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Zusammenfassung / Abstract

In contrast to traditional business models, two-sided platforms internalize indirect network effects that exist between different groups of platform participants. The strength of the network effects has a decisive influence on the success of the platform and its market position. Markets with particularly strong network effects are also often characterized by a high degree of concentration. However, the strength of the network effects is not exogenously given but can be influenced by targeted investment. This paper analyses how platforms can affect network effects by investing in appropriate infrastructure, data, or artificial intelligence. We derive optimal quantities, prices, profits, and investments depending on different types of investments.

Schlagworte / Keywords: two-sided markets, indirect network effects, endogenous network effects, optimal investment strategy
JEL-Klassifikation / JEL-Classification: D21, D42, L10

1 Introduction

Two- or multi-sided platforms create value by using the existence of indirect network effects between two or more distinct groups of customers. At least one of the groups typically benefits from this interaction as a result of a positive indirect network effect (Rochet and Tirole, 2003; Armstrong, 2006). Network effects can be divided into two ideal-typical types of network effects, namely "market-size externalities" and "sorting externalities" (Dewenter and Rösch, 2014; Belleflamme and Peitz, 2015). If market-size externalities exist, the members of one customer group benefit from the pure size of the group on the other side of the market, regardless of the composition of this group. However, in the case of sorting externalities, the composition of the other group is as important as its size. In advertising, for example, the benefit generated by an additional recipient depends on whether he or she belongs to the corresponding target group. However, market-size and sorting externalities rarely occur in isolation but rather simultaneously. In this case, the sorting externality can reinforce the positive effect of the market-size externality. The platform provides an infrastructure that generates value by coordinating the demands of distinct groups. Airbnb, for example, employs a ranking mechanism that pre-filters apartment seekers' search results; Facebook displays ads to users defined as a relevant target group; and dating platforms like Parship[1] try to match the most compatible singles with a personality test. In all these cases, the platform tries to increase the benefit of at least one market side to internalize the indirect network effect and thus capture rent optimally. Therefore, indirect network effects are not exogenous factors over which the platform has no influence but can be strengthened by investment in appropriate infrastructure, data, or artificial intelligence. This paper addresses the question of optimal investment levels for a profit-maximizing platform, given that platforms can improve network effects.

These investments are part of a set of strategic decisions a platform has to face to best exploit the externalities between distinct user groups. The scope and nature of investments depend on the structure of the indirect network effect (strength, direction, and type) and the type and structure of the user groups on both market sides. First of all, a platform must solve the coordination problem. Such a situation can lead to the existence of equilibria

[1]Parship is a German dating platform where every participant has to take a personality test before they can use the platform's services.

in which no one participates in the market (Caillaud and Jullien, 2003). In other words, the platform solves a "chicken-and-egg" problem to get both sides on board. One way to solve the chicken-egg problem is to give one side (or even both sides) of the market such strong incentives that participation is worthwhile even without (or with very little) participation of the other side. This can be achieved, e.g., through subsidized access or the provision of additional services, so-called value-added services (Dou and He, 2017). Another way to solve the coordination problem is through a sequential entry. Platforms first aim at building a critical mass on only one side before granting access to the second side (Evans, Hagiu, and Schmalensee, 2016). Amazon, for example, started as an on-sided online bookseller before turning into a two-sided platform. Once a critical mass has been built on the customers' side, Amazon opened the second side to suppliers of various products. OpenTable, in contrast, started out creating a booking management software only for restaurants before it became an online booking system.

Once the critical mass is reached, the indirect network effect causes an increase of the benefit of market participants with each user on the "other side" of the market since there is a larger number of potential transaction partners. However, additional users can also contribute to congestion and increase search costs. In some cases, additional users on the "own side" of the market lead to a decline in the benefit, as competition between single members intensifies (Belleflamme and Toulemonde, 2009). In some cases, the matching of both sides becomes more complicated when the number of users and their diversity increases. Therefore, the platform's efficiency depends not only on the number of users but also on the potential to find a suitable match on the other market side. We argue that platforms can invest in connecting the market sides even more efficiently, thus strengthening the indirect network effect. A good strategy for the platform could be to provide appropriate mechanisms to reduce search costs. In the case of Airbnb, e.g., the typical searcher sees only about 4.2% of all existing entries for the desired date during the search process. This narrow search should reduce search costs and lead to a higher probability of a match between searcher and provider (Fradkin, 2017). Strategies to further enable the interaction between different market sides are often the main reason why platforms are essential for the functioning of markets (Belleflamme and Peitz, 2015).

