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The Competition Effect of Decentralized Platforms: An Analytical Model

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Abstract

Envelopment angst and concerns about the exploitative appropriation of data network effects can lead to fragmented platform markets. In this paper, we investigate if this fragmentation can be mended with decentralized platform architectures. Abstracting from an exemplary case in the mobility-as-a-service sector, we model a competitive two-platform market with a centralized platform and decentralized alternative. We find that in markets with high envelopment costs, the co-existence of these platforms leads to market segmentation: Complementors with low market power join the centralized platform, while complementors with high market power join the decentralized platform. Furthermore, the existence of a decentralized alternative can increase welfare. Lastly, by considering data control aspects, we demonstrate the effect of favorable platform design on complementor decision-making.

Keywords: Data network effects, envelopment, mobility, modeling, strategy, welfare

Introduction

Large platform operators, such as Apple or Google, have come to dominate various markets. Some platform markets, however, seem to resist consolidation despite the existence of strong network effects. These 'fragmented' markets typically require high degrees of resource integration and data exchange for value co-creation (Vargo & Lusch, 2017). Indeed, when large platform operators mature, they begin to acquire companies from fragmented markets (Miric et al., 2021). One way to acquire other platform operators or complementors is to pursue platform envelopment strategies (Eisenmann et al., 2011, p. 1271). This competitive move describes the "entry by one platform provider into another's market by bundling its own platform's functionality with that of the target's so as to leverage shared user relationships and common components" (Eisenmann et al., 2011) and ultimately foreclose their target's access to customers. Moreover, large platform operators increasingly employ data-driven learning capabilities to leverage data network effects and entrench their dominant positions even further (Gregory et al., 2021; Gregory et al., 2022; Hermes et al., 2020; van Dijck et al., 2019). These network effects describe constellations in which "the more that the platform learns from the data it collects on users, the more valuable the platform becomes to each user" (Gregory et al., 2021).

Other players in these markets strongly resist such envelopment attempts: Complementors, i.e., actors that use platform resources to offer complementary services to potential end users, fear losing their "face to the customer" and, therefore, both their cooperate identity (Schulz et al., 2020) and access to customer data (Hoess et al., 2023). However, smaller platform operators and complementors are not without protection. They can defend against such competitive moves by attracting like-minded allies and increasing their competitiveness through the establishment of a rival platform with a comparable functionality bundle (Eisenmann et al., 2011) or by breaking data access-related advantages (Gregory et al., 2022). One way to combine these defensive strategies are decentralized platform models (Gregory et al., 2022). These models can be realized in various ways, ranging from decentralized governance to decentralized data processing and storage (Clough & Wu, 2022; Ein-Dor & Segev, 1978).

Operators of centralized platforms, in turn, may anticipate the establishment of a decentralized rival platform and invest in making their platforms more attractive. In particular, they can redesign their platforms, e.g., to maintain complementors' access to customers and their data and so reduce their fears or to share data for facilitating collaborative value capture from data network effects (Gregory et al., 2022). In this paper, we aim to study these strategic considerations. We are particularly interested in how economic parameters, such as a complementor's market power, platform fees, and coordination and envelopment costs, influence the choice of complementors to join either a centralized or a decentralized platform. Moreover, we aim to analyze how competition through decentralized platforms affects the decision of centralized platform operators to invest in such anti-envelopment measures. We hence explore the following two research questions:

- *How do key economic parameters impact whether complementors opt to join a centralized or a decentralized platform?*
- *To what extent can a decentralized platform limit the power of a central platform operator?*

To answer our research questions, we develop a two-stage analytical model: Each complementor in our model is faced with the choice of joining either a large, centralized platform or a decentralized alternative. Regardless of the platform choice, complementors face transaction-based platform fees. When complementors join the decentralized platform, they incur additional coordination costs. When joining the centralized platform, complementors incur envelopment costs that result from the loss of direct access to customers and their data. The operator of the centralized platform, in turn, can decide to invest in an adjusted platform design that limits their own access to customers' data as well as the foreclosure of complementors' direct access to customers and their data. Based on this model, we find that if the threat of envelopment is sufficiently large, only complementors with low market power join the centralized platform, while complementors with high market power join the decentralized platform. The parameters that determine market segmentation suggest that the existence or feasibility of decentralized platforms alone may be enough for a centralized platform operator to emphasize collaborative over exploitative value appropriation. Moreover, the coexistence of a centralized and a decentralized platform may increase welfare when the costs related to the threat of envelopment are high. Hence, supporting the establishment of a decentralized platform could provide regulators with a means to make operators of centralized digital platforms behave in a desirable manner.

Background

The literature on digital platforms substantiates the perspective that operating a dominant platform is highly lucrative (Weill & Woerner, 2015) and, therefore, highly contested. For instance, out of the 100 world's largest corporations in 2011, more than half earned more than half their revenues from platform business (Eisenmann et al., 2011). When large platforms integrate the functionalities of smaller platform operators or complementors, these can be subjected to an envelopment attack (Eisenmann et al., 2011; Hermes et al., 2020) that includes the foreclosure of complementors' access to customers and the exploitation of complementor data (Gregory et al., 2021; Gregory et al., 2022; Hermes et al., 2020). Platform envelopment describes the hostile entry of one platform operator into the market of another to leverage shared customer relationships and common components by combining the two platform's functionalities (Eisenmann et al., 2011). Platform envelopment is particularly attractive when the attacker's customer base has a large overlap with the target provider's customer base or when significant economies of scope exist between the two platform's functionalities. Through *bundling*, the attacker can pull customers from the target platform to its own platform and hence deny the target further access to its previous customers (Carlton & Waldman, 2005; Whinston, 1990). This tactic is specifically effective in the presence of strong network effects and economies of scale on the target (Eisenmann et al., 2011). In fact, attackers don't even have to go that far: Simply exploiting complementor data can already be harmful to complementors (Gregory et al., 2022). It allows the platform operator to engage in anti-competitive actions, such as offering successful complements themselves (Hermes et al., 2020), aggressive self-preferencing (Condorelli & Padilla, 2020), and leveraging data network effects to improve complements faster than competing complementors (Gregory et al., 2021; Gregory et al., 2022).

