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**NETWORK COMPATIBILITY
AND INCUMBENT PRICING REGIMES**

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Network Compatibility and Incumbent Pricing Regimes*

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Abstract

The phenomenon where a network’s value escalates with each additional user, known as a direct network effect, exists across industries that may differ in terms of interoperability or compatibility. For instance, while email and telephone services benefit from seamless cross-network communication, social media platforms typically do not, operating in silos (with some exceptions). Recent legislative initiatives, such as the Digital Market Act, spotlight the challenges and opportunities of enhancing network interoperability. This has led to a reevaluation of interoperability’s impact on consumer benefits and API-driven business models, and industry experts and companies are now exploring increased interoperability. Our study introduces a model assessing the compatibility decision, whether by individual firms or unilaterally for the entire industry, and considers how this decision is linked to price regime decisions (personalized or uniform) in markets with direct network effects. We show that the two decisions are often linked, that parties often differ in their preferences across them, and that unilateral compatibility decisions can be used to deter entry and reduce competition.

Keywords: Interoperability, Direct Network Effects, Personalized Pricing, Uniform Pricing

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1 Introduction

Network effects, including direct and cross-market effects, have become ubiquitous thanks to the rapid expansion of platform industries. Among these network effects, the traditional direct network effects (Katz and Shapiro, 1985) still have a significant impact on performance in many markets including social network services, online payments, and online games (Bianchi et al., 2023). Furthermore, the usage of application programming interfaces (APIs) open the door for collaborators and competitors to strengthen direct network effects by improving compatibility (Bianchi et al., 2023). Typical examples are the interoperability of mobile payments (Bianchi et al., 2023), social media (Ma et al., 2024),¹ the cross-platform usage of games (Srinivasan and Venkatraman, 2020), and, with Google’s recent licensing agreement to use Character.AI in Gemini, AI chatbots which may exhibit direct network effects through improved training (Gans, 2024).²

In addition, the increasing availability of consumer information has empowered firms to improve their personalized offerings to consumers, often in the form of personalized prices or personalized ad levels. Indeed, the markets with direct network effects described above often utilize personalization strategies. For example, the three most well-known first-person shooter video games, Call of Duty, Battlefield, and Halo, allow players to purchase personalized functionalities. Indeed this is common place in video and mobile games (Amano and Simonov, 2024). The inherent nature of such functionalities highlights game developer adoption of personalized pricing to sell tailored functionalities (Jiao et al., 2022, Wu et al., 2023).³ Online financial services also utilize personalized pricing (Lin et al., 2023). While not offering personalized prices to consumers, social media platforms personalize the types and amount of advertisements displayed to consumers (Sagtani et al., 2024). Lastly, examining the pricing options offered to consumers by a variety of AI chatbots reveals a wide range of pricing options suggesting some amount of personalized pricing is possible in the AI industry.

¹This obviously occurs between Facebook and Instagram but Whatsapp has also considered allowing messaging from non-Whatsapp users. See “WhatsApp has reluctantly started work on cross-platform messaging due to EU regulation,” in TechCrunch on September 11, 2023, for more.

²See “Google Paid \$2.7 Billion to Bring Back an AI Genius Who Quit in Frustration,” in the Wall Street Journal on September 25, 2024, for more.

³Following their empirical findings, Jiao et al. (2022, p. 3435) mention that game developers can design customized virtual items with personalized pricing. In addition, Wu et al. (2023) conduct counterfactual simulations on the effectiveness of targeted pricing, using data directly from the store website of Steam, a platform for PC-based video games.

The intersection of network effects, network compatibility, and personalized pricing has also gained recent interest from policy circles (e.g., European Commission, 2018, OECD, 2018, Ofcom, 2020, Cabral et al., 2021). This highlights the importance of considering all three factors when evaluating the effectiveness of network strategies and the policies meant to improve them. To better understand the importance of network compatibility in markets with direct network effects and personalized offerings, we model such an industry where network compatibility decisions are either made by each firm individually or unilaterally determined by the incumbent when the incumbent chooses between using uniform or personalized prices (targeted advertising).

We consider a Hotelling duopoly model with competition between an incumbent network and an entrant network. Each network experiences direct network effects and each firm endogenously determines its degree of compatibility with its rival. If a firm chooses a positive degree of compatibility, the rival’s consumers benefit from this decision. In other words, each firm can decide how open its network is to other firms. Using the analytical framework, we consider two pricing regimes employed by the incumbent: (i) uniform pricing and (ii) personalized pricing. We also consider the incumbent’s endogenous choice of the pricing regime and to what extent the incumbent’s choice in compatibility can deter entry.

