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Incentives of Social Networks**

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Abstract

This paper examines social networks' incentives to establish compatibility under fee and ad-sponsored business models. I analyze the competition between two social networks and show that compatibility is only possible when the two networks are ad-sponsored. I also find that even when both networks are ad-sponsored, a network with a significant installed-base advantage may choose not to be compatible when the cost from sharing the market outweighs the benefit from additional ad profits. Finally, compatibility also requires a significant number of single-homing users. The results are consistent with empirical observations of social networks and suggest that increased adoption of ad-sponsored business models may lead to many de-facto standards in high-technology industries.

Keywords: Ad-sponsored; Compatibility; Social networks; Business models

JEL: L15, L10, M21

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1 Introduction

Ad-sponsored business models appear to be dominant on today's Internet. The market of Internet advertising has gone from \$9.6 billion in revenue in 2001 to \$16.8 billion in 2006, making the Internet the fourth largest advertising communication media.¹ Many companies have recently moved away from fee-based business models toward ad-sponsored models. Starting in 2004, for example, AOL made most of its exclusive content available for free on its sites and used ads to generate most of its revenue. Disney tried the ad-sponsored model online in May 2006 by providing their popular ABC shows, including *Lost* and *Desperate Housewives*, together with targeted ads. Even Microsoft, the largest software company, has recently shifted its strategic focus from attracting software developers to attracting advertisers.²

Ad-sponsored business models are particularly prevalent in online social networks. A large number of social networks today rely exclusively on ads to generate revenues, and provide services free of charge such as instant messengers, blogs, peer-to-peer sharing to their users. Interestingly, there has been a trend toward compatibility among these social networks in recent years. For example, in 2005 Microsoft and Yahoo formed a strategic alliance to make their instant messengers compatible. Many social networking sites decided to support Google's OpenSocial platform, which allows different sites to share their membership information and facilitates interactions among their users.

This paper seeks to understand how social networks' decisions to establish compatibility differ under fee-based and ad-sponsored business models. Compatibility of social networks allows users of one network to interact with users of other networks without joining multiple networks.

¹Press release of Interactive Advertising Bureau, "IAB/PwC Release Fourth-Quarter and FY 2006 Internet Ad Revenue Figures," March 7, 2007. http://www.iab.net/about_the_iab/recent_press_releases/press_release_archive/press_release/5124, accessed April 2008.

²Jonathan Thaw and Dina Bass, "Microsoft's AdCenter May Fail to Topple Google From Dominance," May 3, 2006. <http://www.bloomberg.com/apps/news?pid=10000103&sid=aoxKbnwb5qQA>, accessed April 2008.

When networks are fee-based, they charge users membership fees and try to maximize profits from the users. On the other hand, when they are ad-sponsored, they have incentives to draw more users as their revenues are tied to the number of ad clicks. The different incentives under the two business models have important implications for networks' compatibility decisions. I find that under fee-based models, networks have no incentives to be compatible as profits would be driven to zero by intense price competition with compatibility (à la Bertrand). In contrast, under ad-sponsored models, networks may have incentives to be compatible, provided that their membership prices are bounded by zero and their installed bases have similar sizes. I also show that compatibility requires a sufficient number of single-homing users.

The paper contributes to the literature on firms' compatibility decisions in the presence of network effects (e.g., Katz and Shapiro 1985; Farrell and Saloner 1985, 1986, 1992; Economides and White 1994; Economides and Flyer 1997; Crémer et al. 2000; Clements 2004; Doganoglu and Wright 2006; Malueg and Schwartz 2006; Chen et al. 2007). My work differs from many papers in this literature in two aspects. First, in most early studies, products are assumed to be differentiated at the interface level, and the degree of differentiation is often assumed to be sufficiently high so that not all new users adopt the same product in equilibrium. When the products are compatible, they maintain the same level of differentiation. Given that compatibility increases the value of both products because of network effects, under certain conditions (typically when firms' initial installed bases are not too different), firms will prefer compatibility. This assumption on production differentiation, however, does not hold for many software applications or web sites today. For instance, the feature sets of different instant messengers or social networking sites differ only minimally and new features developed by one site are immediately matched by its competitors³ (Faulhaber 2002). Furthermore, these products are often highly customizable. A typical social networking site today has dozens of parameters that users can change to fit their individual tastes. As a

³In general, software interface is not copyrightable. See Lerner and Zhu (2007) for a detailed discussion.

result, users often do not consider the look and feel of these sites to be an important factor when they make adoption decisions. The traditional hotelling-type models would suggest that with such little differentiation, with network effects, one network would dominate. In reality, multiple instant messengers and many social networking sites have co-existed for years and each of them continues to attract new users. Therefore, these traditional models are inappropriate for these markets. I argue that in social networks, the source of differentiation comes from the users rather than product interfaces. A person's decision to adopt an instant messenger depends on how many of his or her friends are using or will use the same instant messenger. Her decision to visit a particular video-sharing web site depends on the type of clips other users are contributing. My analysis shows that distinguishing different sources of differentiation is critical in our understanding of compatibility decisions. When the differentiation is at the user level, the networks lose the differentiation with compatibility. As a result, under fee-based business models, profit-maximizing networks never have any incentives to establish compatibility.