Consequently, when the market is highly fragmented and strong network effects are to be expected, platform complementors are in a difficult situation. Staying competitive by joining a platform that facilitates value co-creation seems necessary, but at the same time this may expose them to an envelopment attack by a large platform operator with a strong digital platform business and a history of such attacks, such as Google, Amazon, Apple, or Microsoft (Eisenmann et al., 2011; Hermes et al., 2020). From a welfare perspective, however, it is not clear whether envelopment is problematic. Envelopment attacks and comprehensive data collection allow platform operators to implement price discrimination (Bergemann et al., 2015; Clough & Wu, 2022) or inhibit competition (Kamepalli et al., 2020). Envelopment can also have positive effects, such as increasing complementor innovation (Foerderer et al., 2018; Suarez & Kirtley, 2012), amplifying network effects (Eisenmann et al., 2011; Schreieck et al., 2019), as well as reducing wasteful development efforts, for instance, in app markets (Wen & Zhu, 2019). In effect, the aggregate welfare effect of envelopment can be difficult to determine.

Eisenmann et al. (2011) suggest two defensive strategies complementors may adopt against envelopment attacks. One option is offering their own bundle. However, it is unclear whether it is more profitable for complementors to compete than to invest in establishing such a bundle: Eisenmann et al. (2011)'s analysis suggests that in most cases, envelopment attempts lead to competition rather than replacement. The second option is establishing a 'decentralized' rival platform. Decentralization on the governance level can be realized by distributing decision rights, accountability, and incentives (Gol et al., 2019). One could, for example, establish a blockchain-based platform that would allow complementors to create a "neutral ground" on which their offerings can be coordinated and combined collaboratively without depending on a centralized platform operator with substantial market power and control over customer access and data (Fridgen et al., 2019; Hoess et al., 2023; Hoess et al., 2021; Hoffmann et al., 2021). Indeed, blockchains' replicated data storage and validation would allow to jointly control data and operate a shared platform (Butijn et al., 2020; Sedlmeir et al., 2022). An alternative approach to establishing decentralized platforms is to distribute data control by deploying systems based on digital identity wallets (e.g., Hoess et al., 2023; Hoffmann et al., 2021). When compared to the replicated data processing on blockchains, this approach would allow for the better protection of sensitive customer and complementors' strategic business data (Hoffmann et al., 2021; Sedlmeir et al., 2022). Other decentralization initiatives do not involve cryptographic solutions but opt for standardized protocols and procedures, such as ActivityPub for Social Media and its federated moderation mechanisms (Rozenshtein, 2022). These forms of decentralization typically come with higher coordination costs (Andersen, 2005; O'Mahony & Karp, 2022; Wiseman et al., 2012).

Large platform operators, in turn, may respond to attempts to establish a decentralized rival platform with investments into designs that make the centralized platform more attractive to complementors. For instance, to mitigate envelopment fears, they can limit their own access to complementors' customers and their data by means of privacy-enhancing technologies (Garrido et al., 2022; Zöll et al., 2021). Moreover, platform operators could decide to share customer data with complementors and define a more collaborative value appropriation scheme, for example, by sharing collaboratively trained machine learning models (Gregory et al., 2022). These types of actions may involve an increased level of complexity as they rely on the sophisticated coordination of bilateral communication channels or the challenging process of integrating privacy-enhancing technologies in organizations (Garrido et al., 2023; Hoess et al., 2023; Zöll et al., 2021).

Empirical Evidence

Our model is motivated by current developments in the mobility-as-a-service (MaaS) industry. We use this industry as an example to illustrate our model assumptions and its results. MaaS services are typically offered on digital transaction platforms that connect various complementors, sometimes also termed mobility service providers (MSPs) (Ketter et al., 2022). These platforms facilitate interactions between customers and complementors in the form of bundling, coordination, payments, and the exchange of mobility services (Cusumano et al., 2019). Today's MaaS platforms, such as Uber and Lyft for ride-hailing or Skyscanner for flights, are typically uni-modal. Multi-modal examples like the mobility platform provided by Germany's national rail company (Deutsche Bahn) that offers not only long-distance train travel but also public transport services are rare (Hoess et al., 2023; Schulz et al., 2018). This is surprising because there is considerable customer demand for integrated mobility services (Casady, 2020; Hoess et al., 2023; Ketter et al., 2022). The high degree of fragmentation is even more surprising when taking into account that there would be strong direct and indirect network effects on a consolidated, multi-modal platform (Smichowski, 2018; Tomaino et al., 2020): On the one hand, MSPs would benefit from a higher number of customers on the platform as they can sell more services. On the other hand, the utility for MaaS customers would increase when more combinations of transportation modes and corresponding MSPs' services are available. Previous work has found that many MSPs are nevertheless reluctant to offer their services on a centralized MaaS platform because they fear losing the 'customer interface' and access to customer data (Fridgen et al., 2019; Hoess et al., 2023; Hoess et al., 2021).

To better understand these concerns, we interviewed 17 informants in the German MaaS industry. These interviews revealed that especially those MSP with a higher degree of market power, like large original equipment manufacturers (OEMs) and MSPs that operate their own MaaS platforms, are hesitant to offer their MaaS services on a larger centralized platform. First, they are aware that platform operation may not only be more profitable than providing mobility services but also lead to a dominant market position of the platform (Polydoropoulou et al., 2020). In the words of a business analyst at a premium OEM: *"Everybody would like to be the central player that actually integrates all the players and everybody is afraid that somebody else might become it and that's why it doesn't lead to these integration efforts as you would expect [...]."* Second, becoming relegated to an invisible complementor is unattractive as it can come with a loss of direct interaction with customers and, thus, visibility and access to their data (Hoess et al., 2023; Schulz et al., 2020). An interviewee from an OEM summarizes this concern: *"Why do I want to avoid the centralized platform scenario? Because that's where all the market power ends up in one company. They practically become exploitative monopolists because they have all the customer loyalty. They have all the data, they can learn from the data, they are optimizing, getting better and better, more and more efficient, stronger and stronger. And those who actually provide the physical service, they're relegated to wheels in the machinery."* As one can see, the concerns expressed by the MSPs match very well with the concept of platform envelopment and the subsequent exploitation of complementor data. Regarding defensive strategies, establishing an alternative, decentralized platform appears to be the preferred course of action for many large MSPs. A quote from a chief architect at a rail company illustrates this: *"[...] to facilitate this data exchange, we need a truly neutral entity. Because of the rejection of all efforts to create a central entity, it needs to be built on a decentralized structure – such that no company considers another's advantage in the construct larger than its own."*

Related Work

Platform literature provides a substantial body of knowledge that empirically investigates envelopment and the entry of platform operators into complementor markets (Zhu, 2019). While this helps to better understand how to model these competitive dynamics, we could identify only few analytical papers on platform disintermediation that are related to our research questions. These works focus mainly on platform leakage and investigate how a centralized platform operator can avoid disintermediation in the form of offline transactions (e.g., Chaves, 2018; Hagiu and Wright, 2023; Sekar and Siddiq, 2023) or on pricing constraints for complementors on the platform (e.g., Liu et al., 2021; Wang and Wright, 2020). To the best of our knowledge, our study is the first that builds on an analytical model to develop a comprehensive understanding of the described attack-defend-attack dynamics in platform competition. Guided by the model structure of Nault and Zimmermann (2019), our model is based on the initial formalization attempts by Eisenmann et al. (2011) as well as typical assumptions for platform fees (Armstrong, 2006; Rysman, 2009), insights from empirical research into the costs associated with 'decentralized' platforms (Andersen, 2005; O'Mahony & Karp, 2022; Wiseman et al., 2012), and anecdotal insights from our empirical evidence in the MaaS sector.