We find that the type of pricing used impacts the individual network compatibility decisions made by each network when deciding the extent to which they make their network compatible with their rival’s. In particular, we find that firms choose to fully silo or make their network fully compatible with their rival and may agree on being fully compatible (incompatible) under uniform (personalized) pricing. This reveals that we expect less compatibility under personalized pricing when individual operators select their compatibility levels.

In terms of price regimes, the incumbent prefers uniform over personalized pricing when the degree of network externality is moderate and its quality disadvantage over the entrant is moderate. We also show that the ideal pricing regime (uniform or personalized) for the incumbent does not align with that for consumer and social welfare so much. This highlights a potential difficulty in regulating either compatibility or pricing regimes as the policy recommendations are unclear and will vary on a case by case basis.

As an extension to individual compatibility decision framework, we consider entry deterrence by the incumbent and find that this incentivizes the incumbent to reduce their

level of compatibility in order to deter entry highlighting how compatibility, in addition to pricing decisions, can be an effective tool in deterring entry. We also investigate an alternative compatibility decision approach where the incumbent unilaterally selects the industry wide level of compatibility. We find that its choice is often at odds with its competitor and with consumers, regardless of the pricing regime. Furthermore, we show that the incumbent’s ability to choose the industry level of compatibility enables it to better deter entry. Thus, both consumers and potential entrants would benefit from a system where compatibility is discussed bilaterally opposed to being unilaterally decided by the incumbent.

2 Related Literature

We contribute to a growing literature that highlights the importance of direct network effects (Economides, 1996, Du et al., 2016, Mardan and Tremblay, 2025, Van Den Brink and Rusinowska, 2024), relevant for those examples discussed in the previous section as well as for collective consumption (Jiang and Tian, 2018, Tian and Jiang, 2018, Giglio et al., 2023), pooled rides in ride-sharing (Zhang et al., 2022, Naumov and Keith, 2023), and platform competition from an OR perspective (Zenny, 2020, Gong et al., 2024, Matsui, 2024, Song et al., 2024, Wu and Zha, 2025). Allowing for direct network effects and compatibility ties our work to an older literature on network compatibility (Katz and Shapiro, 1985, Foros, 2007). However, we differ in two respects. First, we consider personalized pricing which has become fundamental in these industries. Second, we allow for bilateral and unilateral compatibility choices, as well as entry deterrence, which enables us to better understand how these markets can be efficiently run by policy makers in conjunction with industry coalitions.

Since the seminal works by Thisse and Vives (1988) and Shaffer and Zhang (2002), numerous studies examine the effects of personalized pricing on profits and welfare. Key elements in these studies include firm asymmetry (Choudhary et al., 2005, Matsumura and Matsushima, 2015), demand conditions (Liu and Serfes, 2013, Esteves and Resende, 2019, Chen et al., 2020, Esteves, 2022, Esteves and Shuai, 2022, Esteves and Carballo-Cruz, 2023, Matsushima et al., 2023, Rhodes and Zhou, 2024, Lu and Matsushima, 2024), vertical relations (Jullien et al., 2023), data distribution and brokers (Montes et al., 2019, Abrardi et al., 2024), non-price strategic variables (e.g., locations) (Foros et al., 2024),

and two-period competition with behavior-based price discrimination (Liu and Serfes, 2006, Zhang, 2011, Choe et al., 2018, Chen et al., 2022, Choe et al., 2022, Laussel and Resende, 2022, Laussel, 2023). None of these studies incorporate network externalities among consumers.⁴

Our work relates to several papers that also utilize the Hotelling framework.⁵ For example, Choe et al. (2023) consider asymmetric personalized pricing issues, relating to one of the competition regimes where the incumbent uses personalized pricing, and find that the firm with an advantage is able to soften competition; however, they do not include network effects in their model. Instead, He et al. (2012) consider direct network effects that may come from ones own network or a competitor (a form a compatibility in our framework); however, they do not consider personalized pricing nor how compatibility decisions might impact entry deterrence.⁶ Importantly, they do not consider personalized pricing, compatibility, or entry deterrence. Among the papers that explore network externalities and personalized pricing (Foros, 2007, Liu and Serfes, 2013, Kodera, 2015, Hajihashemi et al., 2022, Lu et al., 2024), Foros (2007) is the only one that discusses compatibility but we expand on his work by allowing for quality differences, both unilateral and bilateral compatibility choices, and entry deterrence.⁷

⁴It is also important to note that our framework allows us to consider personalized advertising, a growing literature for markets with network effects (Esteves and Resende, 2016, Karle and Reisinger, 2024, Ma et al., 2024), instead of personalized pricing.