Suppose, e.g., a social network such as Facebook that provides advertisers access to potential consumers (the user side of the social network). In this scenario, the social network user group sends a positive externality to the advertising market, and advertisers compete for the limited attention span of the users. In the absence of sophisticated selection mechanisms, advertisement messages are randomly matched with user attention (Belleflamme and Peitz, 2015). The larger the user group, the more potential customers the advertiser can reach and the higher the probability that the advertising will generate revenue. However, the return on investment for each marketing dollar spent can be improved if the advertisement reaches only users with a high probability of becoming customers of the advertised product. In order to improve the targeting of advertising, the platform can invest in profiling techniques and thus increase the positive effect a growing user base has, i.e., strengthen the indirect network effect. Advertisers value a service more if more members of an audience will react positively to their messages. Concurrently, the benefits of users also increase if there is more valuable content provided by such audience-makers (Evans, 2003).

Facebook's business is heavily dependent on advertising revenue.[2] It has to continuously invest in technology to make its targeting and ad campaigns more efficient and deliver better value to its paying customers on the advertising market. In 2018 Facebook's investments in research and development doubled 2016 to $10,273 MM. They represent about 30% of total cost and thus the most significant cost factor, even before marketing expenses (Facebook, Inc, 2020a). A review of Facebook patent applications confirms this hypothesis. Many of the granted patents aim to analyze the behavior of its users and predict their preferences. For example, posts and messages sent by a user are used to infer their personality traits, which then "may be used for targeting, ranking, selecting versions of products, and various other purposes" (Smith and Braginsky (2012), p. 1). In another case, Facebook uses historical user data to predict life-changing events and provides "advertisements to the user responsive to the prediction of one or more life change events" (Nowak and Eckles (2014), p.1).

In the domain of match-makers, where agents in one group value the matching services of an intermediary (Evans, 2003), an investment in improving the matching probability can increase the utility of market participants. These markets are often characterized by a) heterogeneous user preferences on both market sides (e.g., dating or job platforms), b) on one side that is payoff relevant for the other side (brokers such as travel or real estate agents), or

[2]In 2019, advertising accounted for about 99% of Facebook's total revenues (Facebook, Inc, 2020b).

c) heterogeneous sellers or goods with limited capacity or availability (peer-to-peer markets such as Airbnb). Making selected matches is costly in all these cases, and appropriate matching technology can reinforce indirect network effects. Therefore, dating platforms develop personality tests to connect compatible singles (e.g., Parship); Streaming service providers only show content corresponding to user preferences according to the recommendation systems (e.g., Spotify, Netflix), and peer-to-peer platforms curate search results using a sophisticated ratings-and-reviews system (e.g., Airbnb). The latter is also an important mechanism to build trust among platform participants. In this way, the platform can reduce transaction costs between the actors and enable a secure exchange between strangers, and is considered crucial for the success of a platform (Hagiu and Rothman, 2016).

These examples show that platforms make investments to internalize externalities as much as possible. By strengthening indirect network effects in this way, the benefit of at least one side of the market increases, and the platform can thus maximize its profit. In the following, we address how platforms choose the optimal investment levels. For this purpose, we use an intuitive model framework to analyze how investments of a platform can improve the underlying network effects to maximize its profits.

2 Literature

Our paper contributes to the large body of theoretical literature on two-sided markets, pioneered by the theoretical work of Caillaud and Jullien (2003), Evans (2003), Rochet and Tirole (2003), and Armstrong (2006).[3] The decisive characteristic of multi-sided markets is the existence of indirect network effects that connect two or more market sides in the sense that the utility on one side of the market depends on the participation on the other side(s) of the market.