Notation and Assumptions

Before presenting and solving our analytical model, we define our notation and formally introduce our underlying assumptions. Our model incorporates three types of market participants: complementors, a centralized platform operator, and a decentralized platform. As we consider fragmented markets, we take the perspective that complementors are not yet associated with any platform. We also posit that without a proper defensive strategy (i.e., joining the decentralized platform), all complementors will eventually be subject to a successful envelopment attack. Consequently, they have to choose between joining either the centralized or the decentralized platform. Moreover, we assume that multi-homing is unattractive for complementors due to substantial costs for integrating with each platform and additional complexities when integrating with both platforms (e.g., avoiding double bookings). Therefore, complementors cannot join both platforms. The centralized platform operator collects customer information and coordinates transactions between customers and complementors. The decentralized platform, in contrast, is operated jointly by its complementors in a way such that no single entity has full control over all interactions with customers and the corresponding processing of transactions and access to customer data. We assume that the complementors in our model are heterogeneous in their market power. According to Landes and Posner (1981, p. 937), market power is defined as the "ability of a firm [...] to raise price above the competitive level without losing so many sales so rapidly that the price increase is unprofitable and must be rescinded." Market power is typically high in markets with inelastic demand (Calvano & Polo, 2021) (e.g., because corresponding services are important for many activities in an economy), high entry barriers or network effects (Werden, 2001), or when substantial investments in development, equipment, or infrastructure are required to engage in these markets (Mueller & Tilton, 1969). Several of these assumptions seem plausible for our MaaS example.

Assumption 1 [Complementor Heterogeneity]: *Complementors differ in their market power.* We characterize a complementor by its market power θ and assume θ to be distributed over the interval $[0,1]$ according to a probability distribution function F, with $F(0) = 0$, $F(1) = 1$. The corresponding probability density f satisfies $f(\theta) \geq 0 \quad \forall\ \theta \in [0,1]$. θ represents an increasing level of market power, i.e., complementors with $\theta = 0$ have no market power and complementors with $\theta = 1$ have maximum market power. Without loss of generality, we assume θ to be uniformly distributed over the interval $[0,1]$. This choice is inconsequential for our model as another distribution would not affect our results beyond scaling the effects that are relevant for complementors in choosing one of the platforms and for welfare.

We denote the units of services offered by a complementor by $x \geq 0$. A complementor can offer different "versions" of a service (e.g., an airline offers long- and short-range flights). To account for this diversity within the offering of a complementor, we consider that x increases by different levels for different services that this complementor offers. For example, if the complementors offers one more long-range flight this has a higher impact on the units of service offerings x than if the complementor would offer an additional short-range flight, even though both flights represent one service offering. Services from different complementors can also be heterogeneous (e.g., flights compared to scooter rides). To make services across different complementors comparable despite differentiation in their unit of outcome, we consider them as homogeneous in their unit of value (e.g., $\$1$). In line with Nault and Zimmermann (2019), we further model the profit from selling these services using a reduced-form profit function $PR(\,\cdot\,, x)$. The reduced-form profit function abstracts from details of revenue sources, such as direct payments from end customers or advertisement, abstracts from issues of market structure, and is general enough to represent complementors' profits in industries with various degrees of competition so long as the competition is not strategic (Nault & Zimmermann, 2019). As we assume that complementors make their decision independent of each other, we do not model strategic competition between complementors. By employing the reduced-form profit function, we also abstract from price competition by letting complementors choose their level of output, i.e., their optimal units of service offerings x. Beyond the units of services a complementor decides to offer, the reduced-form profit function also depends on the complementor's market power θ, as according to our definition of market power, revenues are affected by θ. Since inactivity in a market is not associated with any costs or revenues, we also assume that the reduced profit function satisfies $PR(\theta, 0) = 0$ for all complementors, independent of the associated θ.

Assumption 2 [Profits]: *Complementors' profit is increasing in market power and increasing and concave in the units of offered services:*

$$\frac{\partial PR(\theta,x)}{\partial \theta} > 0, \quad \frac{\partial PR(\theta,x)}{\partial x} > 0, \quad \frac{\partial^2 PR(\theta,x)}{\partial x^2} < 0. \tag{1}$$

We consider the reduced-form profit function to be increasing in the complementors' market power and increasing and concave in the units of offered services. These represent standard economic assumptions; for instance, an increasing and concave behavior of the profit function in the output of a firm is consistent with most price-competition settings (Nault & Zimmermann, 2019). Next, we consider the relationship between a complementor's market power and its units of service offerings.

Assumption 3 [Cross-Effects]: *Complementors with greater market power have higher marginal profits than complementors with lesser market power:*

$$\frac{\partial^2 PR(\theta,x)}{\partial \theta\, \partial x} = \frac{\partial}{\partial \theta}\frac{\partial PR(\theta,x)}{\partial x} > 0. \tag{2}$$

This property for cross-effects indeed seems plausible considering the definition of market power by Landes and Posner (1981) above: An increase in market power allows a complementor to increase their revenues for each service that they offer, compared to a setting where corresponding price increases would immediately be compensated by lower units of services sold. That is, complementors with higher market power obtain higher profits from offering additional service units. Note that Assumption 3 is consistent with (and in fact implies for $x > 0$) that complementors' profits are increasing in market power (cf. the first equation in (1)).

In our model, the profit-maximizing centralized platform operator charges a non-negative, transaction-based "platform fee" s_c for its coordination service. We assume that the flat, transaction-based centralized platform fee is given as reduced-form function $s_c(\theta)$.

Assumption 4 [Centralized platform fees]: *The centralized platform fees are non-increasing with complementors' greater market power.*

$$\frac{\partial s_c(\theta)}{\partial \theta} \leq 0. \tag{3}$$

The success of a multi-sided platform depends on the (indirect) network effects and is hence determined by the service offerings and customers on the platform. As such, the centralized platform operator can engage in price discrimination, skewing fees in a way that optimizes exposure to indirect network effects (Parker & Van Alstyne, 2005) to capture more value. Complementors with greater market power have a stronger bargaining position, so the platform is likely to impose smaller transaction fees on larger complementors. Consequently, we assume that centralized platform fees are non-increasing in the market power of a complementor. Considering our MaaS example, adding the service offerings of a national rail provider (e.g.