⁵The Hotelling duopoly model has been used extensively to study markets with direct (Farrell and Saloner (1992), He et al. (2012) and Etzion and Pang (2014)) and indirect network effects (Bakos and Halaburda (2020), Tan et al. (2020), Dou and Wu (2021), and Sui et al. (2023)). Mardan and Tremblay (2025) also indicate that direct and indirect network effects can be one in the same suggesting our results on compatibility and entry deterrence may apply more broadly.

⁶Similarly, Etzion and Pang (2014) consider direct network effects and show that their inclusion increases competition and reduces profits.

⁷Possibly the most significant contribution to the network effect literature on entry deterrence is Zhu and Iansiti (2012). They consider a dynamic two-sided market model and show how platform quality, consumer expectations, and indirect network effects impact a platforms ability to enter into the market and they then apply their model to the case of Xbox’s entry despite the Playstation 2 incumbent. Instead, we focus on the impact that compatibility has on potential entry as this has become a core issue in the industries that our model aims to consider.

3 The Model

Suppose there exists a unit mass of consumers that are distributed uniformly on the unit interval in a market served by an incumbent I and an entrant E , whose locations are respectively 0 and 1 on the interval. The product quality for the incumbent and the entrant are given by q_I and q_E , respectively. For simplicity, we assume that $q_E > q_I$; this assumption also aligns with the fact that any meaningful entry must be of higher quality. We allow the incumbent to consider two pricing regimes: (i) uniform pricing or (ii) personalized pricing. Instead, with limited knowledge about individual consumers, we assume that the entrant offers a uniform price. For simplicity, we assume that both firms have a marginal cost of zero.

At the start of the game, each of the firms chooses the level of their individual compatibility, or compatibility quality, between its own and the rival's networks, thus determining the extent to which APIs can be utilized.⁸ For instance, if the incumbent chooses to make its network compatibility, then the entrant's consumers also enjoy network benefit from the incumbent's service. We denote the amounts of compatibility by $\delta_j \in [0, 1]$ ($j = I, E$), where $\delta_j = 0$ denotes fully incompatible networks and $\delta_j = 1$ denotes fully compatible networks.

Consumer utility for the incumbent and entrant are given by

$$\begin{aligned} u_I(x) &= v + q_I - tx + \gamma(d_I + \delta_E d_E) - p_I, \\ u_E(x) &= v + q_E - t(1 - x) + \gamma(d_E + \delta_I d_I) - p_E, \end{aligned}$$

where v denotes the standalone value, which is large enough as in the standard Hotelling model, t the transportation cost which captures the amount of differentiation between the two networks, γ the direct network effect, d_I (d_E) the expected number of consumers that purchase and use the incumbent's (entrant's) network, and p_I (p_E) the price of the incumbent (entrant).⁹ We assume that information is perfect.

The timing of the game is as follows. The incumbent selects one of the pricing regimes: uniform or personalized. Observing the chosen pricing regime, the incumbent

⁸We also consider an extension where the incumbent unilaterally selects network compatibility for the entire industry in Section 5.

⁹The Hotelling model is widely adopted in by the OR literature (e.g. Ebina et al., 2022, Sui et al., 2023, Xu et al., 2023, 2024).

and entrant make compatibility choices (δ_I and δ_E). Then, the two firms compete and payoffs are realized with the profits of firms I and E given by

$$\pi_I = p_I d_I, \quad \pi_E = p_E d_E.$$

To solve the model, we require some additional assumptions. We assume that expectations are fulfilled once consumers observe publicly available prices. This assumption is standard in models with network effects (Katz and Shapiro, 1985). We focus on the case of full coverage under duopoly competition, $d_I + d_E = 1$, which requires that $t > \gamma$ and $v > (3t - 2\gamma)/2$.

We argue that this setup applies to many industries where consumers experience direct network effects. As discussed in the introduction, both the social media industry and the messaging industry experience direct network effects; while prices to consumers do not exist in these industries, advertising exists so that our price terms correspond to advertising levels (simply replace p with A , ad level). We also mentioned that AI competition with positive prices may also apply and compatibility may become an issue in the future as the industry evolves. Another example that may apply is cryptocurrency exchanges. The exchanges and underlying currencies exhibit direct network benefits (more users makes the coins and exchanges more valuable to the users), and exchanges charge fees to their users. Differentiation between exchanges stems from different levels of trust in the exchanges or their underlying assets across consumers. Finally, compatibility in this case would capture the ability to transact between users on different exchanges (something that does varies across exchanges).

4 Individual Compatibility Sections

Solving the game backwards, we consider each of the pricing regimes in turn.

