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Enabling Resource Efficient Servitization through Intermediated Online Platforms

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Abstract

This thesis examines how operators of intermediated online platforms (intermediaries) can enhance resource efficiency while ensuring the platforms' long-term economic sustainability. As servitization transforms industries by shifting the focus from product ownership to service-based models, platforms play a crucial role in enabling sharing and efficient allocation of resources. The effectiveness of platform-based solutions depends on the platform operator's ability to optimize supply-demand coordination, leverage proprietary knowledge beyond simple matchmaking, and establish viable revenue models. This thesis contributes in three ways to understanding these mechanisms, thus enabling researchers and practitioners to design sustainable platform-based business models.

First, the thesis investigates whether intermediated online platforms improve resource efficiency by optimizing allocation mechanisms. A combinatorial exchange model, applied to a case study on a Production as a Service platform, facilitates operational capacity sharing, significantly increasing matched capacity and supplier payoffs compared to traditional approaches. A corresponding online implementation demonstrates its feasibility in real-world applications. The findings suggest that intermediated online platforms can enable efficient resource utilization, reduce idle capacities, and improve economic outcomes for all participants.

Second, intermediaries can improve resource efficiency beyond optimizing matches by salvaging their proprietary market knowledge. This thesis introduces a novel return policy for online retail platforms to minimize costs and environmental impact by redirecting returns to alternative suppliers based on past demand patterns and shipping distances. An auction-based matching implementation enables the platform operator to optimize the resale process, reduce shipping distances, and increase resale value significantly. Applying the developed model to data of an online retail platform highlights the potential of intermediaries to contribute to the platform's success beyond facilitating transactions by actively increasing market efficiency through innovative platform policies.

Third, this thesis addresses the challenge of sustaining economically viable online platforms by developing a dynamic fee-setting strategy based on deep reinforcement learning. Unlike static fee-setting models, the proposed approach dynamically adjusts platform fees in response to market conditions, allowing the platform intermediary to ensure continuous profitability while maintaining the platform's attractiveness. Balancing affordability with financial sustainability allows the platform operator to optimize user participation and long-term viability. The proposed method illustrates how data-driven, dynamic decision-making can enhance the competitiveness of intermediated online platforms.

This thesis underlines that intermediated online platforms bear significant potential to enhance resource efficiency when intermediaries actively coordinate supply and demand, leverage market knowledge, and implement intelligent fee-setting strategies. The findings of this thesis provide valuable insights for future approaches towards designing sustainable and economically viable platform-based business models. Therefore, this thesis contributes to the broader discussion on digital marketplaces and servitization.

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Für Johanna Liepold

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Acronyms

AI	Artificial Intelligence
B2B	Business to Business
B2C	Business to Consumer
C2C	Consumer to Consumer
CA	Combinatorial Auction
DRL	Deep Reinforcement Learning
GDP	Gross Domestic Product
PaaS	Production as a Service
SAC	Soft Actor-Critic
WDP	Winner Determination Problem

1 Introduction

Servitization, the shift from product-centric business models to an increased offering of services alongside or instead of products, is fundamentally transforming industries. To date, servitization is already a reality in many organizations, with 68% of manufacturers reporting it as either well-established or actively supported by leadership in their company (Wipro, 2024). To successfully implement servitization, companies must rethink how they deliver and scale their newly service-enhanced products and services. Digital platforms have emerged as a key enabler for servitization as they provide the necessary infrastructure to establish service-based business models. As companies embrace these new business models, they must also address a growing challenge: sustainability has become an increasingly decisive factor for both industrial buyers and private consumers, with 85% of consumers reporting firsthand experiences of climate change's disruptive effects, influencing their shift toward more sustainable consumption habits (PwC, 2024).

Platform-based servitization enhances operational efficiency and scalability of service offerings but also presents challenges in balancing economic success with ecological responsibility. Platform operators act as intermediaries between service providers and customers, shaping how resources are allocated, utilized, and optimized within these digital ecosystems. They are key drivers of platforms' economic and ecological success due to their ability to optimize resource allocation, streamline service offerings, and encourage sustainable consumption practices. Understanding how platform operators foster resource efficiency is crucial for the long-term sustainability of online marketplaces. This thesis explores the mechanisms through which platform operators can enable and promote servitization while maintaining sustainable business practices.

The remainder of this chapter first briefly introduces the conceptual background on servitization, resource efficiency in the context of sustainability, and intermediated online platforms (Section 1.1). Afterwards, the chapter details overall aims and scope of this thesis (Section 1.2) and presents both the thesis' structure and its main contributions (Section 1.3).

1.1 Background

In the European Union, the services sector is the largest by Gross Domestic Product (GDP), making up nearly 65% of the GDP in 2023, while the manufacturing or industry sector only accounts for roughly 24% of European GDP (World Bank, 2024). The split is even more pronounced in the United States of America where, in 2023, roughly 80% of employees worked in the services sector while the manufacturing sector accounted for less than 20% of the total number of employees (ILO, 2024). Nearly 77% of the United States' GDP originates from the services sector and only 18% from the manufacturing or industry sector (Central Intelligence Agency, 2025).

Traditionally, services described the provision of labor and task-specific expertise contrary to physical goods. However, over the past decade, the definition of services has evolved, with companies increasingly integrating service-based revenue models into their product offerings to deliver greater value to customers (Örsdemir et al., 2018). **Servitization** (also written servicization) describes the business strategy of selling the functionality of a product instead of the physical product itself (Örsdemir et al., 2018). Under servitization, companies transform their business models away from a focus on selling products to the sale of integrated products and services that deliver additional value to their customers. This equates to shifting from a transactional economy to a functional or service economy, e.g., instead of a consumer buying a washing machine or a car, they may purchase cleaning or mobility services (White et al., 1999). Correspondingly, firms acquire machine hours from their suppliers rather than expanding their production capacity by purchasing new machines.

This thesis examines how servitization reshapes traditional market structures, particularly via intermediated online platforms. For the scope of this thesis, servitization refers to a company's operating principle of selling the functionality of a product rather than the product itself, independent of whether the product is a tangible or a digital one, e.g., by selling machining hours on production machines or by selling access to a digital product.

Shifting the focus from one-time sales to recurring service delivery encourages companies to adopt more sustainable business practices when implementing servitization-based business models. Integrating products with services incentivizes manufacturers to take greater responsibility for their offerings, leading to more sustainable business practices as companies usually retain ownership of their products when implementing servitization (Örsdemir et al., 2018). For example, in a Production as a Service (PaaS) setting, a company offering idle production capacity continues to own the machinery. Servitization enhances **resource efficiency** by reducing idle times and improving the utilization of

investment goods. When retaining ownership, firms are more likely to invest in durable design, repairability, and reusability, further contributing to sustainability. Additionally, variable costs tied to product usage can incentivize customers to use resources more efficiently (Agrawal & Bellos, 2017). Servitization can support enterprises across various sectors to achieve sustainability goals while addressing individual customer needs.

A key aspect of this thesis is to detail how intermediated online platforms can improve resource efficiency by matching demand and supply and by orchestrating the respective market setup beyond pure matching. This thesis particularly focuses on platform-specific features and possible levers of platform operators to optimize resource efficiency for platform-based servitization.

Online platforms use digital technologies to facilitate the connection of and transaction between previously unmatched supply- and demand-side participants, resulting in increased benefits for both of them through network effects (Hagiu & Wright, 2024; Täuscher & Laudien, 2018). These platforms are also characterized by collecting and utilizing data generated from these transactions (Li et al., 2021; Liu et al., 2021b; Zhong et al., 2023). Online platforms can help reduce market information asymmetry, thus increasing market transparency (Liu et al., 2021b).

The online platform operator serves as the **intermediary** connecting two or more distinct groups of users and enables their direct interactions (Dou & Wu, 2021). Intermediaries orchestrate the online platform, e.g., by setting market-clearing or price-determining mechanisms (Nguyen & Kannan, 2021). In addition to connecting user groups, intermediaries may provide further services such as search services, purchase-aggregation services, and consulting services; they improve overall welfare by reducing search friction and centralizing transactions (Donna et al., 2022; Gu & Zhu, 2021).