Deutsche Bahn) to the platform is more attractive in terms of customer data than convincing a local cab company to join the platform, hence the platform operator might charge lower fees to the rail provider.

As detailed above, complementors which offer their services on a centralized platform have already been or will be subjected to a successful envelopment attack. According to Eisenmann et al. (2011), an envelopment attack is likely to be more effective when there is a large overlap between the attacker's and target's customer base. We assume that complementors with larger customer bases have a greater overlap with the attacker's customer base. This assumption seems justified in cases where attackers, such as Google or Apple, provide operating systems for edge devices that customers employ to interact with the platform and its complementors. Consequently, we can take a complementor's own market power as a proxy for the shared customer base, and, therefore, assume that envelopment costs increase with the market power of a complementor. For instance, if Apple has a certain share of the overall smartphone customer base, we assume that Apple will have a similar share of the customers of a given mobility service. Importantly, our model does not assume that a complementor's customer base and market power are proportionate, but only that its customer base is increasing in market power. The centralized platform operator can invest $I \geq 0$ in additional "guarantees" (i.e., services or measures) that increase complementors' data control. These guarantees can decrease the threat ("costs") of envelopment for complementors, i.e., the foreclosure of access to customers and their data. Larger investments allow for more such actions and these investments of the centralized platform operator in additional services and measures impact the exposed "value" to an envelopment attack. In other words, envelopment costs incurred by the complementors also depend on the investment amount I. As our model focuses on a defensive strategy against envelopment attacks, we let the platform decide on the investment amount $I \geq 0$. We denote the costs of an envelopment attack for a complementor with market power θ that joins the centralized platform by $q(\theta, I)$.

Assumption 5 [Envelopment costs]: *Complementors that join the centralized platform are subject to envelopment. Envelopment costs are increasing in market power and decreasing in the investment incurred by the centralized platform:*

$$\frac{\partial q(\theta, I)}{\partial \theta} > 0, \quad \frac{\partial q(\theta, I)}{\partial I} < 0. \tag{4}$$

As we consider market power as a proxy for the shared customer base between the complementor and a potential attacker, i.e., the centralized platform operator, envelopment costs are increasing in the complementor's market power (Eisenmann et al., 2011). Moreover, as we elaborated above, from the complementors' perspective, the exposed "value" to an envelopment attack decreases when the centralized platform operator invests more to improve complementors' data control, e.g., through deploying privacy-enhancing technologies. In other words, the partial derivative of the envelopment costs $q(\theta, I)$ with respect to I is negative.

Complementors that join the decentralized platform face a non-negative, transaction-based decentralized platform fee s_d. From this fee, the decentralized platform covers infrastructure costs, such as servers and networking. Additionally, there are typically fixed costs for governing and implementing a decentralized platform (Andersen, 2005; O'Mahony & Karp, 2022). This covers, for instance, providing and integrating standardized communication endpoints in the form of application programming interfaces (APIs). We denote these coordination costs by C. In more general, s_d and C allow us to represent any affine-linear relation (e.g., using the first order Tayler series) between the costs for running the decentralized platform and the units of services a complementor decides to provide, which is a common approach in economics. We further assume that both parameters s_d and C are exogenous. Considering the availability of a centralized and a decentralized alternative, and that each complementor needs to choose exactly one of these options, we can without loss of generality ignore the fixed integration costs (if any exists) of a complementor that joins the centralized platform and think of C as the additional fixed costs that complementors incur for joining the decentralized instead of the centralized platform.

Model

Figure 1 describes the sequence of decisions in our two-stage model. We solve our model using backwards induction, allowing for strategic interactions between the centralized platform operator and complementor

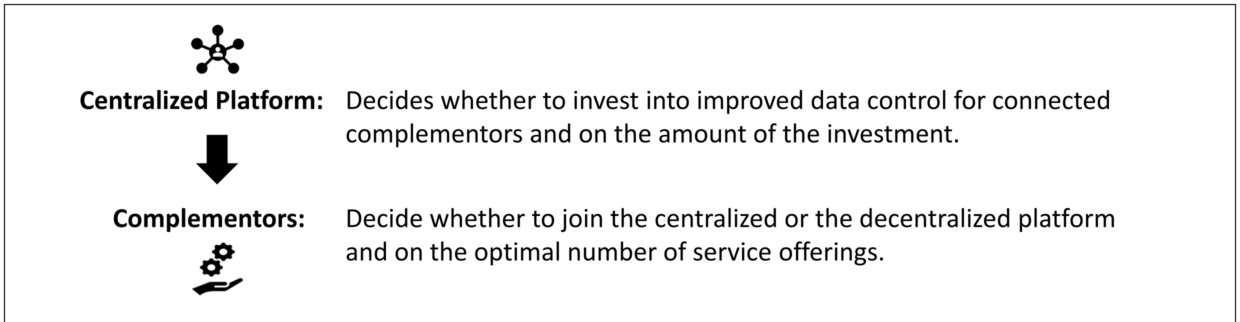

Figure 1. Sequence of Decisions by the Centralized Platform Operator and Complementors

decisions. Thus, we first solve for the complementors optimal units of service offerings and whether they should join the centralized or decentralized platform. Subsequently, we solve for the centralized platform operator's decision on the optimal investment amount in additional measures to increase data control for complementors and, therefore, decrease the corresponding envelopment costs for complementors that join the centralized platform.

Complementor Behavior

We want to analyze the optimal units of a complementor's service offerings by maximizing its profit function. For a complementor that joins the centralized platform, the net profit function Π_c consists of the reduced-form profit function less the platform fees per offered service unit and envelopment costs:

$$\Pi_c = PR(\theta, x_c) - x_c \cdot s_c(\theta) - q(\theta, I). \tag{5}$$

We maximize the net profit function with respect to the units of services that a complementor offers via the centralized platform by considering the first derivative:

$$\frac{\partial \Pi_c}{\partial x_c} = \frac{\partial PR}{\partial x_c} - s_c(\theta) \stackrel{!}{=} 0 \equiv \alpha(x_c, \theta). \tag{6}$$

$\alpha(x_c, \theta)$ implicitly defines a complementor's optimal value function for the service offering units $x_c(\theta)$ it offers. In other words, for the optimal units of service offerings, the marginal profit from an additional service unit should equal the centralized platform fee for this unit. Intuitively, low fees for the centralized platform allow complementors to offer more services, and complementors with higher market power can offer more service units because they gain larger marginal profits from the services they sell. Formally, we obtain this from analyzing the following first-order condition of $x_c(\theta)$ and state our first lemma.

