focusing on production costs in isolation. To make it a viable option, one should focus on value created over the lifetime of a product. Products with better performance can more than justify the increased costs. Exploiting the advantages of metal AM can also necessitate additional costs for advanced designs or changing design routines to the specifics of AM. Hence, the benefits of using AM may not be evident to potential users for two reasons. First, a narrow focus on production cost can obscure cost savings over the product's life cycle. Second, if the product design is not specific to the possibilities of AM, its advantages can remain underexploited.

A potential solution can be employing implementation partners that assist potential users in identifying use cases for AM in terms of its unique advantages. Implementation partners could attract some immediate business, and help disseminate knowledge regarding the use and use cases of AM. Employing implementation partners could create additional revenues in the short and long run.

6.3. Limitations

This dissertation is not without limitations. Studies that compare structural metaphors (such as Chapter 2) share the feature that they strive for clarity or purity in the distinctions between the structural metaphors. Translates into empirical studies in the domain of platforms, this often means distinguishing platform-based and non-platform-based organizations. This could mean considering only organizations with offerings produced by third parties. However, this obscures that, compared to non-platform organizations, an actor can fulfill several roles on a platform. For instance, an actor can join Craigslist as a user when looking for a second-hand item. But this activity can also be a springboard towards activity in the role of a seller. Such dynamics are overlooked when only platforms are compared.

Furthermore, different platform types are often distinguished. The context of video game consoles is exemplary of this tendency. It is one of the most-used contexts of the field and has been described as a pure context that allows for "clean and tractable analysis" (R. S. Lee, 2012, p. 19). In reality, though, different platform types compete with each other and non-platform organizations.

This dissertation relies on reference frameworks for comparing different kinds of literature (Chapter 2). Which criteria are chosen for the comparison matters for the outcome. The infinite dimensionality problem entails that two compared entities can be infinitely similar or dissimilar in response to the attributes considered important (Cattani et al., 2017). In Chapter 2, this pertains to the delineation of different platform types and the criteria used for the comparisons. I use differences in openness for distinguishing platform types (in line with Gawer (2014)) – an attribute that has frequently been used for this purpose. Nevertheless, other classifications are possible (e.g., based on digitality (de Reuver et al., 2018)) and may influence the outcome.

The framework of factors for technology selection presented in Chapter 3 is likely applicable in other contexts with minor adjustments. However, questions regarding generalizability arise as the factors are ranked based on expert opinion. Nevertheless, based on shared characteristics, the prioritization and the framework may especially relate to two classes of technological innovations: process and user-driven.

- Process innovations relate to how organizations operate, so implementing process innovations often requires investments in training and equipment. The chapter's context, metal AM, is a process innovation that changes how products are made. Depending on the specific application, AM offers benefits in terms of efficiency (cost-effectiveness), quality (regarding properties or appearance), or flexibility (adapting the product to different consumer needs) of a product. These aspects surface in the framework presented in Chapter 3 in terms of knowledge and training-related factors. Metal AM's advantages lie specifically in quality and flexibility; hence, it is likely that the framework of factors and, to some extent, the prioritizations are generalizable to process innovations with similar characteristics.
- Chapter 3's findings also relate to user-driven innovation. User innovation refers to innovative activities to *use* rather than *sell* the outcome and can be performed by individuals and firms (von Hippel, 2009). Typically, user innovation concerns inexpensive processes within the means of individuals. Although polymer-based AM is not the empirical focus of the chapter, the literature study was not limited to metal AM per sé, including polymer-based AM. Polymer-based AM is an example of a process innovation that thrives on user innovation (de Bruijn, 2010, as cited in von Hippel, 2016). Improvement and selection of such innovations depend on the engagement of society at large with the technology. Past innovations have followed a similar development, such as the radio, where amateur devices precede mass products (Ortt & Schoormans, 2004). This means that the framework of factors may apply to contexts that relate to user innovation.

Last, Chapter 4 draws on video game consoles as a context. This context is frequently-studied by platform scholars for the comparability of different video game platforms. Nevertheless, the user side in this context is mainly driven by hedonistic motives, and findings based on this context may not necessarily hold in other contexts.