Companies operating in such markets must consider this when making strategic decisions. Hagiu (2014) identifies four core strategic decisions a platform has to take into consideration: the number of sides to bring on board, the platform design, the pricing structures, and the governance rules. In another framework Belleflamme and Peitz (2015) distinguishes between two complementary roles platforms can fulfill: the role of an infomediary

[3] For early empirical work on two-sided markets, see e.g. Rysman (2004), Kaiser and Wright (2006), and Argentesi and Filistrucchi (2007).

("The intermediary acts as an information gatekeeper [...].") and/or a trusted third-party ("The intermediary acts as a certification agent by revealing information about a product's or seller's reliability or quality."). Both Hagiu (2014) and Belleflamme and Peitz (2015) thus emphasize the importance of design choices as a strategic decision-making parameter of a platform. Similarly, Dinerstein et al. (2018) states that the platform design plays a critical role in determining market outcomes.

A large number of studies have been conducted on the optimal pricing of differentiated platforms with homogenous (Rochet and Tirole, 2003; Armstrong, 2006) and heterogeneous network effects (Weyl, 2010; White and Weyl, 2016), respectively in a monopolistic market as well as in a duopoly. On essence, the literature on two-sided platforms reveals that charging relatively less to (or even subsidize) the side that cares less about cross-market benefits to amplify users' gross utility and widen their participation (e.g. see Armstrong (2006), Rochet and Tirole (2006), and Weyl (2010)).

While a huge part of the emerging business and economics literature on two-sided markets mainly focuses on pricing and competition between platform, taking the existence of network effects as given[4], others have focused more on additional strategic decision-making parameters, such as the investment in value added services (Hagiu and Spulber (2013), Dou, He, and Xu (2016), and Dou and He (2017) among others), or other broader strategic questions such as platform design (Hagiu, 2009).

Both pricing and value-added services serve as strategies to either solve the chicken-egg problem and/or further expand the market of at least one side of the market. However, besides solving the chicken-egg problem, one of the most critical functions of market intermediaries is to reduce search costs for the parties they serve (Belleflamme and Peitz, 2015; Dinerstein et al., 2018). Hagiu (2009) argues that each platform's two fundamental functions consist of either reducing search costs/or shared transaction costs among its multiple sides. The greater these cost reductions are, the more value they create (Arnosti, Johari, and Kanoria, 2018). By implementing a market design to reduce transaction costs, the platform can optimally leverage both types of indirect network effects: market-size and sorting externalities. The benefit of agents increases with the number of users on the other side, as a larger number of potential transaction partners increases the probability of finding

[4] **caillaudChickenEggCompetition2003**; Evans (2003), Rochet and Tirole (2003), and Armstrong (2006)

a ”match” that maximizes one’s preferences. These costs are especially high in markets with heterogeneous user preferences or heterogeneous sellers or goods with limited capacity or availability. Li and Netessine (2019) finds that greater market thickness leads to lower matching rates for a platform that operates as a matchmaker for holiday property rental. Keeping search technology and other factors constant doubling the size of the market results in a reduction in traveler confirmation and host occupancy rates. In order to improve matching, Airbnb limits search results using a ranking mechanism that only displays 4.2% of all listings that were potentially visible for the set of preferences (Fradkin, 2017). Dinerstein et al. (2018) provides a theoretical framework to study the effects of search design, e.g., how to optimally navigate buyers toward the desired product in an online marketplace. Using eBay browsing data before and after redesigning the search process, they show that narrowing the consumer choice set can be pro-competitive.

These studies show that the optimal platform design depends on existing network effects’ strength, type, and direction. Additionally, they show that the implementation of such a design can optimally exploit the existing network effects. However, the investment in such an implementation leads to costs a profit-maximizing platform must consider when making strategic decisions. Using an intuitive Cournot approach (Dewenter and Rösch, 2014), this paper investigates the optimal investment level of the platform, or - since the investment is a function of the existing network effect - the optimal level of the indirect network effect. To the best of our knowledge, no study to date takes the investment costs of design decisions into account.