Online platforms also play a critical role as drivers and enablers of servitization. They create digital ecosystems where value is co-created sustainably and collaboratively (Eloranta et al., 2021; Pirola et al., 2020). By providing the infrastructure for seamless interaction between suppliers and buyers, platforms reduce barriers to entry for both sides, aligning with the core principle of servitization, which emphasizes access to services over ownership of products. Platforms facilitate this shift by aggregating demand, enabling resource sharing, and supporting new business models, e.g., pay-per-use or outcome-based pricing.

This thesis provides insights into how intermediaries best orchestrate online platforms to maximize resource efficiency while ensuring the continuous economic sustainability of the platform. Specifically, this thesis explores how intermediaries can leverage proprietary

knowledge and platform data to optimize the platform's design, fee structures, and other market mechanisms to the benefit of all platform users.

To summarize, this thesis methodologically and conceptually contributes to research on online platforms with a particular focus on the role of the intermediary orchestrating the platform setup while utilizing its proprietary knowledge and information. The intermediary aims to increase resource efficiency and economical benefit of all platform users. In particular, this thesis provides insights into three sub-problems in the intersection of intermediated online platforms and resource efficiency:

(1) the general question of whether resource efficiency can be increased through intermediated online platforms;

(2) the broader investigation into whether additional levers for increased resource efficiency can be achieved by the intermediary in addition to more efficient matching of demand and supply in online platforms;

(3) the challenge of how an intermediary can establish and sustain the online platform by configuring a suitable income structure that ensures economic success.

1.2 Aims & Scope

This thesis proposes novel approaches and methods to describe the resource efficient operation of intermediated online platforms and to explore how intermediaries can implement economically and ecologically sustainable platform practices. While two of the topics are applied to specific platform settings, namely PaaS and online retail platforms, they generalize to broader conceptual approaches for platform operations. Against this background, this thesis examines key challenges and opportunities, specifically:

Efficient resource allocation through intermediated servitization platforms: Intermediaries in online platforms aim to facilitate resource efficient allocation by effectively connecting supply and demand. The respective user groups of the platform measure efficiency differently based on their unique approaches towards the platform. While supplier- and buyer-side users assess the feasibility and potential benefits of joining intermediated online platforms, intermediaries must balance supply and demand, maintain trust among participants, and ensure the platform's long-term economic viability through effective governance and incentive structures. This thesis examines how intermediated platforms efficiently influence resource allocation. It presents a PaaS case study, analyzing the intermediary's ability to optimize resource usage compared to hedging-based alternatives. To evaluate the effectiveness of intermediated online platforms for all users as well as the

platform operator, benchmarking these settings against alternative models, particularly with respect to efficient resource allocation, is essential.

Reduction of negative externalities through intermediated online platforms: Establishing online platforms reduces search costs in a one-stop-shop setting for retail customers, which results in increased logistical costs and higher ecological impact. In light of these challenges, intermediaries may use their proprietary knowledge about global demand patterns and user behavior to mitigate these negative externalities. By leveraging this knowledge, they can implement strategies to optimize logistics, reduce waste, and improve sustainability. This thesis develops a novel matching-based framework for reverse logistics operations to reduce costs and environmental impact, which utilizes the platform operator's knowledge of global customer demand and market steering capabilities. The proposed return policy emphasizes economically and ecologically sustainable practices for intermediated online platforms. This thesis therefore also explores how intermediaries can thus further enhance resource efficiency beyond efficient resource allocation strategies.

Development of economically viable intermediated online platforms: It is necessary for intermediaries to establish and sustain economically viable online platforms. To this end, platform fees and pricing structures must balance the users' willingness to pay with their benefits derived from platform participation. However, setting optimal fees is complex due to the dynamic nature of supplier and buyer arrivals, as well as variations in their bid characteristics and behaviors. It is therefore essential to establish a suitable fee-setting policy to allow the platform operator to both react to and steer the two sets of platform participants. This thesis proposes a dynamic non-myopic approach based on Deep Reinforcement Learning (DRL) to optimize fee-setting strategies under uncertainty regarding supplier and buyer arrivals and characteristics. The framework ensures long-term economic sustainability for intermediated online platforms by addressing the trade-offs between affordability and platform profitability.

1.3 Structure & Contribution

Figure 1.1 visualizes the overall contribution of this thesis in the context of intermediated online platforms and resource efficient servitization. The figure highlights the intermediary's central role in optimizing resource efficient servitization practices. Specifically, the intermediary is the middleman between suppliers and buyers joining the platform, each arriving with pricing expectations related to their bids. An auction-based optimization model (focus of Chapter 3) matches these bids, resulting in the fulfillment of the bids,

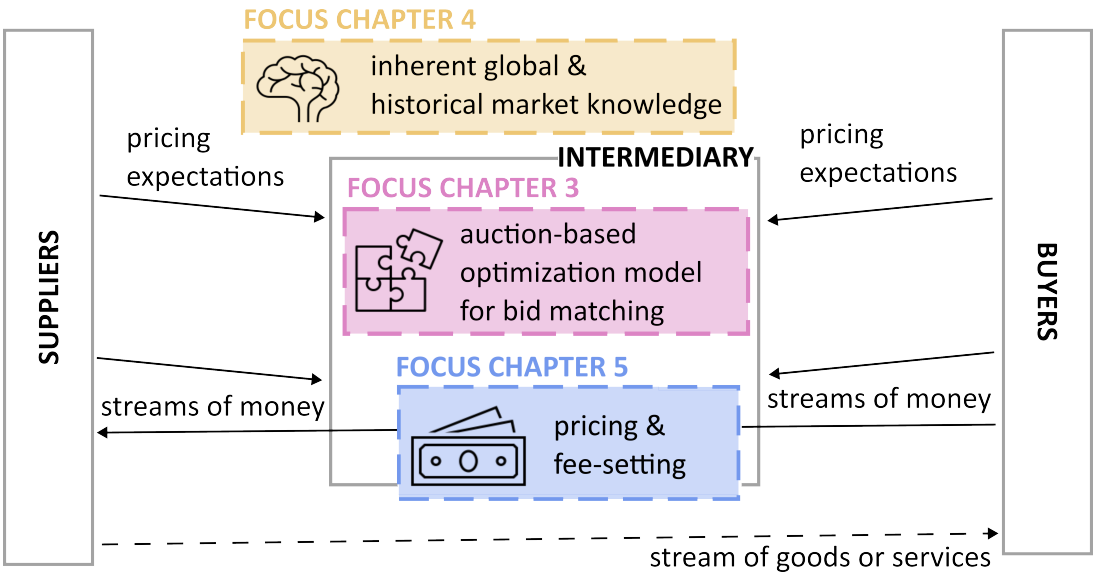

Figure 1.1: Schematic Visualization of the Contents of this Thesis

i.e., buyers receive goods and services while suppliers are financially compensated. Beyond bid matching, the intermediary can leverage its inherent global and historical market knowledge to further enhance resource efficiency within the platform (focus of Chapter 4). Additionally, the intermediary plays a crucial role in managing monetary flows through strategic pricing and fee-setting mechanisms (focus of Chapter 5). Together, these elements represent the key levers available to the intermediary for shaping the platform setup to enable resource efficient servitization.

Chapter 2 reviews the state of the art in literature on servitization and online platforms, with a specific focus on enabling resource efficiency in the context of servitization and a conceptual delineation of online platforms. Additionally, relevant methodologies and solution approaches are discussed for both the operation of online platforms' matching procedures and their pricing and fee-setting decisions.

Chapter 3 investigates whether and how intermediated online platforms can improve resource efficiency by optimizing the matching process between supply and demand. Using the motivating example of PaaS in cloud manufacturing, a novel optimization-based approach for production capacity sharing is developed. A combinatorial exchange model is proposed, extending the Winner Determination Problem (WDP) from procurement auction settings. The results show that the proposed method increases matched capacity by 39% and supplier payoff by up to 74% compared to benchmark heuristics, thus indicating resource efficiency improvement through intermediated online platforms. Furthermore, the chapter introduces an online implementation of the WDP-based model, demonstrating

its practical applicability and near-optimal performance in real-world PaaS environments, bridging the gap between theoretical advancements and practical deployment.