6.4. Directions for future research

Boundaries

I have argued that the literature on platforms strives for clarity because there is a tendency to study platform competition by comparing similar kinds of platforms. Many platforms that come to mind, though, do not exhibit this clarity. Letting go of this focus enables addressing the following questions:

Comparison of platforms to non-platforms. Questions such as when, why, and how platforms fair better than non-platform businesses (Cusumano, 2022) require comparisons of platforms to non-platform businesses in specific market contexts. Several markets, such as the MOOC market, are served by both platform-based businesses and non-platform businesses (some providers of courses produce all content themselves). Future research could address the question of how to deal with mixed businesses (platform – non-platform). A first step would be to develop indicators of when such a mixed organization can be seen as a platform.

Further, some organizations combine platform and non-platform elements (Cusumano, 2022). Consider Amazon: For much of its existence, it has generated more than half of its revenues from its online store (not a platform). Next, it runs several platforms and is usually considered a 'platform firm.' Future research could investigate under what conditions combining or creating hybrid platforms leads to synergetic outcomes.

Boundary-spanning research. Most research in the platform domain focuses on competition between closed substitutes, such as various video game consoles or MOOC platforms. Video game platforms are close substitutes as they offer similarly immersive gameplay (see Chapter 4), and more immersive gameplay than gaming on mobile phones. However, this does not preclude spillover effects between remote substitutes. Multihoming is no longer limited to platforms that are close substitutes. Complements are sometimes offered for both mobile and desktop operating systems and often offer integrations across different device classes. Future research could investigate the interplay between related markets, such as mobile and desktop, or mobile and consoles.

Moreover, metal additive manufacturing was chosen as Chapter 3's context because it primarily relates to industrial applications of AM. The literature study added a factor (dissemination of the technology in society) to the framework that was not part of earlier frameworks. This factor describes communications about and hence familiarity with the technology in society. In AM, desktop-based 3D printers have increased familiarity with the technology in society. These printers are available at a fraction of the cost of industrial-grade printers and are also very popular among hobbyists. Many printers use polymer filaments for printing and are very different from metal AM. Given the completely different material properties, polymer-based AM cannot be seen as a close substitute for metal AM. Nevertheless, polymer-based AM has likely influenced metal AM selection by familiarizing potential adopters with the basics of AM. Future research could investigate whether and to what extent such cross-fertilization has occurred.

Technology selection

Synthesizing literature. One of the contributions of Chapter 2 is the synthesizing of several literature streams that relate to technology selection. Unanswered is *when* more than a single piece of literature is needed to address technology selection. At first glance, this is to do with the level of analysis. At the company or project level, one framework may suffice. However, studying technology selection at a higher abstraction level may require the combination of several frameworks.

Further, a question that needs to be systematically addressed is what frameworks lend themselves for integration. A potential condition could be an overlap in foci. For instance, when studying technology selection, 'large-scale diffusion' and 'becoming widely established' in the market may be part of a similar process.

Additive manufacturing. The framework presented in Chapter 3 also includes AM-specific factors that are not mentioned in the underlying reviewed frameworks. Such factors, for instance, relate to job opportunities, education, and skills development. The prioritization of factors in the context of AM also warrants further examination. There is a contrast between the framework and the prioritized list of factors regarding job opportunities, education, and skills development. These factors are an addition to the framework stemming from the AM field. Paradoxically, these factors turn out at the bottom of the prioritized list in the empirical context of AM. Future research could investigate the source of this paradoxical outcome. A first step could be to inventory formal and informal training opportunities (university degrees, MOOCs) and relate these to the challenges faced by potential adopters.

Ranking Factors. Another direction for future research relates to the understanding of factors by experts. Ranking factors for technology selection based on expert opinions requires a thorough understanding of the factors. While the multi-criteria decision-making methods pay attention to the efficiency of comparisons, the decision-makers' understanding of the factors is given little formal consideration. Future research could develop methods to test whether decision-makers understand the factors sufficiently, and develop procedures that ensure this is the case.