4.1 Uniform Pricing for the Incumbent

The incumbent attracts consumers at x if and only if the following inequality holds:

$$v + q_I - tx + \gamma(d_I + \delta_E d_E) - p_I \geq v + q_E - t(1 - x) + \gamma(d_E + \delta_I d_I) - p_E.$$

There is an x such that the inequality holds with equality and at this x we have $x = d_I = 1 - d_E$; that is, the expectations for the network sizes match with the actual ones. This equations generate the following demand system:

$$d_I = \frac{t - \gamma(1 - \delta_E) - (q_E - q_I) + p_E - p_I}{2t - \gamma(2 - \delta_E - \delta_I)}, \quad d_E = \frac{t - \gamma(1 - \delta_I) + (q_E - q_I) + p_I - p_E}{2t - \gamma(2 - \delta_E - \delta_I)}.$$

As is common in the literature on network externalities, the direct network effect γ makes the demands more elastic. However, compatibility choices ($\delta_j > 0$) mitigate the elasticity of demand. Also, a firm's compatibility choice δ_j directly diminishes its demand d_j but directly enhances the demand of its rival d_{-j} . Therefore, a compatibility choice has a trade-off: mitigating competition through lower price elasticity and diminishing ones own demand.

The price subgame equilibrium, which takes δ_I and δ_E as given, is given by the following:

Lemma 1. *Taking δ_I and δ_E as given, the subgame equilibrium prices and quantities for firms I and E are given by*

$$\begin{aligned} p_j(\delta_j, \delta_k) &= t - \gamma + \frac{(q_j - q_k) + \gamma(\delta_j + 2\delta_k)}{3}, \\ d_j(\delta_j, \delta_k) &= \frac{3t - \gamma(3 - 2\delta_k - \delta_j) + (q_j - q_k)}{6t - 3\gamma(2 - \delta_E - \delta_I)}, \\ \pi_j(\delta_j, \delta_k) &= \frac{(3t - \gamma(3 - 2\delta_k - \delta_j) + (q_j - q_k))^2}{9(2t - \gamma(2 - \delta_E - \delta_I))}, \end{aligned}$$

where $j, k = I, E, j \neq k$.

The results in Lemma 1 reveal that, due to higher price elasticity, the direct network effect γ accelerates competition. However, compatibility choices mitigate this network effect, which is entirely offset when $\delta_I = \delta_E = 1$.

Given the pricing subgame equilibrium, we solve for each firm's optimal level of compatibility by maximizing their profits with respect to their individual compatibility choice. In doing so, we see that no partial compatibility exists for either firm and that the incumbent always makes their network compatible with the entrant. This is due to their lower quality so that compatibility softens competition.

Proposition 1. *The incumbent always chooses $\delta_I^U = 1$ and the entrant chooses $\delta_E^U = 1$ if $\Delta q \equiv q_E - q_I < \sqrt{2t(2t - \gamma)} - t$, otherwise they choose $\delta_E^U = 0$.*

Firm E , which has quality advantage, faces a trade-off regarding its compatibility choice. Compatibility reduces the aggressiveness of the rival, enabling the advantageous firm to increase its price. However, compatibility decreases demand (see the reaction functions in the proof of Lemma 1). When the degree of quality advantage is high, the latter cost dominates the former benefit due to the loss of a high per-consumer margin through a reduction of demand.

Entry deterrence The above compatibility choices may change if we allow the incumbent to deter entry. To see this, note that $\partial \pi_E^*(\delta_E, \delta_I) / \partial \delta_I > 0$ regardless of δ_E and δ_I . Therefore, firm I will choose $\delta_I = 0$ if it's objective is to successfully deter entry. This generates the following result:

Proposition 2. *If the entrant incurs a fixed cost F , then the incumbent's compatibility decision is as follows. If entry costs are low, then the incumbent prefers compatibility ($\delta_I^U = 1$) so that entry occurs and competition is soft: if $F < \pi_E^U(\delta_E^{Ud}, 0)$, then the incumbent chooses $\delta_I^U = 1$ and the entrant chooses δ_E^U in Proposition 1. Instead, if entry costs are high, then incumbent prefers incompatibility ($\delta_I^U = 0$) which successfully deters entry: if $\pi_E^U(\delta_E^{Ud}, 0) \leq F$, then the incumbent sets $\delta_I^U = 0$ to deter entry.*

Propositions 1 and 2 reveal that if entry is certain, then the incumbent makes their network compatible with the entrant to soften competition. However, if it is possible to deter entry, then the incumbent may do so by making its network incompatible with the potential entrant. Thus a networks compatibility selection may be impacted by the incentive to deter potential entry.

4.2 Personalized Pricing for the Incumbent

We assume that only the incumbent can employ personalized pricing because of an incumbency advantage (either due to an existing presence in the market or some pre-existing knowledge about consumers). In the pricing stage, we assume that the entrant sets its price p_E first, and then the incumbent offers personalized prices after observing p_E . This assumption is based on personalized prices being more flexible than publicly

offered uniform prices and it follows similar assumptions in the literature on personalized pricing (Thisse and Vives, 1988, Shaffer and Zhang, 2002, Choe et al., 2018, 2023).