Chapter 4 highlights the intermediary's role in utilizing proprietary knowledge to drive resource efficiency in online platforms beyond demand-supply matching. Focusing on the application case of online retail platforms, this thesis proposes a novel return policy, the *MArket-driven INter-supplier* (MAIN) policy, which leverages the platform's knowledge of historical global demand and supply to mitigate negative externalities of return logistics. MAIN reduces reverse logistic operations' environmental and economical costs by allowing products to be returned to alternative suppliers under conditions that maximize resale likelihood while minimizing shipping distances. The proposed auction-based implementation ensures that suppliers actively participate in creating a more sustainable online retail platform, improving their welfare while also increasing the platform's efficiency. Empirical results demonstrate a reduction in shipping distance of up to 94% and an average 2.5% increase in resale value, emphasizing the potential for intermediaries to enhance resource efficiency through intelligent platform policy design.

Chapter 5 addresses the critical role of fee-setting strategies in enabling intermediaries to sustain economically viable platforms while ensuring affordability and attractiveness for all participants. Unlike static, deterministic approaches, adaptive fee-setting allows intermediaries to respond to market uncertainties and adjust platform fees dynamically. Balancing user attraction with platform profitability, the proposed approach contributes to long-term economic sustainability for the intermediary while maintaining an efficient and attractive platform setup. The chapter also explores the relationship between fee structures and market dynamics, highlighting how forward-looking, adaptive fee-setting enhances user retention, balances payoffs, and improves platform viability over time. Additionally, by applying DRL, more specifically Soft Actor-Critic (SAC), to learn non-myopic fee-setting policies, this chapter presents a novel and adaptive approach that prioritizes the welfare of all platform participants.

Chapter 6 summarizes this thesis' key methodological and managerial contributions and discusses limitations and future research perspectives.

2 State of the Art

This chapter details the state of the art in servitization (Section 2.1) and online platforms (Section 2.2). For both topics, the following sections review relevant literature related to the problems explored in the later chapters of this thesis while also opening up a broader discussion of the overarching themes. Section 2.3 discusses the intersection of servitization, online platforms, and resource efficiency, bringing together the main foci of this dissertation. Section 2.4 provides a concluding summary, outlining how this thesis contributes to existing literature and research.

2.1 Servitization

This section elaborates on the taxonomy of services and their delimitation concerning products, discusses the development towards increasing servitization in corporate practice, and presents the current state of research on servitization.

Definition of services: Traditionally, research and practice differentiate between products and services based on their tangibility and intangibility, respectively (Peppard & Rylander, 2005; White et al., 1999). However, services themselves can also be further categorized. Figure 2.1 illustrates a taxonomy of services, first distinguishing whether a service is related to a product and then differentiating whether it supports or extends the product's functions, building upon the taxonomy proposed by White et al. (1999). In addition, innovative digital services, digitally mediated services, and digital hybrid services are incorporated as outlined by Peppard and Rylander (2005). Specifically, the definition of services expands to include innovative digital services, like cloud-based platforms and location-based apps and digitally mediated services, such as online banking and e-commerce, which leverage the Internet to deliver value without physical products. Additionally, hybrid services combine physical products with complementary digital enhancements, such as fitness equipment paired with online coaching or digital tutorials for tech devices.

History and definition of servitization: Servitization describes the shift from traditional product-centric business models to product-enabled services (Kanatlı & Karaer,

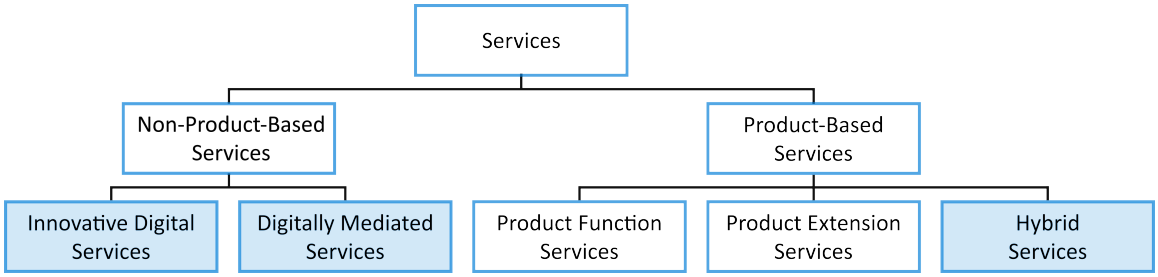

Figure 2.1: Taxonomy of Services - Adapted from White et al. (1999) and Extended based on Peppard and Rylander (2005) as Highlighted in Blue

2022). The concept of servitization first gained momentum in the late 19th century when manufacturing companies started integrating services with their products to establish market entry barriers and enhance competitiveness (Schmenner, 2009). Since the 1970s, servitization has evolved into a core strategic business model, driven by technological advancements and changing corporate priorities (Vandermerwe & Erixon, 2023). While initially only employed in manufacturing companies (Baines et al., 2009), servitization has expanded across industries. In recent years, manufacturing firms have used it to add services to physical products. At the same time, other sectors leverage digital innovations to create holistic, customer-centric solutions both in the Business to Business (B2B) and Business to Consumer (B2C) context (Vandermerwe & Erixon, 2023). Raddats et al. (2019) emphasize the transformative role of digital technologies concerning the servitization paradigm as they reshape how companies engage with their customers, which enables many different servitization-based business models. It is important to distinguish servitization from other emerging business models, e.g., the sharing economy operating in the Consumer to Consumer (C2C) context. Overall, servitization bridges the gap between traditional sales approaches and emerging business paradigms (Chomachaei et al., 2024).

Research on servitization: Örsdemir et al. (2018) analyze the impact of servitization in a game-theoretic framework. They show that servitization can simultaneously increase profits and reduce environmental impact conditional to a firm's operating efficiency and a product's lifespan. From an operational perspective, **servitization drives resource efficiency** by encouraging manufacturers to retain ownership of products and adopt long-term service delivery strategies. This shift motivates firms to prioritize durability, reduce waste, and design products for extended use, thus aligning profitability with sustainability objectives. Agrawal et al. (2019) highlight the need for research on pricing models and economic viability to support the widespread adoption of servitization. Kanatlı and Karaer (2022) compare servitization-based business models to traditional sales strategies regarding durability, pricing decisions, and environmental consequences. Specific imple-

mentations of servitization, such as pay-per-use business models, additionally highlight its economic potential. As discussed by Ladas et al. (2021), these models enable flexible pricing strategies, allowing firms to better address customers' varied usage patterns.

2.2 Online Platforms

The following section presents and discusses the state of the art in research and literature on online platforms. First, a conceptual delimitation of important expressions is presented in Subsection 2.2.1. Then, Subsection 2.2.2 presents key characteristics of online platforms followed by a discussion on the role of the platform intermediary (Subsection 2.2.3), platform competition (Subsection 2.2.4), and pricing and fee-setting in online platforms (Subsection 2.2.5). Finally, Subsection 2.2.6 discusses matching procedures for online platforms.

2.2.1 Conceptual Delimitation

The following presents a brief delimitation of expressions prevailing in the literature and research on online platforms. It is detrimental to differentiate correctly and present a clear definition of each of the following concepts:

- **Platforms** serve as foundational structures enabling interactions between multiple user groups (Rochet & Tirole, 2003). These can be physical, like a shopping mall connecting retailers and consumers, or digital, like an operating system linking application developers with users. The primary goal of platforms is facilitating interactions or transactions between distinct but interdependent groups. Additionally, a platform regulates the behavior of its users by setting rules or establishing governance design (Teh, 2022). Compared to marketplaces, platforms encompass a broader range of interactions beyond mere transactions and can, therefore, be seen as the umbrella term covering over both online platforms and (online) marketplaces.

- **Online platforms** are a subset of and inherit their characteristics from platforms. Online platforms, also called digital platforms, are a set of digital resources enabling interactions between suppliers and buyers, thereby generating mutual value (Constantinides et al., 2018; Parker et al., 2016). Due to their substantial prevalence in literature and research, multiple definitions for online platforms exist, see Subsection 2.2.2.

- **Marketplaces** describe a subset of platforms specifically designed to facilitate transactions of goods or services between buyers and sellers (Hagiu & Wright, 2015).