3 A simple model of endogenous network effects

3.1 Two indirect network effects

3.1.1 Model setup

We use a simple model that aims to examine the impact of investments to enhance network effects. Starting with a monopolistic market where a single platform serves two groups of customers, say, users and advertising customers, linked by two indirect network effects (say d and g). While user’s utility is affected by the amount of advertising, advertising customers’ utility is affected by the number of users.

Since we allow for two different network effects, the model can represent different types of two-sided platforms, e.g., matching platforms such as Amazon, audience builders such as news websites, software platforms such as iOS or Windows, and transaction systems such as PayPal (see e.g. Evans (2003), for a definition of different types of platforms).

To keep the model as simple as possible, we assume that the platform can only influence one of the two network effects, say d. As advertisers' utility (and thus the willingness to pay) increases with the number of users at factor d, the platform has an interest in increasing both the number of users and the strength of the network effect emerging from that market. As outlined above, strategies for increasing the number of users (e.g., through value-added services or subsidized pricing) have been the subject of a large number of studies. However, we consider the possibility that the platform can strengthen the indirect network effect directly through investment. The platform can, for example, invest in improving targeted advertising, which increases the probability that the advertising reaches the relevant target group. This effect, in turn, increases the utility and thus the advertiser's willingness to pay. The platform can also invest in artificial intelligence to improve a matching algorithm used by social networks, rental services or streaming platforms, etc., or invest in data collection technologies to improve its database.

The optimal investment decision depends on the strength of the indirect network effect, as the stronger, this effect is, the higher the costs of further improving a matching algorithm. Furthermore, we assume that the investment cost increases with the number of users on the market side receiving the indirect network effect (i.e., the advertiser market). Furthermore, we also allow that costs can increase with the number of users on the market side sending the indirect network effect (i.e., the search market). The more consumers and advertisers, the more heterogeneous preferences exist and the more costly the matching and the enhancement of indirect network effects.

The monopoly model helps explain the basic functionalities and serves as a reference for different market structures like market entry, competition, or product differentiation. Moreover, two-sided markets are often characterized by a strong supplier with market power close to the monopolistic model, e.g., search engines, social networks, etc..

3.1.2 Monopolistic platform

Suppose that a monopolistic platform serves two markets related by an indirect network effect. This platform could be a marketplace, an audience maker, or a two-sided platform. To keep the model simple, let us assume that the platform is an audience maker serving users and advertising customers.

Due to the indirect network effect $d > 0$, advertising customers' utility increases with the number of users. With an expansion of the network of users, the range of an advertisement increases, and advertising customers show a higher willingness to pay. Advertising, in contrast, is not assumed to affect users' utility, which only depends on the quality of the content (or service) provided and the respective price. Let us also assume that users are affected by the amount of advertising, either positively or negatively. Therefore, the indirect network effects $g \neq 0$ are positive if users value advertising and negative if not. Suppose that a monopolistic platform serves two markets related by an indirect network effect. This platform could be a marketplace, an audience maker, or a two-sided platform. To keep the model simple, let us assume that the platform is an audience maker serving users and advertising customers.

Inverse demand functions for both markets are then given as follows:

$$p = 1 - q + gs \quad \text{and} \quad r = 1 - s + dq \tag{1}$$

where p is the price for content and r is the advertising rate. Given that each user (advertising customer) buys only one quantity of content/service (advertisement), q and s then represent both the quantities of contents and advertisements and the number of users and advertising customers, respectively.

Assume that the platform can strengthen the positive effect of d on r by appropriate investments. The investment expenditures increase with the strength of the indirect network effect d, i.e., investments are characterized by decreasing marginal returns. This assumption is plausible considering the rising annual RD expenditures of companies like Amazon, Alphabet, and Facebook.[5] The innovations resulting from these expenditures include, above all, new or improved processes and models of artificial intelligence, which are

[5] Alphabet spent \$27.57 billion on RD, which is equivalent to 15.1% of its revenue of \$182.57 billion during the fiscal 2020 (Alphabet, 2020). The company's R&D spending has more than doubled since the fiscal 2016 (Alphabet, 2016).

aimed at strengthening the indirect network effects and thus increasing the willingness to pay of advertising customers. However, strengthening network effects is all the more expensive, the stronger the network effects are. We, therefore, assume a quadratic cost function with respect to network effects.