We assume that personalized prices are private, secret, and ineffective in influencing the expectations of consumers for the network sizes. The assumption implies that the incumbent cannot manipulate consumers' expectations and does not have incentives to set negative personalized prices to attract consumers. As a result, the lowest personalized prices are zero.

Once the entrant sets p_E , consumers can expect that the incumbent attracts consumers at x if and only if the following inequality holds:

$$v + q_I - tx + \gamma(d_I + \delta d_E) - 0 \geq v + q_E - t(1 - x) + \gamma(d_E + \delta d_I) - p_E.$$

The last term in the left-hand side, 0, comes from the fact that the incumbent can protect its demand by offering zero personalized price. There is an x such that the inequality holds with equality and at this x we have that $x = d_I = 1 - d_E$ holds; that is, the expectations for the network sizes match the actual ones. This generate the following demand system:

$$d_I = \frac{t - \gamma(1 - \delta_E) - (q_E - q_I) + p_E}{2t - \gamma(2 - \delta_E - \delta_I)}, \quad d_E = \frac{t - \gamma(1 - \delta_I) + (q_E - q_I) - p_E}{2t - \gamma(2 - \delta_E - \delta_I)}.$$

Note that this demand system is almost the same as that in Section 4.1 except for the non-existence of p_I due to the personalized pricing by the incumbent.

The incumbent supplies consumers at $x \in [0, d_I)$, and the entrant supplies at $x \in [d_I, 1]$. The price schedule of the incumbent under p_E is

$$p_I(x) = \begin{cases} t(1 - 2x) + \frac{\{2(q_I - q_E) + 2p_E + \gamma(\delta_E - \delta_I)\}t}{2t - \gamma(2 - \delta_E - \delta_I)} & \text{for } x \in [0, d_I), \\ 0 & \text{for } x \in [d_I, 1]. \end{cases}$$

The price subgame equilibrium, which takes δ_I and δ_E as given, is given by the following:

Lemma 2. *Taking δ_I and δ_E as given, the subgame equilibrium prices and quantities for firms I and E are given by*

$$p_E^p(\delta_E, \delta_I) = \frac{q_E - q_I + t - \gamma(1 - \delta_I)}{2},$$

$$\begin{aligned}
d_E^p(\delta_E, \delta_I) &= \frac{q_E - q_I + t - \gamma(1 - \delta_I)}{2(2t - \gamma(2 - \delta_E - \delta_I))}, \\
\pi_E^p(\delta_E, \delta_I) &= \frac{(q_E - q_I + t - \gamma(1 - \delta_I))^2}{4(2t - \gamma(2 - \delta_E - \delta_I))}, \\
p_I^p(x, \delta_E, \delta_I) &= \begin{cases} (1 - 2x)t + \frac{\{t - \gamma(1 - \delta_I) - (q_E - q_I)\}t}{2t - \gamma(2 - \delta_E - \delta_I)} & \text{for } x \in [0, d_I^p], \\ 0 & \text{for } x \in [d_I^p, 1], \end{cases} \\
d_I^p(\delta_E, \delta_I) &= \frac{3}{4} + \frac{2(q_I - q_E) + \gamma(\delta_E - \delta_I)}{4(2t - \gamma(2 - \delta_E - \delta_I))}, \\
\pi_I^p(\delta_I, \delta_E) &= \frac{t(q_I - q_E + 3t - \gamma(3 - 2\delta_E - \delta_I))^2}{4(2t - \gamma(2 - \delta_E - \delta_I))^2}.
\end{aligned}$$

As in uniform pricing, the network effect γ decreases the uniform price of the entrant if $\delta_I < 1$ (see p_E^p) but can increase personalized prices if $t(\delta_I - \delta_E) > (2 - \delta_E - \delta_I)(q_E - q_I)$, that is, if the incumbent's quality disadvantage is not significant. The positive effect of the network effect on the incumbent comes from its large demand, d_I^p , which is about $3/4$ unless $q_E - q_I$ is large. The large demand directly enlarges the network benefits of the incumbent's consumers, allowing the incumbent to charge high personalized prices.