As platforms, marketplaces constitute the opposite of resellers, where the intermediary purchases products from suppliers and sells them to buyers.

- The **intermediary** is the organization or company acting as the platform operator that manages and governs a platform (Nguyen & Kannan, 2021). Intermediaries are responsible for maintaining the platform's infrastructure, setting participation rules, and ensuring its functionality and security. Among other decisions, intermediaries can choose between setting up the platform as a marketplace or acting as a reseller on the platform (Hagiu & Wright, 2015).

2.2.2 Key Characteristics & Classification of Online Platforms

While their relevance is prevalent in literature and practice, no universally accepted classification exists for online platforms (Chen et al., 2020). To set the stage for the discussions and platform-based applications in this thesis, a cohesive definition of online platforms is presented in the following. Chen et al. (2020) and the European Commission (2022) propose the following three **key characteristics of online platforms**:

(1) use of *digital technologies* to facilitate connection of and transaction between previously unmatched supply- and demand-side participants (see also Täuscher and Laudien, 2018 and Hagiu and Wright, 2024)

(2) collection and further *utilization of data* from these transactions (see also Li et al., 2021; Liu et al., 2021b; Zhong et al., 2023)

(3) resulting benefits for the supply- and demand-side participants through *network effects*.

These characteristics define what is referred to as online platforms in this thesis. In addition, various frameworks have been proposed to categorize platforms based on their structural differences (Chen et al., 2020; Staub et al., 2021; Täuscher & Laudien, 2018). This thesis follows a reduced version of the business model framework introduced by Täuscher and Laudien (2018) to classify online platforms and differentiates between value creation, value delivery, and value capture (see also Teece, 2010). Concretely, a platform creates value by offering users a unique benefit, delivers value through its innovative products or services, and captures value by effectively monetizing its offerings. These dimensions can be further divided into features providing a structured approach to the **classification of online platforms**, as Figure 2.2 illustrates. Concretely, the figure displays the features and possible feature values as detailed in the following:

Value creation: The unique benefit of the online platform is strongly shaped by its operator type. Following Abhishek et al. (2016), Hagiu and Wright (2015), Tsunoda

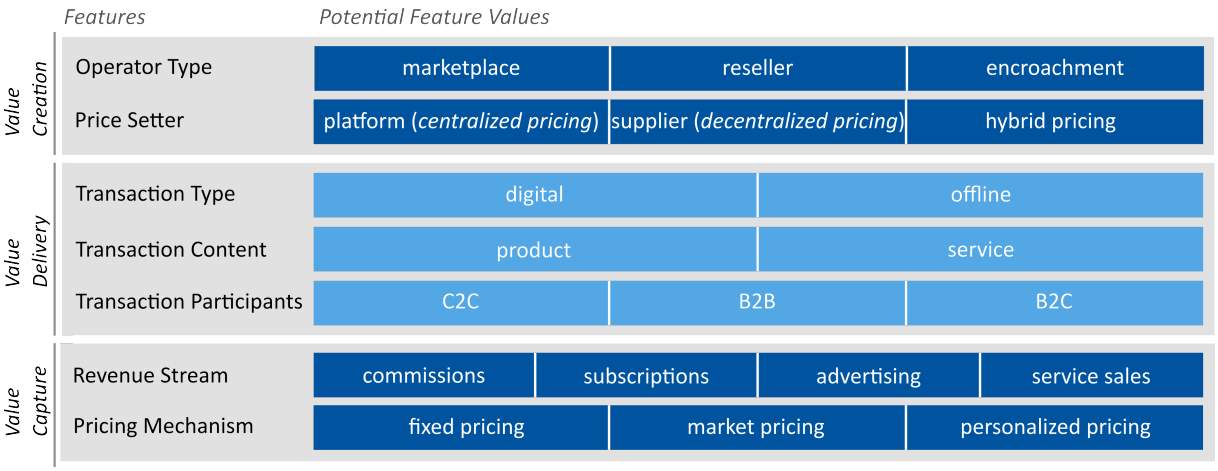

Figure 2.2: Classification of Online Platforms including Features and Feature Values - adapted from Täuscher and Laudien (2018)

and Zennyo (2021), and Zennyo (2022) and others, this thesis differentiates between the platform acting as a marketplace, reseller, or by applying platform encroachment. A platform serves as a marketplace by merely facilitating the matching between supplier- and customer-side participants without stock-keeping. In contrast, a platform operates in reseller (also sometimes called retailer) mode by purchasing products from upstream suppliers and reselling them to the customers. A platform encroaches if it does not only serve as a marketplace between third-party suppliers and customers but also sells its own products in a retailer mode (Zennyo, 2022). An additional feature of value creation is the entity of the price setter in the respective platform (Täuscher & Laudien, 2018). The platform operator can be the price setter (also referred to as centralized pricing). However, it might also accept prices set by the supplier-side of the platform users (decentralized pricing). Alternatively, hybrid pricing can be employed, combining features of both centralized and decentralized pricing. Pricing in online platforms is further discussed in Subsection 2.2.5.

Value delivery: An online platform's value delivery is mainly shaped by transaction type, content, and participants (Täuscher & Laudien, 2018). The transaction type can be digital or offline, and the transaction content can be a product or a service. Combining these two features determines whether the platform offers physical products (e.g., fashion), digital products (e.g., software), online services (e.g., movie streaming) or offline services (e.g., ridesharing). Finally, the transaction participants can span different combinations of consumers and businesses, e.g., Consumer to Consumer (C2C), Business to Business (B2B), or Business to Consumer (B2C).

Value capture: Measuring the value captured by the revenue stream follows Staub et al. (2021). The key revenue stream in an online platform may stem from commissions,

subscriptions, advertising, or service sales. The latter may include information provision, e.g., about the market composition, paid by participants of either side of the platform (Bimpikis et al., 2024) or access fees to use additional software provided by the platform, e.g., table or salon booking software (Hagiu & Wright, 2024). Another feature of value capture is the employed pricing mechanism, which might follow fixed pricing, market pricing, or personalized pricing (Täuscher & Laudien, 2018). For more details on price-setting and pricing, see Subsection 2.2.5.

2.2.3 Intermediated Online Platforms

Intermediaries facilitate matching buyers and suppliers while guaranteeing a certain quality level of the matched bids (Chioveanu & Zhou, 2013; Hagiu & Wright, 2015; Rochet & Tirole, 2006). Intermediaries are active in different contexts, such as two-sided (online) platforms, financial markets, and labor markets (Donna et al., 2022). In his seminal work, Spulber (1996) provides a comprehensive overview of intermediation, highlighting how intermediaries reduce search costs. He defines an intermediary as an *economic agent that either resells goods or facilitates transactions between buyers and suppliers*, emphasizing its two-sided role. Intermediaries enhance welfare by reducing uncertainty, lowering search costs, and ensuring product quality through market expertise. Beyond matching buyers and suppliers, intermediaries offer additional services, such as search services, purchase-aggregation services, and consulting services, to differentiate themselves from pure resellers (Donna et al., 2022).

Intermediaries are studied in many different markets, e.g., in financial markets (Anderson & Liu, 2024; Butler et al., 2021; He & Krishnamurthy, 2013), labor markets (Gu & Zhu, 2021; Hong et al., 2016; Stanton & Thomas, 2016), and energy markets (Aussel et al., 2020; Gao et al., 2024; Hyysalo et al., 2022).

Research on intermediated online platforms has primarily examined the intermediary's active role, as illustrated by the following examples. Bimpikis et al. (2020) carry out a quasi-experiment in retail operations where they investigate the intermediaries' levers to steer the availability of supply over time, thus influencing the overall composition of the marketplace. Liu et al. (2021a) develop a stylized marketplace model on the impact of intermediated online ride-hailing platforms to reduce moral hazard. They extend their work with an empirical analysis comparing intermediated ride-hailing platforms with classical taxi fleets. Wang et al. (2024) investigate the influence of quality differentiation programs set up by the intermediary in a quasi-experiment setting in the context of a vacation home rental online platform. However, a frequently used online platform may give rise to *disintermediation*, where two users from different sides of the market circumvent the platform to avoid fees while still exchanging goods or services with one another without

intermediation (Gu & Zhu, 2021; Gu, 2024).