We further assume that investment costs are also influenced by the size of the networks on one or both sides, e.g. due to increased server costs, in three possible ways: Costs are influenced primarily by a) the number of users, b) the number of advertisers or c) both. Although assuming that both sides of the market influence the investment cost seems to be most realistic for most two-sided markets, we allow for different cost functions. Depending on which side (users or advertising customers) incurs higher costs in the design of the network effects, the investments can be modeled accordingly. In case, for example, the platform invests in technologies to analyze and model user data, $\frac{d^2q^2}{2}$ might be an adequate cost function. This assumption seems reasonable for audience makers such as Google or news sites. In case, however, that platforms invest in, e.g., artificial intelligence for analyzing data on advertising customers, $\frac{d^2s^2}{2}$ should be appropriate. Last but not least, in case that information on both groups is analyzed, cost should be given by $\frac{d^2qs}{2}$. The latter function seems to be adequate also for any matchmaker platform such as social networks or dating platforms.

Neglecting any costs apart from investment in network effects, marginal as well as fixed costs are assumed to be zero. The profit of a monopolistic platform is then given by

$$\max_{q,s,d} \pi = (1 - q + gq)q + (1 - s + dq)s - Inv \tag{2}$$

with

$$Inv \in \left(\frac{d^2q^2}{2}, \frac{d^2s^2}{2}, \frac{d^2qs}{2} \right). \tag{3}$$

Strengthen network effects by analyzing data on users

In the case that a platform invests mainly in technologies to analyze user data, the costs should be given as $\frac{d^2q^2}{2}$. Audience makers analyze, for example, offer their advertising customers the possibility of limiting the target group of their advertising based on increasingly accurate predictive models. To a degree, the analysis of advertising customers may also be of interest. However, this is likely to be costly associated with fixed costs.

Assuming that investment costs increase quadratically in d and q, optimizing equation (2) leads to optimal quantities

$$q = \frac{1+g}{2-g^2} \qquad \text{and} \qquad s = \frac{2+g}{2-g^2}, \tag{4}$$

which are strictly increasing in g. As it is typical for two-sided platforms, quantities are higher with stronger network effects. However, s is always bigger than q, as it is boosted by d as long as quantities are positive (for $g < \sqrt{2}$). In case that $g > 0$ it is therefore restricted to $g^+ \leq \sqrt{2}$.

Optimal network effect d is

$$d = \frac{2+g}{1+g}, \tag{5}$$

which is an decreasing function of g. For positive $g^+ \leq \sqrt{2}$ it follows that $\lim_{g\to\sqrt{2}} d(g) = \sqrt{2}$, in case that the platform is defined as a matchmaker $g \geq 0$. However, in case that the platform acts as an audience maker, g can also turn negative, as advertisement can have a negative effect on the audience. As the upper limit of d is defined as $\lim_{g\to\sqrt{2}} d(g) = \sqrt{2}$ it does not make much sense that the absolute value of a negative g would be higher than $\sqrt{2}$. Thus $\lim_{g\to-\sqrt{2}} d(g) = -\sqrt{2}$.

Optimal investment in network effect d is $Inv = \frac{1}{2}\frac{(2+g)^2}{(2-g^2)^2}$. As investment is costly, with high g there is only limited necessity to invest in d which leads to a lower network effect d.