Turning to the compatibility subgame, we now have that the entrant always silos their network ($\delta_E^p = 0$) and the incumbent either silos or makes their network fully compatible with the entrant's network:

Proposition 3. *The entrant always chooses $\delta_E^p = 0$ and the incumbent chooses $\delta_I^p = 1$ if $q_E - q_I \geq t - \gamma$, otherwise they choose $\delta_I^p = 0$.*

The intuition behind this proposition is as follows. When the incumbent employs personalized pricing, the entrant does not have any strategic benefit from compatibility, which just reduces its demand (see $d_E^p(\delta_E, \delta_I)$). In contrast, the incumbent has a strategic benefit from compatibility, which induces the entrant to increase the uniform price (see $p_E^p(\delta_E, \delta_I)$). Of course, compatibility increases the network benefit for the entrant's consumers, enhancing the entrant's competitive advantage. The former positive effect dominates the latter cost if and only if $q_E - q_I - t + \gamma - \gamma\delta_E > 0$, which is the condition that compatibility increases the demand for the incumbent. Therefore, if the entrant has enough quality advantage, the incumbent chooses compatibility over siloing.

Entry deterrence The above compatibility choice may change if we consider the incumbent's incentive to deter entry. First, note that $\partial\pi_E^p(0, \delta_I)/\partial\delta_I > 0$, where $\delta_E^p = 0$ is the δ_E in Proposition 3. This implies that the incumbent while silo with $\delta_I = 0$ if they deter entry. Second, note that we need to consider the entry decision across the two possible cases if $q_E - q_I \geq t - \gamma$ (where Proposition 3 implies $\delta_i = 1$ when entry is certain): (i) if $F < \pi_E^p(0, 0)$, then the entrant always enters the market and (ii) if $\pi_E^p(0, 0) \leq F$, then the incumbent can deter entry by choosing $\delta_I = 0$. More formally we have the following:

Proposition 4. *When the entrant incurs a fixed cost F , the incumbent's compatibility decision is as follows. First, if $q_E - q_I < t - \gamma$, then firm I chooses $\delta_I^p = 0$. Second, if $q_E - q_I \geq t - \gamma$, then either (i) entry costs are low so that the incumbent prefers compatibility ($\delta_I^p = 1$) and entry occurs: if $F < \pi_E^p(0, 0)$, then the incumbent chooses $\delta_I^p = 1$; or (ii) entry costs are high so that the incumbent prefers siloing ($\delta_I^p = 0$) to deter entry: if $\pi_E^p(0, 0) \leq F$, then the incumbent sets $\delta_I^p = 0$ to deter entry.*

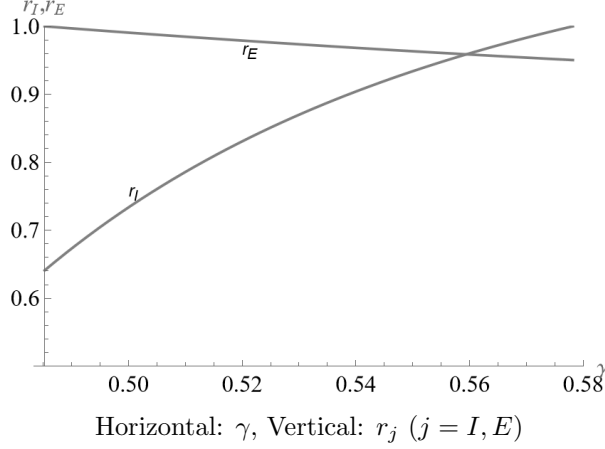
Again we see that, as with uniform pricing, siloing by the incumbent is more likely when entry deterrence is possible as siloing, instead of an otherwise optimal choice of open compatibility, makes entry impossible for the potential entrant.

Labor Market We have shown that the firms are less likely to adopt individual compatibility under personalized pricing. Now, we introduce technology specialists who contribute to improve product quality. The labor market consists of a Hotelling line with length 1 and the utilities from working at firms I and E are $w_I + \tau(1 - y)$ and $w_E + \tau y$, where w_i is the wage of firm i , $\tau(> 0)$ is an exogenous parameter, and $y \in [0, 1]$ is a location of specialist. The indifferent specialists are given by $\bar{y} = (\tau + w_I - w_E)/(2\tau)$. The product qualities, q_I and q_E , depend on the number of employed specialists with $q_I = g\bar{y}$ and $q_E = g(1 - \bar{y})$. In this setting, firms simultaneously choose w_I , w_E , and p_E . Then, consumers form expectations. Finally, firm I offers personalized prices.

To simplify the discussion, we assume that each firm can choose one of the two polar choices: $\delta_j = 0$ and $\delta_j = 1$. In contrast with the comparative statics in this subsection, we find that $q_E^* - q_I^* < 0$ and at least one firm chooses compatibility for a wide parameter range. Concretely, if $\gamma < 0.485t$, both firms choose compatibility; if $0.578t < \gamma$, only the incumbent chooses compatibility and the entrant chooses incompatibility. For $0.485t \leq$

$\gamma \leq 0.578t$, the incumbent chooses compatibility with probability r_I , which is larger than 0.6 and the entrant chooses compatibility with probability r_E , which is larger than 0.9.