In summary, research on intermediated online platforms has mainly focused on empirical study design and different experimental setups. Many natural or quasi-experiments and some conceptual proofs supporting the benefits of intermediated online platform settings have been brought forward. Additionally, it has been investigated how the intermediary steers the platform, e.g., through pricing models or proprietary knowledge that influences the participation levels or matching likelihoods.

2.2.4 Inter-Platform Competition

Competition is a key consideration of any platform setup, as discussed by the seminal works of Armstrong (2006) and Rochet and Tirole (2006). Competition in the context of platforms can be analyzed at the intra- and inter-platform level. Firstly, literature and research discuss competition within a platform (intra-platform), i.e., among the users of the platform. Lai et al. (2022) and others discuss the effects of price- and service-based intra-platform competition between suppliers on a platform. Cullen and Farronato (2021), on the other hand, discuss the competition between users of either side of the two-sided platform, i.e., suppliers competing for buyer-side bids or buyers competing for supplier-side bids. Secondly, there is research on competition between platforms (inter-platform), which will be the focus of the following subsection. When competing among each other, platforms add another layer of complexity to the setup of two-sided platforms in addition to the variability of demand and supply arriving at the platform as well as matching, pricing, and fee-setting decisions (Zhang et al., 2022). Platforms under competition compete for suppliers and buyers alike.

The remainder of this subsection will further discuss **inter-platform competition** and present current research on this topic. As one main result of inter-platform competition, platform operators must balance attracting users on both sides while maintaining competitive pricing (Bernstein et al., 2021; Foros et al., 2024). Nguyen and Kannan (2021) formulate a setting of inter-platform competition where competing platform operators determine the quantities of products offered on the platform, resulting in Cournot-determined prices. Halaburda et al. (2018) show that a two-sided matching platform can compete with others on the basis of limiting potential customer choices.

Inter-platform competition is often closely tied to **multihoming** of users on either or both sides of the platform. Multihoming takes place when users of one platform also join other platforms. Under inter-platform competition, platform operators aim to have multihoming users join their platform while preventing singlehoming users from multihoming with competing platforms (Li & Zhu, 2021). As outlined by Armstrong and Wright (2007), both sides of a two-sided platform may multihome. Buyers do so to

access different suppliers or platform-specific features. In contrast, suppliers multihome to access non-overlapping buyer bases, mitigate fixed costs, or reduce their dependency on a single platform. Competitive bottlenecks occur when a platform successfully secures exclusive participation from one side of the platform, which means that users on this side singlehome and only use this platform. As a result, users on the other side of the platform will have to multihome to the respective platform to maintain access to these exclusive users. Exclusive contracts and differentiation influence the extent to which either side multihomes, with platforms often leveraging pricing strategies to limit multihoming. However, as Bakos and Halaburda (2020) highlight, the low adoption costs of online platforms have made multihoming increasingly common for both buyers and suppliers. This dynamic can reduce differentiation between competing platforms, as the same users are active on multiple platforms (Cennamo et al., 2018).

Current research on inter-platform competition examines various methodological approaches to investigate the effects of multihoming. Most papers (e.g., Bernstein et al., 2021; Dou and Wu, 2021; Li and Zhu, 2021; and Zhang et al., 2022) use game-theoretic models to examine platform competition under multihoming. Others base their reasoning on analytical models deriving equilibrium outcomes (Belleflamme & Peitz, 2019; Lin et al., 2020). Bakos and Halaburda (2020) and Foros et al. (2024) explicitly use a Hotelling model to study platform competition and location-based differentiation. The research settings differ according to which users potentially multihome: both sides can multihome (Li & Zhu, 2021; Teh et al., 2023), only the supplier-side (Bernstein et al., 2021), only the buyer-side (Foros et al., 2024; Zhang et al., 2022), or either of the two sides while the other continues singlehoming (Belleflamme & Peitz, 2019).

Overall, research on inter-platform competition mainly focuses on the impact of (potentially) multihoming platform users. Specifically, mostly static approaches have been discussed so far (c.f., Bakos and Halaburda, 2020; Bernstein et al., 2021; Dou and Wu, 2021), while real-world platforms often need to adjust their market mechanism dynamically to react to changing market conditions. Additionally, the model setup often assumes homogeneous platforms (c.f., Bernstein et al., 2021) and symmetric user behavior (c.f., Bakos and Halaburda, 2020; Foros et al., 2024), which is not always the case in practice.

2.2.5 Pricing & Fee-Setting in Online Platforms

The following subsection discusses the approaches and decisions underlying the setup of prices and fees in online platforms. In particular, it presents the differences between centralized and decentralized pricing and fee-setting approaches in online platforms.

Pricing in online platforms: Platform operators can act as price setters that directly control the pricing mechanisms to quickly adapt to changing market conditions. **Centralized pricing**, i.e., the price setting platform's paradigm, is particularly beneficial under homogeneous preferences and highly perishable goods and services (Cramer & Krueger, 2016), as it increases the utilization of assets, which results in higher revenues, but also higher transaction costs (Filippas et al., 2023). Under centralized pricing, the platform operator cannot observe or utilize the private costs of the suppliers (Filippas et al., 2023; Hayek, 1945). Centralized pricing has been applied in many different contexts and types of platform setups, e.g., for online ride-hailing platforms for which Yan et al. (2020) present a thorough survey. A large share of work also focuses on the ridesharing market and how to centrally price the spatial differences between customers and suppliers (Bernstein et al., 2021; Bimpikis et al., 2019). Additionally, Bai et al. (2019) analyze optimal prices and commission rates for different supplier-to-customer ratios and customers' waiting times. Taylor (2018) examines how a platform operator in an on-demand service market sets the optimal price and commission rate depending on suppliers' patience and independence. Lin et al. (2020) combine centralized pricing and bundling strategies for competing e-commerce platforms. Guda and Subramanian (2019) discuss the effects of centralized surge pricing and forecasting-based information provision of on-demand platforms.

Decentralized pricing enables the adaptation of prices to the private supplier cost information, thus increasing supplier participation in and influence on the platform setup. Decentralized pricing is out of the control of the platform operator, allowing the supplier-side users of the platform to make selfish pricing decisions, e.g., by disregarding platform externalities (Aouad et al., 2023). However, the decentralized pricing paradigm may lead to pricing inefficiencies due to double-marginalization and limited welfare, see e.g., Donna et al. (2022). Different decentralized price-setting mechanisms can be implemented, e.g., posted prices, auctions, and price recommendations (Einav et al., 2015). Arnosti et al. (2021) discuss a decentralized market setup, i.e., a two-sided matching market without an intermediary, with decentralized pricing. Allon et al. (2012) compare platform operators utilizing decentralized pricing approaches with those implementing centralized pricing approaches while Ke and Zhu (2021) examine the truthfulness of bidders and bidding strategies in freelancing platforms under decentralized pricing. Most recently, Birge et al. (2024) present an analytical model for revenue maximization under demand uncertainty where suppliers set prices and the platform operator may only influence their price-setting decisions through incentives and information revelation.

As an alternative to centralized and decentralized pricing approaches, the notion of **hybrid pricing** has been brought forward. This approach combines the benefits of centralized pricing, such as centralized market information and the regulation of non-

efficient competition, with the benefits of decentralized pricing, e.g., the option to utilize private cost information of platform users. Different variants of hybrid pricing have been proposed, among them an initial price or price menu set by the platform operator within which the supplier selects the final price (Aouad et al., 2023) or adjusts the price by some factor to modify the price either positively or negatively (Filippas et al., 2023) or only positively (Haliem et al., 2021).

A strong focus has been placed on researching centralized pricing in online platforms. Therefore, further investigation of decentralized price-setting is necessary, especially considering the multiple benefits of this approach, such as better acceptance from supplier-side users. Especially under inter-platform competition, the platform operator needs to secure users' participation from both sides. Additionally, with the increasing development of price-setting mechanisms supported by Artificial Intelligence (AI) such as automated bidding or algorithmic pricing tools, it remains an open question how these advances influence price-setting in online platforms.