The cost side of strategy

Effective strategizing requires understanding the strategy's potential and cost. To confidently choose one strategy over the other would require weighing the costs of implementing a strategy against its benefits. This is not to argue that a single strategy, such as subsidizing one platform side, should not incur costs, as such a strategy can be effective as part of a bundle of strategies. In detail, we see the following directions:

Cost-side of platform strategy. Strategies to reduce costs have been observed in larger platforms. But the current optimal distinctiveness literature is mostly concerned with maximizing performance in terms of revenues, or the number of users, with no particular attention to costs. We expect ample opportunities for research on costs in the domain of platforms as much of the current literature used proxies for performance that do not directly capture costs (such as installed base or revenues instead of profits).

Cost-side of strategy in technology selection. In the context of additive manufacturing, Chapter 3 prioritized factors concerning their influence on technology selection. However, two similarly important factors may incur very different costs when being addressed. Hence, knowing the critical factors alone only partially answers the question of which factors to address. An effective strategy requires an understanding of both costs involved benefits. As an extension of the research design in Chapter 3, future research could incorporate costs by conducting case studies on how specific factors are addressed in practice to conclude regarding their cost-effectiveness. Another approach would be to rank factors based on expert opinions regarding how costly they are to address.

Platform size and strategy

The relationship between platform size and strategy addressed in Chapter 5 offers several entry points for future research:

Growth objective. There is a tendency to assume that, across the board, platforms similarly strive for size, even within the distinctiveness framework. In economics, it is common to distinguish organizations based on their growth aspiration and potential, or how entrenched they are. For instance, small and medium-sized enterprises (SMEs) and startups can be similarly large but may have different market positions, outlooks, and ambitions. SMEs are often well entrenched in a market and provide existing services and products, whereas startups are often concerned with new products and services, and may hence have a high growth potential. From the distinctiveness competitive logic follows that both are possible in the domain of platforms. However, the distinction is usually not made. Conclusions about different strategies depend on the assumptions regarding which outcomes are maximized. A more fine-grained distinction between platforms based on their objectives may facilitate more targeted advice and policy.

Optimal distinctiveness. Making platform size explicit also has implication s for optimal distinctiveness theory. Optimal distinctiveness is recognized as very contextual. Chapter 5 introduces platform size as a contextual aspect of optimal distinctiveness. Future research could test specific distinctiveness strategies in response to platform size. The propositions presented in Chapter 5 could form a point of departure. Further, existing research has shown that distinct platforms can, but need not be, smaller than competitors. Consequently, it is not necessarily the case that more distinct platforms are smaller or less distinct platforms are bigger. What growing means for optimal distinctiveness is largely unknown. Future research could address distinctiveness strategies in response to specific growth objectives.

Technology in platforms

Chapter 2's comparison of dominant designs and platforms opens several questions about the role of technology in platforms. One main finding of Chapter 2 is that the cyclical thinking that is at the core of dominant design theory is mostly absent in platform research. Several opportunities for future research occur at the intersection.

Technology landscapes. There are hardly any studies that address how entire platforms, including complementor ecosystems, jointly evolve over time and in response to technological developments. Future studies could address competition between platforms in response to changing technological landscapes. For instance, at the level of enabling technologies, one may ask how the emergence of new enabling technologies, such as blockchain, affects the competition of platform ecosystems.

Additive manufacturing and platforms

This dissertation draws on two empirical contexts, video game consoles and AM. While video game consoles are a prototypical example of a platform market and fit this dissertation's framing (platforms), AM is typically not the first example that comes to mind when considering platforms, but it has platform characteristics. Similar to platforms, AM relates to both economies of scope and scale:

- *Economies of scope*. AM facilitates economies of scope by removing the need for product-specific tooling. Within the boundaries of an AM machine, designs can be altered without incurring production-related costs. Thereby, it enables mass customization.
- *Economies of scale*. As AM has obviates the need for product-specific tooling, the investment into AM machines can be recouped over different products (scope) rather than the quantity of a product (scale). As a result, the minimum effective scale is reduced.