This paper also contributes to the literature on two-sided markets (e.g., Rochet and Tirole 2003; Caillaud and Jullien 2003; Parker and Alstyne 2005; Hagiu 2005). A market is two-sided when it is intermediated by a platform which enables transactions between participants on both sides. This paper is closely related to studies in which one side of the market consists of advertisers. Most of these studies focus on media industries such as newspaper and television, and have examined firm strategies such as product positioning (e.g., Steiner 1952; Beebe 1977; Spence and Owen 1977; Doyle 1998; Gabszewicz et al. 2000; Gal-Or and Dukes 2003; Gabszewicz et al. 2004), versioning (Jiang 2007), pricing (e.g., Crampes et al. 2006; Gabszewicz et al. 2005, 2006) and consumer welfare (e.g., Holden 1993; Anderson and Coate 2005). My study looks at the competition between two ad-sponsored networks in the presence of direct network effects (Katz and Shapiro 1985) on the user side and focuses on compatibility decisions.

Finally, this paper adds to the literature on the formation of interfirm alliance (e.g.,

Gulati and Gargiulo 1999). Previous research has looked at factors such as firms's past experience with each other, their willingness to accept uncertainty, and their complementarity in performing tasks (e.g., Gulati 1995; Baum et al. 2005; Rowley et al. 2005) to explain their incentives to share resources. This paper suggests that firms' business models may be an important determinant of their decisions to form strategic alliances.

The rest of the paper is organized as follows. Section 2 presents two case studies in which social networks move toward compatibility. Section 3 discusses the model. Section 4 extends the analysis to allow for user multi-homing. Section 5 concludes.

2 Two Case Studies

2.1 Instant Messengers

AOL introduced the first instant messaging service for its dial-up subscribers in 1989. In 1997, AOL made its instant messenger available online free to non-AOL subscribers, and bought ICQ, an instant messenger whose users are primarily outside the US. AOL made its instant messenger compatible with ICQ in 2003.

In 1999, several firms including Microsoft and Yahoo started to offer similar instant messengers. All of them are sponsored by advertisers and are free to all users. Microsoft and Yahoo built their messengers in a way that their users could communicate with AOL messenger users. The move led to a cat-and-mouse game of AOL blocking communications from its competitors, and Microsoft and Yahoo re-establishing communication with each software update. By the end of 1999, Microsoft and Yahoo finally gave up.

Users who were interested in talking to friends in multiple instant messengers had to either multi-home (i.e., install multiple client software), or use multiprotocol instant messenger clients like Trillian. These multiprotocol clients allow a user to chat with their friends on multiple programs under a common user interface. AOL, Microsoft and Yahoo tried to block these multiprotocol clients by changing their protocols several times.

Table 1. Market Shares of Instant Messengers in September 2005

Instant Messenger	Users (Millions)	Market Share
AOL	51.5	49.8%
Microsoft MSN	27.3	26.4%
Yahoo	21.9	21.2%
Skype	1.2	1.2%
Trillian	0.9	0.9%
ICQ	0.7	0.7%

Source: Nielsen/NetRatings

In October 2005, Microsoft and Yahoo announced plans to make their instant messengers compatible. Table 1 shows the market share of each instant messenger around that time. AOL instant messenger dominated the instant-messaging market in the United States, with 51.5 million users in September 2005, compared with Microsoft’s 27.3 million and Yahoo’s 21.9 million. In December 2005, Google and AOL expanded their partnership. Under the strategic alliance, Google invested \$1 billion for a 5% equity stake in AOL,⁴ and the two companies agreed to make their instant messengers compatible.⁵ Starting from the second quarter of 2006, Microsoft instant messenger users were able to exchange messages and make PC-to-PC voice calls with Yahoo users. It was not until the end of 2007 that Google and AOL messengers became compatible.

2.2 Social Networking Sites

Social networking sites are designed to facilitate user interactions by providing functions such as chat, messaging, email, file sharing, blogging and discussion groups. They are often differentiated by user demographics. For example, MySpace and Facebook are mostly used in North America, and Orkut users are mostly from India and Brazil. iLike consists mostly

⁴Press release of Google, “Time Warner’s AOL and Google to Expand Strategic Alliance,” December 20, 2005. http://www.google.com/press/pressrel/twaol_expanded.html, accessed April 2008.