Fee-setting in online platforms: Fees enable platforms to recover fixed costs, sustain profitability, and regulate off-platform interactions. Additionally, fees allow platforms to capture user surplus, support service improvements, and promote long-term engagement (Rochet & Tirole, 2006). Platforms commonly charge at least one type of fee, either commissions relative to the transaction values or subscription-based flat fees to access the platform (Birge et al., 2021). A large-scale analysis by Antikainen and Handgraaf (2023) shows that the selected fee-setting approach depends mainly on the type of platform. For example, platforms selling physical goods are more likely to employ commissions, digital goods platforms favor subscription fees, and delivery platforms utilize both fees. Among surveyed platforms, 48% charge only suppliers, 33% charge both sides and 14% charge only buyers. Commissions are used by 51% of platforms, with rates ranging from 6.5% to 30% (Makkonen, 2024).

Fee-setting strategies in two-sided markets were first discussed by Rochet and Tirole (2003, 2006) and Armstrong (2006), who present optimal commission and subscription fee settings for two-sided markets under the impact of network externalities. Armstrong and Wright (2007) extend this by outlining the connection between fee-setting and multi-homing, utilizing subscription fees to maintain equilibrium and maximize profits. Cachon et al. (2022) show that there exists a unique combination of commissions and subscription fees that maximizes the platform payoff even under decentralized pricing. One common assumption of these works is equilibrium pricing, where competitive market forces determine final prices (Birge et al., 2021, 2024). Despite extensive research on fee-setting, existing models often assume full information on all transactions. However, real-world

platforms face dynamic market conditions, incomplete information, and strategic user behavior. Therefore, further research is needed to explore, e.g., adaptive fee structures, and their performance under realistic market conditions.

2.2.6 Matching in Platforms

The implementation of demand and supply matching in platforms varies depending on the platform's characteristics. Platform operators may utilize various matchmaking strategies such as suppliers searching for buyers, buyers searching for suppliers, both sides searching for their respective match, or centralized matching (Shi, 2023). Literature and research have discussed different approaches towards implementing the matching procedure in platforms. Although empirical analyses of market equilibria (c.f., Arnosti et al., 2021; Cullen and Farronato, 2021) have been explored, this review focuses on *algorithmic and optimization-based approaches to matching in platforms*, discussing equilibrium models, dynamic matching algorithms, and resource allocation problems.

Equilibrium models capture the behavior of both sides of the platform and the operator's response on an aggregated level, focusing on the strategic setup of the platform and its decision-making. Operational problems of matching specific buyer-side requests to supplier-side bids are not discussed in this context (Ausseil et al., 2022). Joint pricing and matching decisions or policies are often established under equilibrium conditions. For example, Özkan (2020) determines which pricing and matching policies a ridesharing platform operator should follow. More generally, Chen and Hu (2020) focus on an integrated pricing and matching policy given that strategic users arrive dynamically and stochastically on a two-sided platform.

Online matching algorithms base on the **online bipartite matching** problem as introduced by Karp et al. (1990). This problem formulation is graph-based; vertices on one side (corresponding to users on one side of the platform) are revealed sequentially and have to be matched to static vertices on the other side of the graph to maximize the number of matches. Generally, bipartite matching assumes that users on one market side have already arrived, while others on the other side are revealed sequentially, e.g., arriving demand vertices (online) are allocated to available supply vertices (offline). This notion is extended to allow for modeling more complex resource allocation settings; see, for example, Feng and Niazadeh (2024) for a very recent implementation. One possible extension of online bipartite matching is **dynamic matching**, where vertices arrive dynamically on both sides of the graph (Afeche et al., 2022; Gurvich & Ward, 2015). Additional assumptions are also taken into account in dynamic matching problems, such as the decision

autonomy of suppliers (Ausseil et al., 2022) or suppliers' assortments (Aouad & Saban, 2023). The so-called *online welfare maximization problem* generalizes online matching by allowing suppliers to be assigned to multiple buyers according to their sub-modular valuations over the set of all buyers (Kapralov et al., 2013).

Online matching is closely related to the concept of **resource allocation/resource assignment** as both involve optimizing the assignment of resources to users or tasks in real-time. Resource allocation describes the problem of optimal resource assignment to (dynamically) arriving demand. Platform operators face this allocation challenge under additional constraints concerning goods, services, or capacities needing to be allocated efficiently to maximize the overall platform objectives of welfare maximization or maximizing the number of matches (Asadpour et al., 2020; Bateni et al., 2022). Resource allocation or assignment problems are often based on the so-called *assignment game* brought forward by Shapley and Shubik (1971). This game is described by a tuple (I, J, b, c) with finite sets of customers I and service providers J and their preference matrices b and c, respectively. For each pair (i, j), b_{ij} represents the benefit customer i derives from provider j's service and c_{ij} the provider's cost for serving the customer. An outcome of the assignment game is a tuple (x, u, v) where $x_{ij} = 1$ if the respective customer is matched to the provider, u denotes the surplus of the customer and v the surplus of the provider. The resulting tuple must satisfy additional constraints of unit demand and capacity and cannot allow side payments to be feasible. Each tuple (x, u, v) satisfying the unit demand and unit capacity constraints is called a *matching*. Guo et al. (2012) argue that the resource assignment problem can also be considered a special case of the **combinatorial exchange** modeled as a two-sided market in which a set of individuals needs to be matched with an equal number of positions. The assignment problem (respectively the combinatorial exchange problem) combines a double auction (McAfee, 1992), where multiple buyers and suppliers trade multiple units of an identical good, and a Combinatorial Auction (CA), where a single supplier sells multiple heterogeneous items (Cramton et al., 2006). CAs allow bids on combinations of items, so-called bundles, based on inherent complementarities between the items (Pekeč & Rothkopf, 2003). Bundling is particularly important in settings where a bid might not be attractive unless combined with others, e.g., in collaborative vehicle routing (Gansterer & Hartl, 2018). The price the winner pays in an auction can be interpreted as either a Walrasian or a Vickrey–Clarke–Groves payment. While these payments only coincide in specialized cases, they typically differ in CAs. The goal is to determine the winning combinations of the two-sided bids (Bichler et al., 2018; Li et al., 2022). Alternative approaches have also been brought forward (Boysen et al., 2022), e.g., an exact optimization algorithm for matching demand and supply on crowdshipping

platforms based on the team orienteering problem; see Chao et al. (1996) for the original paper on this problem and Vansteenwegen and Gunawan (2019) for the most recent survey.

Existing research on matching in platforms primarily focuses on optimization and algorithmic approaches but lacks insights into user behavior, strategic decision-making, and incentives. These aspects are crucial, as platforms often struggle to align user behavior with algorithmic recommendations, particularly when users have private information or strategic motives. Empirical studies could help bridge this gap by evaluating the performance of optimization-based approaches in real-world platform settings.

2.3 Platforms, Servitization, and Resource Efficiency

Research in the nexus of servitization, online platforms, and resource efficiency highlights the intrinsic interdependence of these three topics. Additionally, the respective intersections highlight potential levers of research and practice to facilitate the efficient transition from product-centric to service-oriented business models through online platforms. This subsection synthesizes these three research areas and outlines key challenges at their respective intersections.

The role of online platforms in servitization: Online platforms are key enablers of servitization as they allow firms to transition their business models from selling products to offering integrated services. This capability to servitize a firm's business model is inherently dependent on either the participation of this particular firm on a platform or the firm establishing itself as an intermediary. Platforms then enable firms to bundle their products with services, e.g., in maintenance or leasing models (Raddats et al., 2019; Vandermerwe & Erixon, 2023). Additionally, the operator's capability to collect platform-wide, real-time supply and demand data allows the operator and supplier-side users to tailor their service offerings to the demand. The operator can establish and adjust dynamic pricing schemes and set up a suitable overall platform design (Kanatlı & Karaer, 2022). Finally, the network effects of digital platforms allow firms to efficiently expand service offerings (Hagiu & Wright, 2015; Parker et al., 2016).

Servitization and resource efficiency: Servitization supports resource efficiency by encouraging long-term product ownership, reducing waste, and extending product lifecycles as producing firms optimize product design for durability, leading to increasingly efficient products (Örsdemir et al., 2018). Usage-based pricing in servitization settings discourages overconsumption and enables improved capital utilization (Agrawal et al., 2019;

Ladas et al., 2021). Therefore, it is promising to integrate servitization approaches with online platforms as these platforms and their operators facilitate various sustainability efforts, such as remanufacturing and product leasing (Chomachaei et al., 2024).