Next to economies of scale and scope, a structure based on core and peripheral systems is a frequently-mentioned feature of platforms. Along the core-periphery divide, platforms are usually associated with the core, but the periphery is also part of a platform ecosystem. AM can *be* the platform (the core) or be part of the platform's periphery:

- *Core*. The AM machine can be at the core of a production system. One could picture AM printers that are installed, for instance, in care garages, and serve as the basis for complementors to design spare parts to be produced with these machines. Similar to prototypical examples of platforms, access to the core could be organized via standardized interfaces.
- *Periphery*. Am machines can form the periphery. Production with AM can be organized via platforms and in ways similar to how Uber organizes cab rides by intermediating between drivers and customers. For example, several companies have created online platforms to facilitate the interaction between AM production facilities and customers (e.g., 3D Hubs, 3D Systems, or Protolabs). Based on uploaded digital 3D designs, customers can obtain cost estimates, invite offers, and place orders. AM has evolved via complementarities between several platforms relating to AM hardware, printing service platforms, design software platforms, and crowdfunding platforms (Kwak et al., 2018).

Platforms with AM machines at the core only partially resemble common platform examples and are hardly covered but offer interesting angles for future research. Opposed to more relatable platform examples, such as operating systems and apps, the core of an AM-based platform would be used to produce physical goods. Physicality has implications for management and strategy, as the zero-marginal costs often associated with platforms no longer apply.

AM machines in the periphery of platforms are documented in the literature (Kwak et al., 2018). Such platforms likely resemble internet of things (IoT) platforms or industrial internet of things (IIoT) platforms. Essentially, IoT combines physical and digital elements into new products and innovations (Wortmann & Flüchter, 2015). IoT platforms are software-based systems that allow users and systems to interact with smart objects (Hodapp et al., 2019; Mineraud et al., 2016). Compared to the more frequently studied examples of platforms, such as Google Android or Apple iOS, IoT or IIoT platforms are more numerous. As a result, these contexts are more heterogeneous (Wortmann and Flüchter, 2015). In these contexts, the relations between different platform sides, and different platforms, are more diffuse, and central topics such as platform openness have only been sparsely addressed (Mosterd et al., 2021). Furthermore, complements are, more often than not, physical products, such as smart meters or smart light bulbs. Here, too, applies that physicality changes how platforms scale as marginal costs are no longer zero, as is the case with software.

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Vladimir C.M. Sobota was born on May 16, 1992 in Hagen, Germany. Vladimir holds a B.Eng in Naval Architecture and Ocean Engineering from Bremen University of Applied Sciences, in Bremen, Germany, and an M.Sc in Management of Technology, with a specialization in Economics and Finance, from Delft University of Technology, in Delft, The Netherlands. During his studies, Vladimir spent one semester at Universidad de Costa Rica (San Jose, Costa Rica) and worked in the German shipbuilding industry. In his master's thesis, Vladimir studied the productivity effects of temporary agency work against the context of the German industrial relations systems.

In October 2018, Vladimir joined the Economics of Technology and Innovation section at TU Delft's Technology, Policy, and Management faculty. During the dissertation, Vladimir was involved in the EU-funded H2020 project Innovation, Additive Manufacturing, and Responsible Research and Innovation (IAMRRI), which studied innovation value chains in additive manufacturing. His research interests lie in managerial and strategic aspects of technological innovations, specifically technology platforms. His research has been published in *Technovation* and *Journal of Manufacturing Technology Management*. Vladimir taught the course Strategic Management Game, part of the minor Companies and Innovation. Additionally, Vladimir supervised three master theses, held several guest lectures at the M.Sc level, and co-organized the 2021 Ph.D. summer school NITIM.

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Mosterd, L., Sobota, V. C. M., van de Kaa, G., Ding, A. Y., & de Reuver, M. (2021). Context dependent trade-offs around platform-to-platform openness: The case of the Internet of Things. *Technovation*, *108*, 102331. https://doi.org/10.1016/j.technovation.2021.102331

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