Figure 1: Mixed strategies



If we consider the labor market under uniform pricing, the quality levels q_I and q_E are the same in equilibrium because of the firm symmetry. Then, the firms choose compatibility in equilibrium.

4.3 The Optimal Pricing Regime

We are able to consider the optimal pricing regime by the incumbent and by a social planner. To do so, note that the profits, consumer surplus, and total surplus in each case of Proposition 1 (uniform pricing) are given by:

$$\begin{aligned}
\pi_E^U(1, 1) &= \frac{(3t + \Delta q)^2}{18t}, \quad \pi_I^U(1, 1) = \frac{(3t - \Delta q)^2}{18t}, \\
CS^U(1, 1) &= v - \frac{5(9t^2 + \Delta q^2)}{36t}, \quad TS^U(1, 1) = v - \frac{9t^2 + \Delta q^2}{36t}, \\
\pi_E^U(0, 1) &= \frac{(3t - \gamma + \Delta q)^2}{9(2t - \gamma)}, \quad \pi_I^U(0, 1) = \frac{(3t - 2\gamma - \Delta q)^2}{9(2t - \gamma)}, \\
CS^U(0, 1) &= v - \frac{(5t - 2\gamma)(18t(t - \gamma) + 5\gamma^2 + 2\Delta q(\gamma + \Delta q))}{18(2t - \gamma)^2}, \\
TS^U(0, 1) &= v - \frac{t(18t(t - \gamma) + 5\gamma^2 + 2\Delta q(\gamma + \Delta q))}{18(2t - \gamma)^2},
\end{aligned}$$

where $CS^U(0, 1) > CS^U(1, 1)$ and $TS^U(0, 1) < TS^U(1, 1)$. Similarly, the profits, consumer surplus, and total surplus in each case of Proposition 3 (personalized pricing) are given by:

$$\begin{aligned}
\pi_E^p(0, 1) &= \frac{(t + \Delta q)^2}{4(2t - \gamma)}, \quad \pi_I^p(0, 1) = \frac{(3t - 2\gamma - \Delta q)^2 t}{4(2t - \gamma)^2}, \\
CS^p(0, 1) &= v - \frac{3t(3t - 2\gamma - \Delta q)^2 + (t + \Delta q)^2(5t - 2\gamma)}{8(2t - \gamma)^2}, \\
TS^p(0, 1) &= v - \frac{t(5t^2 - 6t\gamma + 2\gamma^2 - 2(t - \gamma)\Delta q + \Delta q^2)}{4(2t - \gamma)^2}, \\
\pi_E^p(0, 0) &= \frac{(t - \gamma + \Delta q)^2}{8(t - \gamma)}, \quad \pi_I^p(0, 0) = \frac{(3t - 3\gamma - \Delta q)^2 t}{16(t - \gamma)^2}, \\
CS^p(0, 0) &= v - \frac{3t(3(t - \gamma) - \Delta q)^2 + (t - \gamma + \Delta q)^2(5t - 4\gamma)}{32(t - \gamma)^2}, \\
TS^p(0, 0) &= v - \frac{t(5(t - \gamma)^2 - 2(t - \gamma)\Delta q + \Delta q^2)}{16(t - \gamma)^2},
\end{aligned}$$

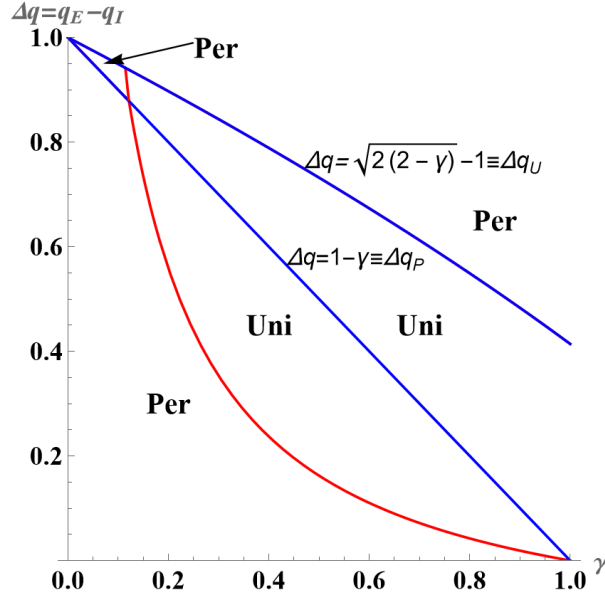
where $CS^p(0, 0) < CS^p(0, 1)$ if $\Delta q < \frac{(t - \gamma)\{8t^2 - 7t\gamma + \gamma^2 - (2t - \gamma)\sqrt{13t^2 - 12t\gamma + 2\gamma^2}\}}{6t(t - \gamma) + \gamma^2} < \frac{(8 - 2\sqrt{13})t}{6} \simeq 0.131t$, which is decreasing in γ , and $TS^*(0, 0) < TS^*(0, 1)$.