⁵Google’s instant messenger, Google Talk, was launched in August 2005. In March 2006, Google Talk had about 0.87 million users, according to Nielsen/Netratings. <http://www.bigblueball.com/forums/general-other-im-news/34413-im-market-share.html>, accessed April 2008.

music fans, while most Hi5 users are Hip-Hop and R&B (rhythm and blues) fans.

Table 2 shows the market share of major social networking sites in April 2007. All these sites are ad-sponsored and free of charge. The market is highly concentrated with MySpace and Facebook together having more than 90% market share. MySpace claimed that it had 100 million user accounts in August 2006.⁶

On November 1, 2007, Google released OpenSocial, a platform with a set of common application programming interfaces (APIs) for web-based social networking applications. OpenSocial APIs allow social applications to access core data such as friendship information and user activity information. Applications implementing the OpenSocial APIs are interoperable with any social networking site that supports them. Users in different social networks could use these applications to communicate with each other or play games together.

OpenSocial is now supported, or is committed to be supported, by more than 20 social networking sites including Bebo, Friendster, Hi5, MySpace, Ning, Orkut and XING, representing an audience of about 200 million users globally.^{7,8}

3 The Model

I analyze the competition between two social networks to explore networks' incentives to be compatible. Let A and B denote two social networks, and N_A and N_B denote the number of existing users (i.e., installed bases) of the two social networks. Without loss of generality, I assume that $N_A > N_B$, and normalize the total size of the installed bases, $N_A + N_B$, to be 1.

A group of new users with mass 1 choose the network to join, and therefore the mass of total consumers is 2. Assume for the moment that they all single-home: each of them only

⁶Pete Cashmore, "MySpace Hits 100 Million Accounts," August 6, 2006. <http://mashable.com/2006/08/09/myspace-hits-100-million-accounts/>, accessed April 2008.

⁷Press release of Google, "Google Launches OpenSocial to Spread Social Applications Across the Web," November 1, 2007. <http://www.google.com/intl/en/press/pressrel/opensocial.html>, accessed April 2008.

⁸Facebook launched its own proprietary platform, Facebook Platform, in May 2007, and is the only major social networking site that does not support OpenSocial platform.

Table 2. Market Shares of Social Networking Sites in April 2007

Site	Market Share
MySpace	79.7%
Facebook	11.5%
Bebo	1.3%
Imeem	1.0%
BlackPlanet.com	0.9%
Tagged	0.8%
Yahoo! 360	0.7%
Xanga	0.7%
Hi5	0.6%
Gaiaonline.com	0.6%
LiveJournal	0.5%
Friendster	0.4%
Orkut	0.3%
MyYearbook	0.2%
Flixster	0.2%
Buzznet	0.2%
Windows Live Spaces	0.2%
HoverSpot	0.1%
Urban Chat	0.1%
MiGente.com	0.1%
Other	0.0%

Source: Hitwise.com

join one network. I relax this assumption in Section 4. Each user is characterized by a type parameter θ , uniformly distributed in $[0, 1]$. User i derives a utility of θ_i from interacting with each user of network A , and $1 - \theta_i$ from interacting with each user of network B . For example, if network A consists of people who are interested in music and network B consists of people who are interested in arts, θ_i could measure the degree to which user i is interested in communicating about music.

Empirical observations suggest that one-way compatibility (e.g., Farrell and Saloner 1992; Economides and White 1996) is rare in social networks. Therefore, in my analysis, compatibility can only be achieved when both networks choose compatibility over incompatibility. I analyze compatibility decisions under fee-based and ad-sponsored business models separately.

3.1 Fee-based Business Models

The game under fee-based business models proceeds as follows. In the first stage, both networks simultaneously make compatibility decisions. In the second stage, they engage in price competition, and new users decide which network to join. In the third stage, each user interacts with other users in the same network and in the compatible network (if any). Without loss of generality, I assume that each user pair interacts once.

A new user i 's utility from adopting network j is

$$u_{ij} = v + \theta_i S_j - p_j.$$

v is intrinsic utility of joining a network. As the feature sets of social networks are similar, I assume v to be the same for both networks. I also assume that v is sufficiently high so that the market is covered. S_j is the final size of network j . Without compatibility, S_j includes both the installed base and new users of network j . With compatibility, as any user can interact with all other users in the two networks, $S_j = 2$. Finally, p_j is the membership fee charged by network j .