Optimal Prices can be derived by inserting quantities into inverse demand function and are given by

$$p = 1 - \frac{1+g}{2-g^2} = \frac{1-g^2-g}{2-g^2} \qquad \text{and} \qquad r = 1. \tag{6}$$

While r is fixed to one, p is decreasing in g. The stronger the network effect from advertisers to users (g), the lower the price for users. This effect is somewhat controversial to the usual two-sided market logic, where prices follow network effects originating from the market sides of the respective price. The intuition behind this pricing behavior is as follows: The analysis of user data leads to a stronger network effect (d) and, therefore, greater market enlargement. However, a low g leads to a relatively high investment in d, leading to a rather strong effect of data analysis on market enlargement and profits. To maximize the effect of d, the platform can lower the price p

to attract a high number of users whose data can be analyzed. The ability to make predictions about user preferences increases the more data is available to train these models.

Turning to profits, market enlargement by an increasing network effect g leads to higher overall profits

$$\pi = \frac{1}{2}\frac{3+2g}{2-g^2}. \tag{7}$$

Not surprisingly, neither profits, nor quantities, prices or optimal investment depends on the endogenous network effect d but only on g. As investment in artificial intelligence is costly platforms invest more the weaker the network effect g is.

Other forms of investment

The assumption that investment costs increase with the size of the advertising market rather than with the number of users is not as intuitive for advertise-financed platforms. In this case, a network effect d is strengthened by data on the target of users but not user data ($inv = \frac{d^2s^2}{2}$). However, a higher number of advertisers might lead to more heterogeneity in preferences, demanding more sophisticated models that allow customization of the matching algorithm, for example. A more intuitive example for this assumption would be a matching platform like Airbnb, where users search for a suitable match (with firms or other service providers). The platform can attract more firms to join when the matching algorithms become more elaborated, i.e., leads to better matches. The cost of improving the matching algorithm (i.e., strengthening the indirect network effect) increases with the number of firms. The case that platforms use data on both market sides ($inv = \frac{d^2qs}{2}$) is also likely to be associated with matching platforms. A dating platform, for example, needs to analyze the needs of women and men alike. Amazon needs to analyze users' preferences as well as the prices and characteristics of products.

Table 1 shows optimal quantities, prices, investment levels and profits for all investment types. Investment type I and II are identical with respect to the optimal network effect d, investments and profits. However, quantities are inverted ($q_I < q_{II}$ for $g < \sqrt{2}$) and prices are different between both models. The reasoning behind this difference is that costs now increase with

s instead of q. As a consequence, r_{II} is always larger than $r_I = 1$. $p_{II} \leq 0$ is always lower than p_I and decreases in g.

Table 1: Model outcomes with varying investment functions and two network effects

Case	I	II	III
Inv	$\frac{d^2q^2}{2}$	$\frac{d^2s^2}{2}$	$\frac{d^2qs}{2}$
q	$\frac{1+g}{2-g^2}$	$\frac{2+g}{2-g^2}$	$\frac{2}{3-2g}$
s	$\frac{2+g}{2-g^2}$	$\frac{1+g}{2-g^2}$	$\frac{2}{3-2g}$
d	$\frac{2+g}{1+g}$	$\frac{2+g}{1+g}$	1
p	$1-\frac{1+g}{2-g^2}$	$1-\frac{2+g}{2-g^2}$	$1-\frac{2}{3-2g}$
r	1	$\frac{g^3+g^2-4g-5}{(1+g)(g^2-2)}$	1
Inv	$\frac{1}{2}\frac{(2+g)^2}{(2-g^2)^2}$	$\frac{1}{2}\frac{(2+g)^2}{(2-g^2)^2}$	$\frac{2}{(3-2g)^2}$
π	$\frac{1}{2}\frac{3+2g}{2-g^2}$	$\frac{1}{2}\frac{3+2g}{2-g^2}$	$\frac{2}{3-2g}$

Not surprisingly, allowing cost to increase with both quantities leads to different results. For the definition range $g < \sqrt{2}$, $q_I < q_{III} < q_{II}$, the same holds for s and p. $r_{III} = r_I < r_{II}$ and investments are lower with symmetric costs, such that $Inv_I = inv_{II} > Inv_{III}$. Consequently, profits are also lower with symmetric (and therefore higher) investment costs $pi_I = pi_{II} > pi_{III}$. In case platforms analyze both market sides, and if both sides increase costs with market size, investments are lower than the other types of investment in network effects.