Lemma 1. *The service offering units by a complementor on the centralized platform are increasing in the complementor's market power.*

Proof. The inequality follows directly from the implicit function rule and our Assumptions 2, 3, and 4 (equations (1), (2), and (3)):

$$\frac{\partial x_c}{\partial \theta} = -\frac{\frac{\partial \alpha}{\partial \theta}}{\frac{\partial \alpha}{\partial x_c}} = -\frac{\frac{\partial^2 PR}{\partial x_c \partial \theta} - \frac{\partial s_c}{\partial \theta}}{\frac{\partial^2 PR}{\partial x_c^2}} > 0. \tag{7}$$

□

For complementors that offer their services via the decentralized platform, the net profit function Π_d consists of the reduced-form profit function less the platform fees and the fixed costs of decentralization, which include additional integration costs for implementing interfaces and coordination costs:

$$\Pi_d = PR(\theta, x_d) - x_d \cdot s_d - C. \tag{8}$$

Analogous to (6), maximizing the profit function with respect to the units of services that a complementor offers via the decentralized platform, we find that

$$\frac{\partial \Pi_d}{\partial x_d} = \frac{\partial PR}{\partial x_d} - s_d \stackrel{!}{=} 0 \equiv \beta(x_d, \theta, s_d), \tag{9}$$

where $\beta(x_d, \theta, s_d)$ implicitly defines the optimal value function for the service offering units $x_d(\theta, s_d)$. Again, marginal profits should equal marginal costs, i.e., the transaction-based decentralized platform fee. We analyze the implicit function $x_d(\theta, s_d)$ and state our second lemma.

Lemma 2. *The service offering units of a complementor that joins the decentralized platform are increasing in the complementor's market power and decreasing in the decentralized platform fee.*

Proof. Analogous to the proof of Lemma 1. □

In line with the corresponding intuition, we obtain that low decentralized platform fees and high market power lead to complementors offering more services on the decentralized platform.

Indifferent Complementor

When a complementor decides whether to join the centralized or decentralized platform, it chooses the option that leads to greater net profits. We denote the complementor that is indifferent between joining the centralized or the decentralized platform by $\tilde{\theta}$. It follows that

$$PR(\tilde{\theta}, x_c(\tilde{\theta})) - x_c(\tilde{\theta}) \cdot s_c(\tilde{\theta}) - q(\tilde{\theta}, I) - PR(\tilde{\theta}, x_d(\tilde{\theta}, s_d)) + x_d(\tilde{\theta}, s_d) \cdot s_d + C = 0 \equiv \Lambda(\tilde{\theta}, I, s_d, C). \tag{10}$$

$\Lambda(\tilde{\theta}, I, s_d, C)$ implicitly defines the indifferent complementor $\tilde{\theta}(s_d, I, C)$. From the perspective of a complementor, the main differences between the two platforms are the envelopment costs incurred on the centralized platform and the (additional) coordination costs on the decentralized platform. By analyzing the indifferent complementor's behavior, we find our first theorem:

Theorem 1 (Market segmentation). *There exists a $\tilde{\theta} \in \mathbb{R}$ that defines the indifferent complementor and segments the market. When envelopment costs from integrating with the centralized platform are sufficiently high, then $\tilde{\theta} \in [0, 1]$ is unique. This implies the coexistence of the centralized and decentralized platform, where only complementors with market power below $\tilde{\theta}$ join the centralized platform.*

Proof. For a given θ, a complementor will join the centralized platform if $\Lambda(\theta, I, s_d, C) > 0$ holds. Conversely, for $\Lambda < 0$, the complementor will join the decentralized platform. Analyzing Λ with respect to the indifferent complementor, we obtain

$$\begin{aligned} \frac{\partial \Lambda}{\partial \tilde{\theta}} &= \frac{\partial PR(\tilde{\theta}, x_c(\tilde{\theta}))}{\partial \tilde{\theta}} + \frac{\partial PR(\tilde{\theta}, x_c(\tilde{\theta}))}{\partial x_c} \frac{\partial x_c(\tilde{\theta})}{\partial \tilde{\theta}} - \frac{\partial x_c(\tilde{\theta})}{\partial \tilde{\theta}} \cdot s_c(\tilde{\theta}) - \frac{\partial s_c(\tilde{\theta})}{\partial \tilde{\theta}} \cdot x_c(\tilde{\theta}) - \frac{\partial q(\tilde{\theta})}{\partial \tilde{\theta}} \\ &\quad - \frac{\partial PR(\tilde{\theta}, x_d(\tilde{\theta}, s_d))}{\partial \tilde{\theta}} - \frac{\partial PR(\tilde{\theta}, x_d(\tilde{\theta}, s_d))}{\partial x_d} \frac{\partial x_d(\tilde{\theta}, s_d)}{\partial \tilde{\theta}} + \frac{\partial x_d(\tilde{\theta}, s_d)}{\partial \tilde{\theta}} \cdot s_d \\ &= \frac{\partial PR(\tilde{\theta}, x_c(\tilde{\theta}))}{\partial \tilde{\theta}} - \frac{\partial PR(\tilde{\theta}, x_d(\tilde{\theta}, s_d))}{\partial \tilde{\theta}} - \frac{\partial s_c(\tilde{\theta})}{\partial \tilde{\theta}} \cdot x_c(\tilde{\theta}) - \frac{\partial q(\tilde{\theta})}{\partial \tilde{\theta}}. \end{aligned} \tag{11}$$

The last line is obtained using the optimality conditions from the proofs of Lemma 1 (equation (7)) and Lemma 2: We can factor out the terms $\partial_{\tilde{\theta}} x_c$ and $\partial_{\tilde{\theta}} x_d$ and identify the terms $\partial_{x_c} PR - s_c = 0$ and $-(\partial_{x_d} PR - s_d) = 0$, respectively. Considering the remaining terms, the first and third term are positive and the second and fourth term are negative by Assumptions 2, 4 and 5 (equations (1), (2), and (3)). By the mean value theorem, there exists some $\bar{x}$ between $x_c(\tilde{\theta})$ and $x_d(\tilde{\theta}, s_d)$ such that

$$\frac{\partial PR(\tilde{\theta}, x_c(\tilde{\theta}))}{\partial \tilde{\theta}} - \frac{\partial PR(\tilde{\theta}, x_d(\tilde{\theta}, s_d))}{\partial \tilde{\theta}} = \left(x_c(\tilde{\theta}) - x_d(\tilde{\theta}, s_d)\right) \cdot \frac{\partial^2 PR(\tilde{\theta}, \bar{x})}{\partial \theta \partial x} \approx 0. \tag{12}$$