First consider the case of incompatibility. Let θ^* denote the indifferent user. Hence, $S_A = N_A + 1 - \theta^*$ and $S_B = N_B + \theta^* = 1 - N_A + \theta^*$. θ^* is implicitly defined by:

$$v + \theta^*(N_A + 1 - \theta^*) - p_A = v + \theta^*(1 - N_A + \theta^*) - p_B. \quad (1)$$

Hence

$$\theta^* = 1 - N_A + p_A - p_B. \quad (2)$$

Assuming that the marginal cost of serving users is zero for both networks, I have the following profit functions:

$$\pi_A = (1 - \theta^*)p_A \quad (3)$$

$$\pi_B = \theta^*p_B \quad (4)$$

Proposition 1. *Under fee-based business models, equilibrium prices are $p_A = \frac{1+N_A}{3}$, $p_B = \frac{2-N_A}{3}$, and equilibrium profits are $\pi_A = \frac{(1+N_A)^2}{9}$ and $\pi_B = \frac{(2-N_A)^2}{9}$.*⁹

Now consider the case when the two networks are compatible. User i receives $u_{ij} = v + 2\theta_i - p_j$ from network j . The network with a lower membership fee will attract all new users. Bertrand competition suggests that equilibrium prices are $p_A = p_B = 0$ and equilibrium profits are $\pi_A = \pi_B = 0$. Thus I have

Proposition 2. *Under fee-based business models, the networks have no incentives to be compatible.*

3.2 Ad-sponsored Business Models

I now turn to analyzing the competition under ad-sponsored business models. In this case, the market is two-sided. The game proceeds similarly as in the case of fee-based models except that in the second stage, network j charges an advertiser a fee, γ_j , every time its ad

⁹All proofs are included in the appendix.

is displayed, in addition to the membership fee, p_j , on the user side, and advertisers decide whether to advertise to the network. This pay-per-view advertising model can be easily modified to accommodate other payment schemes such as pay-per-click and pay-per-action by assuming that a fraction of the views leads to actual clicks or purchases.

Advertisers can multi-home: they can place ads in both networks. Meanwhile, an advertiser's decision to advertise to network A is independent of the decision to advertise to network B . When a network is sponsored by advertisers, the larger the number of consumers, the more attractive the product is for the advertisers. Following Gabszewicz et al. (2006), I assume that the advertising rate charged by network i to each advertiser, γ_j , is an increasing linear function of the number of interactions in the network, D_i^2 , where D_i is the number of users of network i . Mathematically, $\gamma_i = \beta D_i^2$, where $\beta > 0$. For each interaction, assume that each network can display m ads. Space constraints on the social networking sites often impose limits on the number of ads that can be displayed at once. Assuming there is no cost for displaying the ads, $k = m\beta$ is thus the profit per interaction.¹⁰ Note that k is independent of the number of users in each network and is thus the same for both networks.

3.2.1 Compatibility Decisions

I first consider the incompatible case. A new user i 's utility from adopting network j is: $u_{ij} = v + \theta_i S_j - p_j$.¹¹ The type of the indifferent user, θ^* , can be similarly derived as $\theta^* = 1 - N_A + p_A - p_B$.

¹⁰Alternatively, one can assume that each user interact with a fraction ρ of all users in the same network. In this case, $k = m\beta\rho^2$ and all results will follow.

¹¹The nuisance cost from ads is often negligible as social networks frequently use technologies such as rotating banners to minimize the nuisance cost of viewing the ads. Some studies in the media industries find that viewers actually enjoy the ads (e.g., Kaiser 2007), while several other theoretical studies use the assumption that the nuisance cost of viewing ads increases with the number of ads (see, for example, Anderson and Coate 2005).

The two networks maximize their profits:

$$\pi_A = (1 - \theta^*)p_A + (N_A + 1 - \theta^*)^2 k \quad (5)$$

$$\pi_B = \theta^* p_B + (N_B + \theta^*)^2 k \quad (6)$$

$(N_A + 1 - \theta^*)^2$ and $(N_B + \theta^*)^2$ measure the total number of interactions in each network. Under ad-sponsored business models, social networks have incentives to lower their prices to entice more users to join their networks. I impose a non-negativity constraint on membership fees: $p_j \geq 0$.¹²

Solving profit maximization of the two networks, I have

Proposition 3. *When $k < 1/4$, both networks charge users positive membership fees: $p_A = \frac{(1-4k)(1+N_A-2k)}{3-4k}$ and $p_B = \frac{(1-4k)(2-N_A-2k)}{3-4k}$; p_A and p_B decrease with k . When $k \geq 1/4$, $p_A = p_B = 0$.*

Indeed, it is optimal for both networks to lower their membership fees as the ad profit per interaction, k , increases. When k is sufficiently large, both networks provide their services to the users free of charge.

Now consider the case where the two networks are compatible. On the user side, Bertrand competition leads to zero prices for both networks, i.e., $p_A = p_B = 0$. Each network attracts half of the new user population in equilibrium and makes its profit entirely from the advertiser side:

$$\pi_A = (N_A + 1/2) \cdot 2 \cdot k = (2N_A + 1)k$$

$$\pi_B = (1 - N_A + 1/2) \cdot 2 \cdot k = (3 - 2N_A)k$$

Comparing the networks' profits with and without compatibility, I obtain

¹²A negative price means that the social network is compensating users for joining its network. Such practice would attract users who join only for the compensation but not for interacting with others and is thus seldom used in practice.