3.2 A numeric example: monopolistic platform and one single indirect network effect

In order to take a closer look at the optimal investment effects under different market structures, we now turn to an even more simplistic model assuming that only a single network effect exists (Armstrong, 2006). For a two-sided platform to exist, there only needs to be a single indirect network effect originating in one of the two markets. By limiting ourselves to such an effect, simple results can be calculated to simplify the interpretation of the results. Not surprisingly, allowing cost to increase with both quantities leads to different results. For the definition range $g < \sqrt{2}$, $q_I < q_{III} < q_{II}$, the same holds for s and p. $r_{III} = r_I < r_{II}$ and investments are lower with symmetric costs, such that $Inv_I = inv_{II} > Inv_{III}$. Consequently, profits are also lower with symmetric (and therefore higher) investment costs $pi_I = pi_{II} > pi_{III}$. In case platforms analyze both market sides, and if both sides increase costs with market size, investments are lower than the other types of investment in network effects.

Besides the ease of interpretation, the model also has practical relevance. While we assume that users' utility is not affected by the amount of advertising, advertising customers benefit from the number of users on the other side of the platform. We assume that there is only a unilateral network effect by these means. While this assumption serves to simplify our model, it adequately reflects reality, particularly to market circumstances in which the advertising market is one of the market sides. Using Google as a prominent platform example, it becomes evident that the effect of the advertising market on the search market is negligible. At the same time, advertisers' demand exclusively depends on the search market, or to be more precise, on the consumers who use the search engine. We thus follow Argenton and Prüfer (2012) in assuming that users on the search market neither derive positive nor negative utility from advertisements.

Assuming that only a single network effect exists, the demand equations simplify to

$$p = 1 - q \quad \text{and} \quad r = 1 - s + dq \tag{8}$$

Again, neglecting any costs apart from investment in network effects, profits of a monopolistic platform are then given by

$$\max_{q,s,d} \pi = (1-q)q + (1-s+dq)s - Inv \tag{9}$$

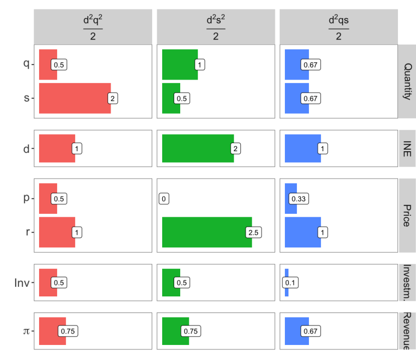
with

$$Inv \in \left(\frac{d^2q^2}{2}, \frac{d^2s^2}{2}, \frac{d^2qs}{2}\right). \tag{10}$$

Although we assume that only one network effect exists, we allow investment costs to vary and to be based on q (case I) or s (case II) or both (case III). Thus, it is possible, and likely, that the platform will have to evaluate both user and advertiser data to provide the most accurate targeted advertising possible. Inserting the three different expressions for Inv into the profit function in succession and using respective first-order conditions with respect to q, s, and d leads to optimal quantities, prices, profits, and investments observed from Table 1. 2.

Table 2: Model outcomes with varying investment functions

Case	I	II	III
Inv	$\frac{d^2q^2}{2}$	$\frac{d^2s^2}{2}$	$\frac{d^2qs}{2}$
q	1/2	1	2/3
s	2	1/2	2/3
d	1	2	1
p	1/2	0	1/3
r	1	5/2	1
Inv	1/2	1/2	8/81
π	3/4	3/4	2/3



Due to the simple modeling, we can derive simple numeric results. In the first case, in which the costs additionally depend on the market size q, the optimal quantities are given by $q = \frac{1}{2}$ and $s = 2$. Although q sends a positive network effect to s and thus increases platform profits, the greater q is, the more expensive it becomes to strengthen this effect. The platform invests such that the network effect d is set to 1, and monopolistic profits are given by $\frac{3}{4}$. Optimal prices result as $p = \frac{1}{2}$ and $r = 1$, which means that the market side that sends the network effect (search market) is subsidized. This price structure holds for all three cases and corresponds to the aforementioned studies on pricing in two-sided markets.