For an indifferent complementor, the difference between the optimal service units that it offers on the centralized and on the decentralized platform should be close to zero. Indeed, for $s_c(\tilde{\theta}) = s_d$, the optimal service offering units $x_c(\tilde{\theta})$ and $x_d(\tilde{\theta}, s_d)$ are equal by their optimality functions (6) and (9), so their difference is exactly zero. Otherwise, when $s_c(\tilde{\theta}) \neq s_d$, their difference is likely small in absolute terms as both fees are transaction-based. Therefore, the marginal profits $\partial_{x_c} PR$ and $\partial_{x_d} PR$ must be approximately equal. As the profit function is strictly concave, so must the service offering units. Consequently, the difference between the marginal profits is small and the terms that represent price discrimination and envelopment costs dominate in (11). Because we are solving our model using backward induction, the investment of the centralized platform operator is known and so are the exogenous decentralized platform fees and the coordination costs when complementors decide which platform to join. It follows that there are only two cases and the derivative of Λ is either strictly increasing or strictly decreasing in $\tilde{\theta}$.

Case 1: $\frac{\partial \Lambda}{\partial \tilde{\theta}} < 0, \text{if } |\frac{\partial s_c(\tilde{\theta})}{\partial \tilde{\theta}} \cdot x_c(\tilde{\theta})| < |\frac{\partial q}{\partial \tilde{\theta}}|$; Case 2: $\frac{\partial \Lambda}{\partial \tilde{\theta}} > 0, \text{if } |\frac{\partial s_c(\tilde{\theta})}{\partial \tilde{\theta}} \cdot x_c(\tilde{\theta})| > |\frac{\partial q}{\partial \tilde{\theta}}|$.

We investigate whether Λ is positive or negative for $\tilde{\theta} = 0$:

$$\Lambda(0, s_d, I, C) = PR(0, x_c(0)) - x_c(0) \cdot s_c(0) - q(0, I) - PR(0, x_d(0, s_d)) + x_d(0, s_d) \cdot s_d + C \geq 0. \quad (13)$$

The profit functions, the service offering units, and the envelopment costs are increasing in the market power of a complementor, and for $\theta = 0$, these function values are small. Even though the centralized platform fee increases for complementors with lesser market power, as service offering units are small, so will be the product. Hence, the constant term (i.e., the coordination costs C) exceeds the other values and we infer that $\Lambda(0, s_d, I, C) \geq 0$.

Summarizing the findings from above, we find that in case 1, there exists a unique solution for $\tilde{\theta}$ such that $\Lambda = 0$, as it starts with a positive value for $\tilde{\theta} = 0$ and the derivative of Λ is strictly negative. In case 2, the derivative is increasing, which implies that $\Lambda > 0$ for all $\tilde{\theta} \in [0, 1]$. Consequently, all complementors join the centralized platform, and we can think of this as some $\tilde{\theta} > 1$. □

As complementors always choose the platform that leads to higher net profits, Theorem 1 has the following implication: Only when the additional envelopment costs are higher than a complementor's savings due to price discrimination exercised by the centralized platform operator, we can observe market segmentation among co-existing platforms: Complementors with market power above the threshold $\tilde{\theta}$ will join the decentralized platform, while complementors with market power below the threshold join the centralized platform. Considering our running MaaS example where MSPs consider an envelopment attack and the corresponding costs as an essential threat (c.f. the Background section), it holds that $\tilde{\theta} \in (0, 1)$ and there are MSPs with greater market power that are better off joining the decentralized platform and MSPs with lesser market power that choose the centralized platform instead. In a market where envelopment costs are small, all complementors will join the centralized platform according to the theorem.

Only case 1 in the proof of Theorem 1 leads to market segmentation where both a centralized and a decentralized platform can coexist. Consequently, we can analyze only for the case where envelopment costs are sufficiently high the behavior of the threshold $\tilde{\theta}$ that determines the segmentation of complementors in the market. Considering the indifferent complementor (equation (10)), we find that $\tilde{\theta}$ depends on the fixed coordination costs C, the decentralized platform fee s_d, and the investment I determined by the centralized platform operator. Intuitively, low decentralized platform fees attract more complementors to join the decentralized platform. Moreover, the centralized platform operator attracts more complementors if the fixed costs of decentralization are high, and it can actively increase the range of θ for which complementors join it by increasing its investment I. We formalize these observations mathematically by the following lemma.

Lemma 3. *For sufficiently high envelopment costs, the threshold that defines the indifferent complementor is increasing in the decentralized platform fee, the investment of the centralized platform operator, and the coordination costs of the decentralized platform.*

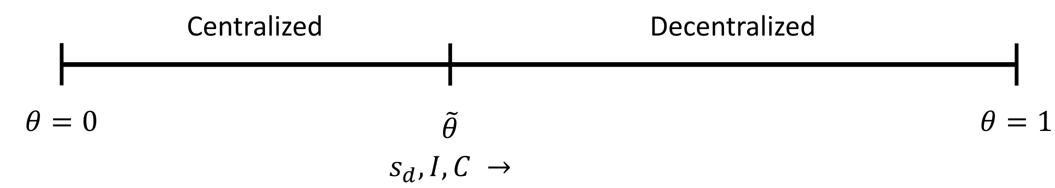

Figure 2. Segmentation of the Market for $\tilde{\theta} \in [0,1]$

Proof. Using the implicit function rule, Assumption 4 (equation (3)), Theorem 1, and the optimality conditions (6) and (9), as well as the definition of Λ in (10), the statement follows:

$$\frac{\partial\tilde{\theta}}{\partial s_d} = -\frac{\frac{\partial\Lambda}{\partial s_d}}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} = -\frac{x_d(\tilde{\theta}, s_d)}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} > 0, \qquad \frac{\partial\tilde{\theta}}{\partial I} = -\frac{\frac{\partial\Lambda}{\partial I}}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} = -\frac{-\frac{\partial q(\tilde{\theta}, I)}{\partial I}}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} > 0, \qquad \frac{\partial\tilde{\theta}}{\partial C} = -\frac{\frac{\partial\Lambda}{\partial C}}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} = -\frac{1}{\frac{\partial\Lambda}{\partial\tilde{\theta}}} > 0. \tag{14}$$

□

We can derive the following insights from Lemma 3: When the investment I of the centralized platform increases, and for markets where the fee s_d or the coordination costs C of the decentralized platform are high, more complementors join the centralized platform even though they are subject to envelopment. Figure 2 summarizes the results of Theorem 1 in case that $\tilde{\theta} \in (0,1)$. The arrow indicates the direction in which the threshold $\tilde{\theta}$ changes when the market parameters increase in their value.[1]