Proposition 4. *When $k < 1/8$, both networks prefer incompatibility. When $k > 1/8$, network B always prefers compatibility and there exists a threshold N_A^* such that when $N_A < N_A^*$ ¹³, network A also prefers compatibility. N_A^* increases (weakly) with k . In particular, when $k \geq 1/4$, $N_A^* = \frac{1+\sqrt{5}}{4} \approx 0.81$.*

There are three forces behind the networks' compatibility decisions. First, given the size of a network, compatibility increases the number of interactions initiated by the network users and leads to more ad clicks. Second, with compatibility the larger network loses its installed-base advantage and does not attract as many new users as in the case without compatibility. The smaller network, on the other hand, benefits from sharing the installed base and, as a result, attracts more new users. Third, with compatibility, both networks lose the power to charge new users.

When the ad profit per interaction, k , is low, the third effect dominates and both networks prefer incompatibility. When k is sufficiently high, network B is always willing to forgo the profit from membership fees and become compatible, and network A also prefers compatibility if the second effect is not strong. The result is consistent with the observation that AOL, because of its significant installed-base advantage, refused to make its instant messenger compatible with others even at repeated requests of other instant messenger providers.

4 User Multi-homing

I have assumed that new users single-home. In reality, when social networks are not compatible, some users may choose to participate in multiple social networks. In this section, I analyze the situation in which some new users multi-home. For simplicity, I still assume single-homing installed bases in both networks.

Under fee-based business models, the analysis is similar to the single-homing scenario. With compatibility, new users no longer need to multi-home, and the analysis is similar

¹³All thresholds are defined in the appendix.

to the single-homing case. Since compatibility leads to zero profits for both networks, the networks have no incentives to be compatible. I therefore focus my analysis on ad-sponsored networks.

Assume that $\alpha \in (0, 1)$ new users multi-home and $1 - \alpha$ new users single-home. In addition, the types of multi-homing and single-homing users are both uniformly distributed in $[0, 1]$. I first consider the incompatible case. The type of the indifferent new user, θ^* , is determined by

$$v + \theta^*(N_A + \alpha + (1 - \alpha)(1 - \theta^*)) - p_A = v + (1 - \theta^*)(1 - N_A + \alpha + (1 - \alpha)\theta^*) - p_B.$$

Hence $\theta^* = \frac{1 - N_A + \alpha + p_A - p_B}{1 + 2\alpha}$. The profit functions of the two networks are:

$$\begin{aligned}\pi_A &= ((1 - \alpha)(1 - \theta^*) + \alpha)p_A + (N_A + \alpha + (1 - \alpha)(1 - \theta^*))^2 k \\ \pi_B &= ((1 - \alpha)\theta^* + \alpha)p_B + (1 - N_A + \alpha + (1 - \alpha)\theta^*)^2 k\end{aligned}$$

Proposition 5. *When $k < k^{**}$, $p_A > 0$ and $p_B > 0$; when $k^{**} < k < k^{***}$, $p_A > 0$ and $p_B = 0$; when $k > k^{***}$, $p_A = p_B = 0$. Here, $k^{**} > 1/4$. k^{**} and k^{***} increase with α .*

Proposition 5 is similar to Proposition 3 in that the equilibrium membership fees decrease with the ad-profit-per-interaction. With some multi-homing users, the thresholds of the ad-profit-per-interaction for the networks to offer free services are greater. The intuition is that when users multi-home, the two networks are not competing for these users and hence have greater market power to charge users. As a result, the benefit from the advertiser side has to be greater for them to offer free services.

When the networks are compatible, their profits are the same as in the case of single-homing. I focus the analysis on the most interesting scenario where the networks are free without compatibility, i.e., $k > k^{***}$.

Proposition 6. *When $k > k^{***}$, the two networks are compatible when $\alpha < 2\sqrt{2} - 1$ and*

$N_A < N_A^{**}$, where $N_A^{**} < \frac{1+\sqrt{5}}{4}$ and decreases with α .

When the number of multi-homing users increases, the number of interactions for each network increases. Hence, multi-homing decreases the benefit from compatibility. As a result, the two networks may prefer incompatibility when there is a sufficient number of users multi-homing. Since the installed-base advantage and multi-homing both reduce the attractiveness of compatibility for network A , when the number of multi-homing users increases, the installed-base advantage of network A has to be smaller to maintain network A 's willingness to establish compatibility.