The role of online platforms in resource efficiency: Online platforms improve resource efficiency by optimizing supply-demand matching through dedicated allocation algorithms (Ausseil et al., 2022; Bimpikis et al., 2019). By dynamically adjusting resource assignment, these platforms can reduce waste and increase utilization rates. Beyond efficiency gains, platform operators can actively shape sustainability outcomes through strategic pricing and fee-setting mechanisms. For instance, platform operators may implement surge pricing to manage demand peaks or offer eco-discounts to promote environmentally friendly products and services (Bimpikis et al., 2020; Liu et al., 2021b).

Challenges at the nexus of online platforms, servitization, and resource efficiency: As discussed, online platforms, servitization, and resource efficiency are interconnected and synergistic. However, three main challenges remain when integrating and advancing these topics.

The first challenge is the complexity of pricing and fee-setting. While servitization enables resource efficiency, determining optimal pricing and fee-setting strategies that align incentives for platform operators, suppliers, and buyers remains difficult. As the central controller, the platform operator has to find a suitable balance between managing or setting prices and generating revenues via subscriptions or commission fees (Hagiu & Wright, 2015; Rochet & Tirole, 2006).

The second challenge is the adoption of the new marketplace and servitization models. Both firms and consumers may hesitate to adopt servitization models due to uncertainties in demand forecasting and unclear cost structures. Consumers may additionally be reluctant to switch from traditional ownership models to service-based access (Kanatlı & Karaer, 2022).

The third challenge is regulatory alignment. Overall, digitalization and related concerns on data privacy, liability, and fair competition go alongside the growth of servitization- and platform-based business models. The role of intermediaries in setting rules and influencing market behavior introduces regulatory challenges that have yet to be fully addressed in research (Filippas et al., 2023; Nguyen & Kannan, 2021).

In summary, online platforms enable servitization by providing scalable infrastructure for the delivery of services, data-driven insights, and resource allocation mechanisms. To fully leverage their potential for resource efficiency, intermediaries must navigate complex pricing and fee-setting dynamics, address adoption barriers, and comply with evolving regulatory frameworks.

2.4 Conclusion

This chapter reviewed literature related to the research areas explored in this thesis, namely servitization, resource efficiency, and intermediated online platforms. These research fields have been subject to increasing activity in recent years, emphasizing their relevance to research and practice. This thesis addresses the research gaps identified in the preceding sections, contributing to the growing body of literature in these fields, as detailed in the following:

Matching in intermediated online platforms: While platforms optimize supply-demand interactions, current research lacks insights into how platform operators can leverage advanced matching mechanisms for servitization models. Most research on matching focuses on consumer-facing applications (e.g., ridesharing, e-commerce) rather than servitization contexts where companies establish service-based business models. This thesis proposes new optimization-based matching models for intermediated servitization platforms.

Leveraging platform operators' knowledge for increased resource utilization: Existing research discusses how platforms collect and utilize data, but few studies explore how intermediaries can leverage this information to enhance servitization outcomes and improve resource efficiency. Additionally, the role of the platform intermediary as an active decision-maker in managing supply-side sustainability is underexplored. This thesis investigates how platform operators can utilize proprietary data to optimize long-term resource allocation in servitization ecosystems.

Developing advanced fee-setting approaches: Traditionally, research has focused on static fee-setting models for platform servitization. However, platform competition, user behavior, and long-term engagement require the adoption of dynamic fee-setting approaches. Most existing models assume fixed transaction fees or static commissions, neglecting how platforms can dynamically adapt fees based on demand fluctuations and service utilization patterns. This thesis develops an adaptive fee-setting mechanism for intermediaries, optimizing long-term user engagement on and efficiency of online platforms.

By addressing these gaps, this dissertation contributes to a better understanding of how intermediated online platforms can enable resource efficient servitization.

3 Cloud Manufacturing Platforms - Production Capacity Resource Allocation

Cloud manufacturing, one of the trends subsumed under Industry 4.0, influences industrial production settings as it transforms resource utilization into a shared on-demand service. Central to cloud manufacturing is the Production as a Service (PaaS) paradigm, which allows intermediaries to coordinate supply and demand of idle production capacities and enables collaboration in production through outsourcing. Current practical implementations of PaaS use multiple steps to connect buyers and suppliers through an intermediary that treats each demand request individually and subsequently contacts a pool of suppliers. In contrast, we study a novel optimization-based PaaS approach and develop a combinatorial exchange model for production capacity sharing among multiple suppliers and buyers. To this end, we adapt the winner determination problem from procurement auction settings. We find that key performance indicators such as matched capacity, overall payment, and unfulfilled minimum demand depend on both the employed bidding behavior and the buyer and supplier ratio. We additionally develop a corresponding online counterpart that can be readily implemented in practice and show that it yields close to optimal solutions. Finally, we show that our solution approach increases the efficiency of matching idle production capacities on average by 39% and also increases the average supplier payoff by up to 74% compared to a practice-based benchmark heuristic.

This chapter is based on a paper co-authored with Okan Arslan, Gilbert Laporte, and Maximilian Schiffer that has been published in the Journal *Computers & Operations Research* in 2024. The full chapter is included in the examiners' copies of this dissertation. In order to avoid plagiarism or dual publication, it is not included in the freely accessible version of this dissertation. The first and second co-authors gratefully acknowledge funding provided by the Natural Sciences and Engineering Research Council of Canada under grants 2022-04979 and 2015-06189, respectively. The paper was accepted for presentation at the Graduate Program in Operations Management (GPOM 2021) at University of Passau, Germany and the International Conference on Operations Research (OR 2021) at University of Bern, Switzerland.

4 Mitigating Retail Platform Externalities via Inter-Supplier Returns

Online retail platforms such as *Amazon Marketplace*, *Zalando*, or *Hudson's Bay* are increasingly successful as they decrease transaction costs for both suppliers and customers. Online retail platforms act as intermediaries connecting suppliers and customers while usually carrying no stock. As their success depends on a sufficient customer and supplier count, platforms establish customer-friendly, benevolent return policies to attract customers and, in turn, increase their attractiveness towards suppliers. Thus, the likelihood of long-distance shipments and returns increases, which can result in severe economic and environmental costs. Mitigating the negative externalities of return shipments is a major challenge for internationally active platforms. We suggest utilizing the platform's knowledge of global customer demand and its ability to foster information sharing among participating suppliers to allow for reduced return shipment distances and increased platform efficiency. We propose, implement, and evaluate a novel *MArket-driven INter-supplier (MAIN) return policy*, which mitigates financial and environmental externalities of returns in online retail platforms. Contrary to classical return shipments, the MAIN return policy allows the return of the product to *any* supplier conditional to maximizing the resale likelihood while minimizing the return shipment distance. We design an auction-based implementation where suppliers bid on customer-issued returns to increase their welfare while reducing negative return externalities. Implementing MAIN can mitigate the drawbacks of benevolent return policies for online retail platforms. Using a data set on retail platform transactions, we show that the resale value of returns increases on average by 2.5%; shipping distance and related emissions decrease by up to 94%.

This chapter is based on a paper co-authored with Pedro Amorim and Maximilian Schiffer that is currently under review for publication. The full chapter is included in the examiners' copies of this dissertation. In order to avoid plagiarism or dual publication, it is not included in the freely accessible version of this dissertation. The paper was accepted for presentation at the INFORMS Manufacturing and Service Operations Management Conference (MSOM 2023) at McGill University, Montréal, Canada, the GERAD Seminar at HEC Montréal (2023), and the 23rd Conference of the International Federation of Operational Research Societies (IFORS 2023) at Universidad de Chile, Santiago de Chile, Chile.