Platform Decision

Next, we consider the first stage of our model, where the centralized platform operator optimizes its profit by setting the investment amount for increased complementors' data control, while anticipating optimal complementors' behavior. We use the abbreviation $(*) = (s_d, I, C)$ to simplify our notation. The centralized platform operator's profit function comprises the platform fees less the investment amount it decides to spend for improving the level of complementors' data control:

$$\Pi_{\text{cp}}(I) = \int_0^{\tilde{\theta}(*)} x_c(\theta) \cdot s_c(\theta)\, \mathrm{d}\theta - I. \tag{15}$$

The centralized platform operator will choose I such that $\Pi_{cp}(I)$ is maximized:

$$\frac{\partial\Pi_{\text{cp}}}{\partial I} = \frac{\partial\tilde{\theta}}{\partial I} \cdot x_c(\tilde{\theta}) \cdot s_c(\tilde{\theta}) - 1 \stackrel{!}{=} 0 \equiv \zeta(I, s_d, C). \tag{16}$$

$\zeta(I, s_d, C)$ implicitly defines the optimal investment of the centralized platform operator. Equation (16) indicates that for an optimal investment, the profit of the platform from complementors that decide to join the centralized platform due to additional investments in data control should equal the marginal investment amount. When envelopment costs are small, according to Theorem 1, all complementors join the centralized platform. Hence, investing into data control does not yield additional complementors joining the centralized platform, such that the optimal investment is zero, i.e. $I = 0$. Otherwise, when envelopment costs are high, the coexistence of the decentralized platform represents an incentive for the centralized platform operator to invest in additional data control measures for complementors, as in this case the term on the left-hand side in (16) is positive and the term on the right-hand side is negative.

To determine the marginal profit of the centralized platform operator, we distinguish between two cases. If (i) $\partial_I \Pi_{\text{cp}} < 0$ for all $I \geq 0$, then the optimal investment is $I = 0$ as the centralized platform profits are

[1] Similarly, the threshold $\tilde{\theta}$ is decreasing in the centralized platform fee s_c. However, as we do not model centralized platform fees as a decision of the centralized platform operator, but assume them to be a given function, we do not formalize and prove this statement.

decreasing in the investment. Else, (ii) there exists an optimal investment $I > 0$ such that $\partial_I \Pi_{\text{cp}} = 0$, In other words, the coexistence of the decentralized platform incentivizes the centralized platform operator to invest in additional data control for complementors. The case that $\partial_I \Pi_{\text{cp}} > 0$ for all $I \geq 0$ is infeasible from an economic point of view as this would imply that every additional investment increases the profit, such that an infinite investment amount is optimal for the centralized platform operator. Consequently, there is an optimal solution $0 \leq I < \infty$ for the investment. However, analyzing the optimal behavior of the optimal investment amount requires further assumptions regarding the envelopment costs. For our running MaaS example, a centralized and decentralized platform will co-exist. As several MSPs mentioned in the interviews (c.f. the Background section) that their major concerns are related to the impact of foreclosure of access to customer data and the exploitation of data network effects by the centralized platform operator, it is conceivable that an investment by the centralized platform operator in data control measures leads to a sufficiently strong effect on the threshold that segments the market such that (ii) from above holds and the optimal investment is positive, i.e., $I > 0$.

Welfare Analysis

We now analyze the welfare effect of the coexistence of a centralized and a decentralized platform in the market. The welfare function is defined as the sum of the market participants' net profits. We investigate in particular the impact of the first complementors switching to the decentralized platform when envelopment costs are sufficiently high (cf. Theorem 1). We denote by the superscript (2) the case where all complementors join the centralized platform and by the superscript (1) the case when the first complementors switch to the decentralized platform. When all complementors join the centralized platform (i.e., $\tilde{\theta} \geq 1$), there is no incentive for the centralized platform operator to invest in additional data control measures as it cannot extract any additional profits from such investments (cf. (16)). In this case, $I = 0$ holds. Further, there is no decentralized platform fee, and no additional integration costs arise, such that $s_d = C = 0$. Transfers cancel in the welfare function, such that we obtain that the welfare is given by

$$W^{(2)}(0,0,0) = \int_0^1 PR(\theta, x_c(\theta)) - q(\theta, 0)\,\mathrm{d}\theta. \tag{17}$$

When the first complementors switch to the decentralized platform (i.e., $0 < \tilde{\theta} < 1$), these complementors pay a decentralized platform fee for their service offerings and also face additional integration costs. Hence, $s_d > 0$ and $C > 0$. Further, the centralized platform operator has an incentive to invest in data control measures and $I \geq 0$ holds. In this case, welfare is given by

$$W^{(1)}(I, s_d, C) = \int_0^{\tilde{\theta}} PR(\theta, x_c(\theta)) - q(\theta, I)\,\mathrm{d}\theta + \int_{\tilde{\theta}}^1 PR(\theta, x_d(\theta, s_d)) - C\,\mathrm{d}\theta - I. \tag{18}$$

The welfare effect of the decentralized platform is given by the difference in welfare between (1) and (2):

$$\begin{aligned} &W^{(1)}(I, s_d, C) - W^{(2)}(0,0,0) \\ &= \int_0^{\tilde{\theta}} q(\theta, 0) - q(\theta, I)\,\mathrm{d}\theta + \int_{\tilde{\theta}}^1 PR(\theta, x_d(\theta, s_d)) - PR(\theta, x_c(\theta))\,\mathrm{d}\theta + \int_{\tilde{\theta}}^1 q(\theta, 0) - C\,\mathrm{d}\theta - I. \end{aligned} \tag{19}$$

Analyzing this equation, we find our last theorem.

Theorem 2 (Welfare)**.** *When envelopment costs are high, the coexistence of a decentralized platform increases welfare. Otherwise, it decreases welfare.*

Proof. Considering the last line in (19) and using the fact that q decreases in I by Assumption 5 (equation (4)), we find that the difference in the integrand of the first integral is positive, such that the integral is positive. In the second integral, the integrand is negative if the centralized platform fee is lower than the decentralized platform fee for complementors with greater market power (between $\tilde{\theta}$ and 1) and is positive otherwise: According to Assumption 2 (equation (1)), PR is increasing in x. Comparing the optimality functions (6) and (9), it follows that a complementor will increase (decrease) its service offering units when switching to the decentralized platform if the costs of offering a service decrease (increase). As the centralized platform fee is lower for complementors with greater market power according to Assumption 4 (equation (3)), the difference is likely to be negative. However, for a fixed market power, if a complementor switches from the centralized to the decentralized platform, it will probably offer approximately the same service offering units, such that the difference is small (c.f. the proof of Theorem 1). Consequently, the value of the second integral will be small as well. The remaining terms have opposing effects. On the one hand, the reduction in envelopment costs due to fewer complementors joining the centralized platform increases welfare. On the other hand, the additional coordination costs C of the decentralized platform and the additional investment $I \geq 0$ of the centralized platform operator decrease welfare. Hence, the welfare effect strongly depends on the extent to which complementors are subject to envelopment risks. □