5 Conclusions

In this paper, I examine compatibility decisions in the context of social networks. My results show that business models have critical impact on networks' incentives to establish compatibility, and suggest that increased adoption of ad-sponsored business models online today may lead to many de-facto standards in high-technology industries.

My results are applicable to many social networks besides instant messengers and social networking sites. For instance, many peer-to-peer file sharing networks allow users to search and download content from each other's network, and fee-based dating clubs do not share member information with each other.

In my analysis, I consider networks' compatibility decisions when they are financed by either membership fees or ad revenues. One can also examine networks' strategies when one network employs a fee-based business model and the other employs an ad-sponsored model. Since the nuisance cost from viewing ads is negligible, with compatibility both networks will charge zero prices. Hence, the fee-based network will not prefer compatibility. As a result, compatibility is only possible when both social networks are ad-sponsored.

I also impose a non-negativity constraint on membership fees. Without this constraint, the networks, even if they are both ad-sponsored, have no incentives to establish compati-

bility, as Bertrand price competition on the user side will compete away all profits from the advertiser side.

Future research could extend this work to situations where there are more than two networks. In such cases, the networks also need to decide when and with whom to establish compatibility. For example, after Microsoft and Yahoo make their instant messengers compatible, their total size is similar to the size of AOL network. As a result, AOL may now have the incentive to be compatible. However, if AOL foresees the compatibility agreement between Microsoft and Yahoo, it may be optimal for AOL to establish compatibility with Microsoft first and make their joint network stay incompatible with Yahoo. Small networks in such cases should actively look for compatibility opportunities to survive.

Appendix: Proofs of Propositions

Proof of Proposition 1. The first order conditions of the profit functions, equation (3) and (4), yield $p_A = \frac{1+N_A}{3}$ and $p_B = \frac{2-N_A}{3}$. It is easy to verify that the second order conditions are both negative. I obtain $\theta^* = \frac{2-N_A}{3}$ from equation (2). The maximized profits can then be computed from equation (3) and (4). \square

Proof of Proposition 2. Without compatibility, both networks earn positive profits but with compatibility, both earn zero profits. Hence the claim. \square

Proof of Proposition 3. The first order conditions of the profit functions, equation (5) and equation (6), yield $p_A = \frac{(1-4k)(1+N_A-2k)}{3-4k}$ and $p_B = \frac{(4k-1)(2-N_A+2k)}{3-4k}$. The second order conditions, $\pi_A'' < 0$ and $\pi_B'' < 0$, require that $k < 1$.

It is easy to see that when $k < 1/4$, $p_A > 0$, $p_B > 0$ and $\theta^* = \frac{4kN_A+N_A-2}{4k-3} \in (0, 1)$. When $k = 1/4$, $p_A = p_B = 0$.

I now proceed to show that given the non-negativity constraint on the membership prices, when $k > 1/4$, $p_A = p_B = 0$. I consider the case where $1/4 < k < 1$ and $k \geq 1$ separately.

Case 1: $1/4 < k < 1$

First, I show that it is impossible that in equilibrium $p_A \geq p_B > 0$. Network A 's profit function can be re-written as

$$\pi_A = (k-1)p_A^2 + ((1-4k)N_A + (1-2k)p_B)p_A + k(2N_A + p_B)^2 \quad (7)$$

As $k < 1$, equation (7) obtains its maximum at $p_A = \frac{(1-4k)N_A + (1-2k)p_B}{2(1-k)}$ if $\frac{(1-4k)N_A + (1-2k)p_B}{2(1-k)} > 0$. When $\frac{(1-4k)N_A + (1-2k)p_B}{2(1-k)} < 0$, π_A is maximized at $p_A = 0$. It is easy to show that $p_A < p_B$ in both cases given that $p_B > 0$ and $1/4 < k < 1$. Hence in equilibrium $p_A \geq p_B > 0$ is not possible.

Second, I show that it is also impossible that in equilibrium $p_B \geq p_A > 0$. I proceed

similarly and re-write network B 's profit function as

$$\pi_B = (k-1)p_B^2 + ((1-N_A)(1-4k) + p_A(1-2k))p_B + k(2-2N_A+p_A)^2 \quad (8)$$

Hence π_B is maximized at $p_B = \frac{(1-N_A)(1-4k)+p_A(1-2k)}{2(1-k)}$ if $\frac{(1-N_A)(1-4k)+p_A(1-2k)}{2(1-k)} > 0$ and $p_B = 0$ otherwise. In both cases, it is easy to show that $p_B < p_A$. Hence $p_B \geq p_A > 0$ is impossible.

Finally, I show that $p_A = 0$ if $p_B = 0$ and vice versa. When $p_B = 0$, $\pi_A = -(1-k)p_A^2 - (4k-1)N_A p_A + 4kN_A^2$. Hence π_A is maximized when $p_A = 0$ as $p_A \geq 0$. Similarly I could show that $p_B = 0$ if $p_A = 0$.