5 Dynamic Fee-Setting under Uncertainty in Two-Sided Marketplaces

Two-sided marketplaces are online platforms that facilitate exchanges between suppliers and buyers by reducing search costs, for example, in the context of vacation rentals, freelancing, or beauty services. These platforms rely heavily on effective fee-setting mechanisms to ensure their profitability and long-term sustainability. Existing approaches to fee determination are primarily deterministic and base on predefined, static fee structures. However, these models have certain limitations, such as reduced adaptability to changing market conditions, which may result in welfare losses. To alleviate these drawbacks, we develop and evaluate a dynamic, learning-based approach to setting marketplace fees that adapt over time based on observed market responses. Compared to static and optimization-based benchmarks, the proposed method enables marketplace operators to better balance their own revenue goals with the participation and satisfaction of suppliers and buyers. The findings demonstrate that dynamic fee-setting yields more balanced outcomes across stakeholders, even under high marketplace variability. We show that dynamic pricing significantly enhances marketplace performance by balancing user payoffs and platform welfare. The approach also proves robust across a range of market conditions, including different valuation spreads, time structures, and levels of user fluctuation. Together, these results offer a proof of concept for dynamic fee-setting approaches and their learning-based implementation, illustrating that this fee-setting can promote balanced user payoffs without compromising economic goals.

This chapter is based on a working paper co-authored with Maximilian Schiffer. The full chapter is included in the examiners' copies of this dissertation. In order to avoid plagiarism or dual publication, it is not included in the freely accessible version of this dissertation. The paper was accepted for presentation at the International Conference on Operations Research (OR 2024) at Technical University of Munich, Germany and the INFORMS Annual Meeting 2024 in Seattle, WA, United States of America.

6 Conclusion

The following chapter summarizes this thesis and its main contributions to the research fields of servitization, platform and market mechanisms, and resource efficiency (Section 6.1). This chapter closes with a discussion of the limitations of this thesis and corresponding promising future research avenues (Section 6.2).

6.1 Main Contributions

This thesis starts with a general overview of the state of the art of research on online platforms with a particular focus on the conceptual delimitation of online platforms, relevant methodologies, and solution approaches for matching and fee-setting decisions. The concept of servitization and its contribution to increased resource efficiency are also presented and discussed. Finally, challenges of and this thesis' contributions to research in the nexus of servitization, online platforms, and resource efficiency are highlighted.

Chapter 3 introduces a novel optimization-based approach for PaaS, where an intermediary facilitates operational production capacity sharing among the users of a two-sided online platform. The intermediary aids in maximizing the utilization of production capacities, reducing idle times on the respective machines, and improving production cost efficiency. The proposed WDP-based combinatorial exchange model aims to improve the matching of buyers and suppliers of idle production capacities. Furthermore, this chapter demonstrates the effectiveness of the proposed approach. Specifically, the solution approach increases the efficiency of matching idle production capacities on average by 39%. It also increases the average supplier payoff by up to 74% compared to a practice-based benchmark heuristic. Additionally, the online variant of the WDP-P yields close to optimal solutions, which deviate from the offline results under perfect information by less than 20%. While this chapter focuses on the application area of servitization in industrial production, i.e., the possibilities to sell and purchase idle production capacities on demand, it can be easily abstracted to other two-sided online platform settings under availability and pricing constraints. Additionally, the proposed WDP-P can also be further extended to tailor it to any particular platform setting.

Chapter 4 shows how the platform operator can optimize reverse logistics operations by reducing their negative externalities in the exemplary setting of the e-commerce sector. Specifically, this chapter proposes the MAIN return policy, a CA-based framework for rerouting product returns. This chapter demonstrates that the proposed policy reduces return shipment distances while increasing average resale values. Implementing the MAIN return policy increases the resale value of returns on average by 2.5% while reducing shipping distances and related emissions by up to 94%. Additionally, the chapter illustrates that proposed alternatives to mitigate reverse logistics' negative externalities are not universally applicable. For example, central warehousing leads to return shipment distances increasing by up to 76% compared to the MAIN return policy. The proposed policy enables the marketplace operator to balance the overall welfare maximization of users with the minimization of externalities resulting from operating the platform. Utilizing proprietary knowledge of global and historical demand, the platform operator can thus actively steer the operations on the platform even outside of matching demand and supply. This chapter's findings are transferable from the presented case study on an online fashion retail platform to other globally operating two-sided platforms. The application of the proposed MAIN return policy is especially relevant for platforms aiming to improve their operational sustainability and decrease their ecological footprint.

Chapter 5 introduces a dynamic approach toward fee-setting in two-sided online marketplaces. It proposes a novel method for dynamically setting users' non-myopic subscription fees via a SAC-based implementation. Unlike traditional deterministic models with static fees, this approach minimizes regret in fee-setting decisions, ensuring long-term sustainability and adaptability. The SAC model incorporates an attention mechanism to handle variable numbers of buyers and suppliers. Comparing the DRL-based approach to optimization-based benchmarks demonstrates that the former can balance supplier and buyer payoffs with stable revenue for the platform operator. The approach mitigates the trade-off between maximizing platform welfare and maintaining supplier and buyer payoffs, particularly in cases where traditional optimization approaches prioritize platform welfare at the cost of suppliers' and buyers' payoffs. This balance is robust across a range of marketplace configurations including varying valuation spreads, operational/tactical time periods, and user dynamics. While individualized fee-setting does not offer additional performance gains and may introduce complexity without benefit, the generalized SAC-based approach maintains fairness and payoff stability without exploiting users. The developed fee-setting approach provides a proof of concept for dynamic fee-setting and can be readily adapted to various real-world scenarios where balancing user payoffs with platform sustainability under market fluctuations and competitive dynamics is essential.

Possible applications include ride-sharing services, online labor marketplaces, or digital service platforms.

6.2 Limitations and Future Research

While this thesis makes several conceptual, methodological, and managerial contributions, it also opens up exciting avenues for further exploration. The following section details and discusses specific areas where future research could build upon the findings presented in this thesis.

The approach presented in **Chapter 3** lays the foundation for further investigations into how platform operators' capacity allocation processes can dynamically adjust in response to sudden fluctuations in the platform setup. So far, the decision-making processes of suppliers and buyers are modelled from a purely optimization-based perspective. Incorporating behavioral factors, such as trust, risk aversion, or platform loyalty, could provide additional insights, refine the matching process, and increase its practical applicability even further. Additionally, further building on the developed PaaS-setting, future research could explore the role of smart contracting, e.g., through the incorporation of blockchain technology. It would be an interesting follow-up research project to identify whether this technology, which allows for securing the transactions of production data to increase trust in operational production capacity sharing, can further support the practical implementation of PaaS and servitization in general.

Chapter 4 assumes that users on both sides of the platform comply with the suggested return policies without considering cases of fraudulent returns or strategic customer behavior. An interesting extension would be to incorporate ML models to detect fraudulent returns or undesired customer behavior, allowing for personalized return policies, e.g., based on trust scores. While the developed MAIN return model primarily focuses on minimizing return shipment distances and related costs, it also creates opportunities for supporting general circular economy objectives. Future research could explore methods to enhance resale, refurbishment, or material recovery through optimized reverse logistics operations enhanced by the approaches presented in this chapter. Additionally, instead of only focusing on the return operations of a single platform, it would be interesting to explore the setup of a shared logistics system, where returns can be rerouted across multiple platforms and their users to further improve the efficiency and sustainability of platform operations.

The model presented in **Chapter 5** focuses on a single intermediary between suppliers and buyers, which provides a strong foundation for future research on more complex platform setups. One possible extension is to explore multi-tiered intermediaries, where different layers of platforms interact, such as multiple subcontractors in B2B settings. Furthermore, incorporating regulatory considerations into the model setup could provide new insights, particularly given that many marketplaces currently face regulatory scrutiny over their fee structures. Policy-aware DRL, where constraints and limitations concerning fair fee-setting practices or comparable considerations are explicitly incorporated, can be a promising extension. This modification of the presented setup will additionally enhance the applicability of adaptive fee-setting mechanisms in regulated markets.

Finally, while all problem settings explored in this thesis have been rigorously tested on realistic and real-world instances, their practical implementation presents a natural next step. Extending the proposed approaches to a real-world case study would enable direct comparisons between platforms that implement these methods and those that do not. Such an extension would provide valuable insights into the practical applicability and key implementation considerations of the presented problem settings for capacity allocation, utilization of platform-specific information, and fee-setting to improve platform efficiency and user experience.

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