Theorem 2 states that for markets where the exposed value to an envelopment attack is sufficiently high, the coexistence of a centralized and a decentralized platform will increase welfare compared to the sole existence of a centralized platform. The coexistence may lead to an investment of the centralized platform operator into additional data control for complementors. As such, it reduces envelopment costs for complementors that join the centralized platform and increases their net profits. Further, complementors that are subject to large envelopment costs have an opportunity to avoid envelopment, which can also increase their net profit if the increase compensates for the additional coordination costs. In our empirical MaaS illustration, where complementors fear large envelopment costs, a decentralized platform would not only help complementors to defend against an envelopment attack performed by a centralized platform but also lead to increased value creation.

Discussion and Conclusion

In this work, we study the competition effect of introducing a decentralized platform into a market with a high risk of envelopment; more specifically, the foreclosure of access to customers and their data. In particular, we develop an analytical model that examines the decisions of platform complementors with heterogeneous market power to either join centralized or decentralized platforms. Moreover, we analyze how competition by a decentralized platform affects the decision-making of the centralized platform operator regarding the implementation of improved data control measures for conmplementors. Lastly, we study how the platform operator's decision impacts complementor segmentation and overall welfare.

We find that when envelopment costs are sufficiently high, the centralized and decentralized platforms will coexist. In this case, complementors with low market power join the centralized platform while complementors with high market power join the decentralized platform. The coexistence of a decentralized platform, in turn, provides an incentive for the centralized platform operator to invest in safeguards for complementors against envelopment. When envelopment costs for complementors are high, the coexistence of a decentralized platform increases welfare. When they are low, the existence of a decentralized platform may decrease welfare. Our model assumptions build on basic economic principles and related work on platform attack and defense strategies. Additionally, we support our assumptions using anecdotal evidence from an interview study with stakeholders from the German MaaS sector. The interviews also provide the intuition that a complementor's decision to join a centralized or a decentralized platform does not depend strongly on platform fees.

Despite this grounding in the German MaaS sector, our model may generalize well to other data-heavy industries. For instance, the fragmentation of IT systems has been identified as one of the main causes of unsustainable costs and poor quality in the U.S. healthcare system (Elhauge, 2010; Stange, 2009). Since the healthcare industry is also a service-dominated market in which the integration of resources and the exchange of data are essential for value co-creation, a concentration of service providers in the healthcare system on large platforms could also be expected in the long term. In this context, Alt et al. (2019) highlight the importance of customer-induced service orchestration in healthcare systems, as the decision on the treatment path is decisive for subsequent decisions on the selection of other complementary services for the customer. Also e-commerce or online education represent data-heavy industries where to date many complementors interact (at least to some degree) competitively and where market power is relevant.

Theoretical Contributions

Our model contributes to the literature on offensive and defensive platform strategies in various ways. First and to the best of our knowledge, our model is the first to analytically study the effects of envelopment (Eisenmann et al., 2011; Hermes et al., 2020) and the exploitative appropriation of data network effects (Clough & Wu, 2022; Gregory et al., 2022). Specifically, our model is the first that combines platform operator and complementor decision-making, complementors' market power, and their fear of envelopment and loss of data control in an analytical model. Thus, we develop a very general understanding how these economic parameters influence the decision of complementors and large platform operators in the market. Second, we show how complementors' market power influences their preferences for a decentralized platform when envelopment costs from integrating with a centralized platform are sufficiently high. As only complementors with lower market power join the centralized platform, it may be optimal for a platform operator to invest in additional safety measures for complementors. This will attract more complementors to the platform. Third, we find that in markets where complementors are subjected to high envelopment costs, the mere existence of a decentralized platform increases welfare.

Practical Implications

Our model offers powerful practical implications – especially for regulators and operators of centralized platforms. In particular, our model suggests that the establishment of decentralized platforms could be a promising means to encourage centralized platform operators to act in a desirable way. In this sense, they could be complimentary to platform regulation such as the European Union's Digital Markets Act, which mandates large platform operators, such as Amazon or Google, to provide customer data to complementors in an attempt to reduce these platforms' increasing market dominance (Cabral et al., 2021; Weigl et al., 2023). While the regulatory framework helps complementors to defend against envelopment attacks by reducing the foreclosure of direct access to customers and their data, it does not account for data network effects of large platform operators and, consequently, only partially addresses the negative implications of joining a centralized platform that we model using envelopment costs. Specifically, subsidies that support the development and reduction of a decentralized platform's coordination costs and usage fees could incentivize platform operators to invest more in measures that reduce envelopment risks and the exploitation of complementor data. These operators, in turn, may use our model to estimate the competitive consequences of the introduction of a decentralized platform. When such an introduction would lead to an unfavorable separation of the market, they may need to re-design the architecture of their platform. When such redesigns are costly or difficult to implement, they can look into building dynamic capabilities that will allow them to implement such changes quickly when the need arises (Teece, 2007; Teece, 2017). All in all, our discussion suggests that enabling a decentralized platform may be a preferential option compared to imposing regulatory burdens on centralized platform operators, as its mere existence can increase welfare.

Limitations and Future Research

Although our model contributes to a broad and general understanding of the competition effect of decentralized platforms, there are several limitations that provide potential starting points for further research. First, our model accounts for the decision-making of complementors as well as a centralized platform operator, but it does not consider the decisions of customers. We assume that when customer demand is sufficiently inelastic and multi-homing is unattractive, they may join both platforms. This assumption seems reasonable, at least for the mobility case that informed our model, as interacting with two corresponding MaaS apps involves relatively low coordination costs for customers, and owing to the need for mobility in business, sensitivity for prices is relatively low. Yet, modeling the customer decision could also provide further insights into how the coexistence of a decentralized platform can impact the decision-making of a centralized platform operator, in particular when multi-homing is unattractive or when demand is elastic. Secondly, we do not consider an outside option for complementors that enables them to offer their services without any intermediary platform. While we consider that in the presence of strong network effects, complementors would not choose the outside option (at least in the long run), this should be studied in future research. Third, there are further economic parameters beyond the investment amount which the centralized platform could use to attract complementors. For example, the centralized platform could charge a fixed fee, which would be beneficial for complementors that offer many services, as they are no longer charged a pay-per-use platform fee. Future work could consider further design options for the centralized platform and economic parameters it can decide on to investigate how these impact complementors' decisions.

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