I conclude, based on the above analysis, that when $1/4 < k < 1$, $p_A = p_B = 0$ in equilibrium.

Case 2: $k \geq 1$

The case where $k = 1$ is simple. When $k = 1$, $\pi_A = -((4k-1)N_A + p_B)p_A + (2N_A + p_B)^2$. Hence, π_A is maximized when $p_A = 0$. Similarly, $\pi_B = -(3(1-N_A) + p_A)p_B + (2-2N_A+p_A)^2$ and is maximized when $p_B = 0$.

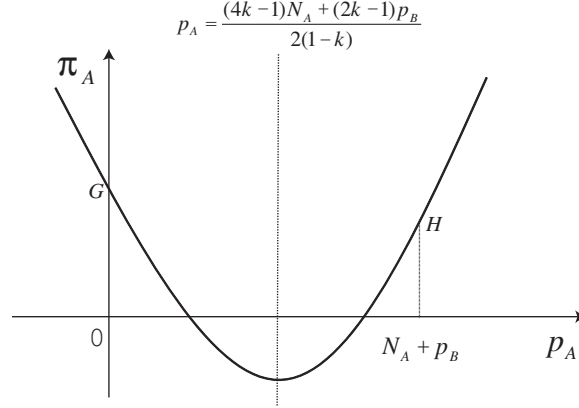
When $k > 1$, π_A and π_B are convex functions. Note that as $\theta^* = 1 - N_A + p_A - p_B \in [0, 1]$, I must have $p_A \leq N_A + p_B$ and $p_B \leq 1 - N_A + p_A$. I plot π_A as a function of p_A in Figure 1. It is easy to show that $N_A + p_B > \frac{(4k-1)N_A + (2k-1)p_B}{2(k-1)} > 0$. Therefore, the maximum of π_A is achieved at either $p_A = 0$ or $p_A = N_A + p_B$. $\pi_A = k(2N_A + p_B)^2$ when $p_A = 0$, and $\pi_A = kN_A^2$ when $p_A = N_A + p_B$. Hence, π_A achieves its maximum at $p_A = 0$.

I could proceed similarly to show that π_B achieves its maximum when $p_B = 0$. Therefore, when $k > 1$, the equilibrium prices p_A and p_B are both zero.

This complete the proof that when $k \geq 1/4$, $p_A = p_B = 0$.

When $k < 1/4$, $\frac{dp_A}{dk} = -\frac{2(4N_A+7-8k(3-2k))}{(3-4k)^2} < 0$ and $\frac{dp_B}{dk} = \frac{16(3-2k)k+8N_A-22}{(3-4k)^2} < 0$. That is, p_A and p_B decrease with k when $k < 1/4$. □

Figure 1. π_A over p_A



Proof of Proposition 4. Without compatibility, when $k \geq 1/4$, I have $p_A = p_B = 0$. Hence, $\theta^* = 1 - N_A$. Hence $\pi_A = k(N_A + N_A)^2 = 4kN_A^2$ and $\pi_B = 4k(1 - N_A)^2$.

For both networks to prefer compatibility, I need $4kN_A^2 < k(2N_A + 1)$ and $4k(1 - N_A)^2 < k(3 - 2N_A)$. The first inequality gives $N_A < \frac{1+\sqrt{5}}{4} \approx 0.81$. The second inequality always holds. Now consider the case where $k < 1/4$. In this case, $\theta^* = \frac{4kN_A + N_A - 2}{4k - 3}$.

I have

$$\pi_A = \frac{16(2N_A - 1)k^3 - 8(2N_A(N_A + 2) - 3)k^2 + (2N_A(8N_A - 1) - 9)k + (N_A + 1)^2}{(3 - 4k)^2}$$

$$\pi_B = \frac{16(1 - 2N_A)k^3 - 8(2N_A(N_A - 4) + 3)k^2 + (2N_A(8N_A - 15) + 5)k + (N_A - 2)^2}{(3 - 4k)^2}$$

Hence for compatibility to be possible, I have

$$\frac{16(2N_A - 1)k^3 - 8(2N_A(N_A + 2) - 3)k^2 + (2N_A(8N_A - 1) - 9)k + (N_A + 1)^2}{(3 - 4k)^2} < k(2N_A + 1)$$

$$\frac{16(1 - 2N_A)k^3 - 8(2N_A(N_A - 4) + 3)k^2 + (2N_A(8N_A - 15) + 5)k + (N_A - 2)^2}{(3 - 4k)^2} < k(3 - 2N_A)$$

Solving the first inequality yields

$$N_A < \frac{8k^2 - 10k - \sqrt{2}\sqrt{-256k^5 + 672k^4 - 592k^3 + 186k^2 - 9k + 1}}{16k^2 - 16k - 1}$$

As $N_A > 1/2$, I need $k > 1/8$. Hence, when $k \leq 1/8$, network A will always prefer incompatibility. When $k > 1/8$ and $N_A < N_A^*$, where $N_A^* = \frac{8k^2 - 10k - \sqrt{2}\sqrt{-256k^5 + 672k^4 - 592k^3 + 186k^2 - 9k + 1}}{16k^2 - 16k - 1}$, network A will prefer compatibility.