Interestingly, assuming that costs are affected by the number of advertising customers, a price $p = 0$ results. Content and services in the user market come at no (monetary) cost, as is a usual result for search engines and similar services of internet platforms. Consequently, the advertising rate $r = \frac{5}{2}$ increases in comparison to the former case. Assuming that the market side receiving the indirect network effect (advertising market) has a positive impact on the investment cost, the optimal market size on this side drops to $s = \frac{1}{2}$. In contrast, the optimal market size on the other side doubles to

$q = 1$. Both the optimal investment level ($Inv = \frac{1}{2}$) and the profit of the monopolistic platform ($\pi = \frac{3}{4}$) correspond to the result of the first case, i.e., regardless of which network drives the costs, investment, as well as profits, are identical in both cases.

A different result can be observed when we assume that both sides of the market have an equal impact on investment costs, i.e., information from both sides is required to strengthen network effects. In this case, the optimal investment is considerably lower ($Inv = \frac{8}{81}$) because of the much higher costs resulting in lower profits ($\pi = \frac{2}{3}$), compared to the first two cases. As q and s increase cost equally, both quantities are equal in equilibrium. Again, the optimal prices $p = \frac{1}{3}$ and $r = 1$ reflect the fact that the platform can exploit the network effect by subsidizing users in the search market. However, user price is higher compared to the second case as in this case III, costs depend on q and s. Lowering p would increase q, which would increase costs. As costs are sensitive to variations in both quantities, d is restricted to 1, which equals the network effect in case I.

Accordingly, the optimal strength of the network effect d differs depending on the cost structure: In case I, when the costs of investments are purely driven solely by the size of the advertising market drives, the optimal network effect equals 2. The price p for using the search engine equals zero to maximize the number of users and therefore quantity q and profits. For case II, assuming that the size of the advertiser market drives investment costs, the profits (and investments) are identical. However, the optimal indirect network effect the platform sets decreases from $d = 2$ to $d = 1$ to reduce the cost of investment and to compensate the lower profits from the advertising market with positive profits from the search market. In case III, where both market sizes are cost drivers, the platform cannot compensate higher costs by increasing just one of the two quantities. As investments are costly, the platform invests much less; profits also fall from 3/4 to 2/3.

4 Conclusion

In contrast to traditional pipeline business models, two-sided platforms internalize indirect network effects between at least two groups of platform participants. The strengths and the ability to internalize the network effects have a decisive influence on the platform's success and, therefore, its market position. In this paper, we investigate the optimal investment level under the assumption that the indirect network effects are endogenous, i.e., the two-sided platform can strengthen the effect through investment. The cost of these investments depends on the indirect network effects and the size of both market sides. We derive optimal quantities, prices, profits, and investments depending on investment cost structures.

Overall, the following can be outlined from these results:

(1) The conventional price structure for platform markets remains valid: The market side that receives the stronger indirect network effect subsidizes the respective other market side by paying a higher price.

(2) Optimal quantities reflect the impact of the market side on the investment cost: the optimal quantity for the market side, being the larger cost driver, is lower. The optimal quantities are identical if both sides of the market equally influence the costs.

(3) Not surprisingly, the optimal investment level and profit is identical for the first two cases and lower if both market sides have an impact on costs (which comes at higher investment costs).

(4) The strength of the indirect network effect is lower if the market side sending the indirect network effect has an increasing effect on the investment costs.

The structure of investment costs clearly drives the result. Interestingly, assuming that investment depends on the strength of the network effect and the number of firms (i.e., the size of the market that receives the indirect network effect), the price for using the platform is set to zero for the users (i.e., the respective other market side that sends the indirect network effect), which is a typical result for many internet platforms.

Based on these results, future research could focus on the welfare analysis for the different investment structures. Furthermore, it would be interesting to conduct an empirical analysis of RD costs (including an analysis of their patents) of different platforms considering their underlying business model.

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