The second inequality yields

$$N_A > \frac{8k^2 - 6k + \sqrt{2}\sqrt{-256k^5 + 672k^4 - 592k^3 + 186k^2 - 9k} - 2}{16k^2 - 16k - 1}.$$

I only need to consider the case where $k > 1/8$. In this case, the right hand side is always below 0.5. Hence, the inequality always holds. That is, network B always prefer to be compatible.

To summarize, when $k > 1/8$, if $N_A < N_A^*$, both networks will prefer compatibility. Otherwise, the two networks are incompatible. It is easy to verify that N_A^* increases with k when $k \in (1/8, 1/4)$. As N_A^* is a constant when $k \geq 1/4$, I conclude that N_A^* increases weakly with k when $k > 1/8$. \square

Proof of Proposition 5. Solving the joint profit maximization problem without considering the non-negativity constraint on prices, I have

$$\begin{aligned} p_A &= \frac{2(2k^2 + 5k + 3)\alpha^3 + (-2N_A + 2k(N_A + 5) + 13)\alpha^2 + (-12k^2 + 2(N_A - 7)k + N_A + 7)\alpha + (4k - 1)(2k - N_A - 1)}{(1 - \alpha)(-4k + \alpha(4k + 6) + 3)} \\ p_B &= \frac{2(2k^2 + 5k + 3)\alpha^3 - (2k(N_A - 6) - 2N_A - 11)\alpha^2 - (12k^2 + 2(N_A + 6)k + N_A - 8)\alpha + (4k - 1)(2k + N_A - 2)}{(1 - \alpha)(-4k + \alpha(4k + 6) + 3)} \end{aligned}$$

I follow the procedure in the proof of Proposition 4 and obtain that $p_A > 0$ and $p_B > 0$ when

$$k < k^{**}, \text{ where } k^{**} = \frac{-5\alpha^3 + (N_A - 6)\alpha^2 + (N_A + 6)\alpha - 2N_A - \sqrt{(\alpha - 1)^2(\alpha^4 - 18(N_A - 1)\alpha^3 + (N_A^2 - 54N_A + 51)\alpha^2 + (4N_A^2 - 42N_A + 38)\alpha + (3 - 2N_A)^2) + 5}}{4(1 - \alpha)^2(\alpha + 2)}.$$

It is easy to verify that $k^{**} > 1/4$ when $\alpha \in (0, 1)$ and $N_A \in (1/2, 1)$. In addition, I find

that when $k^{**} < k < k^{***}$, where $k^{***} = \frac{(2\alpha + 1)(\alpha^2 - (N_A - 2)\alpha + N_A)}{2(2 - \alpha - \alpha^2)(\alpha + N_A)}$, $p_A > 0$ and $p_B = 0$; when

$k \geq k^{***}$, $p_A = p_B = 0$. It is easy to verify that both k^{**} and k^{***} increase with α . \square

Proof of Proposition 6. When $k > k^{***}$, $p_A = p_B = 0$. The profit of the two networks are

$$\begin{aligned}\pi_A &= (\alpha + (2 - \alpha)N_A)^2 k \\ \pi_B &= (\alpha + (2 - \alpha)(1 - N_A))^2 k\end{aligned}$$

Compatibility requires that $(\alpha + (2 - \alpha)N_A)^2 k < (2N_A + 1)k$ and $(\alpha + (2 - \alpha)(1 - N_A))^2 k < (3 - 2N_A)k$. Hence, I have $N_A < \frac{\alpha^2 - 2\alpha + 1 + \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2}$ and $N_A > \frac{3 - 2\alpha - \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2}$. I also have $(\alpha - 2)^2 > \frac{\alpha^2 - 2\alpha + 1 + \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2}$ when $\alpha > 2(\sqrt{2} - 1)$, and $\frac{\alpha^2 - 2\alpha + 1 + \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2} < 1/2$ when $\alpha > 2(\sqrt{2} - 1)$. Therefore, compatibility is only possible when $\alpha < 2\sqrt{2} - 1$ and $N_A < \frac{\alpha^2 - 2\alpha + 1 + \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2}$ and it is easy to verify that $\frac{\alpha^2 - 2\alpha + 1 + \sqrt{3\alpha^2 - 8\alpha + 5}}{(\alpha - 2)^2} < \frac{1 + \sqrt{5}}{4}$. □

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