The incumbent's optimal pricing is presented in Figure 2 where the area "Per" denotes personalized pricing and the area "Uni" denotes uniform pricing. First, consider the case in which $\Delta q < t - \gamma$. Under uniform pricing, both firms choose compatibility, mitigating competition. However, under personalized pricing, no firm chooses compatibility, accelerating competition. If the disadvantage of the incumbent is significant within the case ($\Delta q < t - \gamma$), it chooses uniform pricing to mitigate price competition (the "Uni" below the equation $\Delta q = 1 - \gamma$ in Figure 2).

Second, consider the case in which $t - \gamma \leq \Delta q < \sqrt{2t(2t - \gamma)} - t$ ($1 - \Delta \leq \gamma < \min\{1, (3 - 2\Delta q - \Delta q^2)/2\}$). Under personalized pricing, only the incumbent chooses compatibility, increasing the entrant's uniform price. Under uniform pricing, both firms choose compatibility, mitigating competition. The degree of price increase is higher as the degree of network benefit γ becomes higher. Therefore, whenever γ is larger than a threshold value, the incumbent chooses uniform pricing to mitigate price competition (the "Uni" between equations $\Delta q = 1 - \gamma$ and $\Delta q = \sqrt{2t(2t - \gamma)} - t$ in Figure 2).

Third, consider the case in which $\sqrt{2t(2t - \gamma)} - t \leq \Delta q$ ($\min\{1, (3 - 2\Delta q - \Delta q^2)/2\} \leq$

Figure 2: The Incumbent's Optimal Pricing Regime



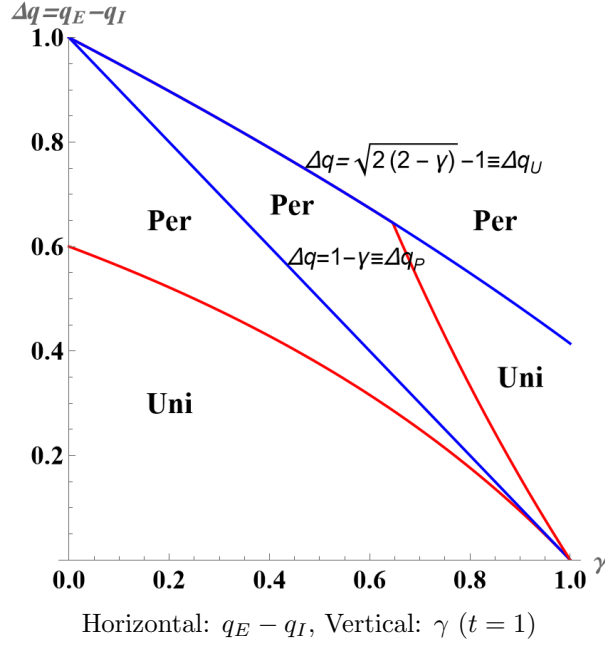
γ and $\sqrt{2} - 1 < \Delta q$). Under uniform pricing, only the incumbent chooses compatibility, mitigating competition a little. Because of the asymmetric compatibility choices under uniform pricing, the gain from choosing uniform pricing for the incumbent is lower. The lower gain induces the incumbent to choose personalized pricing.¹⁰

In terms of consumers, note that consumer surplus under personalized pricing is always higher than under uniform pricing. By comparing consumer and incumbent price regime preferences we see that the incumbent does not always implement what is best for consumers (they would prefer a greater use of personalized pricing). However, the comparison between the incumbent and total surplus is even less straightforward.

In terms of total surplus, Figure 3 reveals that uniform pricing dominates if $\gamma <$

¹⁰It is important to remark on the sequential timing of the pricing regime and compatibility choices. If the incumbent and the entrant simultaneously choose pricing regime and compatibility, the result of “Uni” under which $\Delta < t - \gamma$ does not hold. In this case, the incumbent deviates from uniform pricing with compatibility to personalized pricing without compatibility given that the entrant chooses compatibility. Anticipating the deviation, the entrant chooses incompatibility and then the incumbent employs personalized pricing without compatibility. Thus, the commitment to uniform pricing is crucial to derive the uniform pricing outcome under which $\Delta < t - \gamma$. In contrast, we still obtain the derived results under which $t - \gamma \leq \Delta q < \sqrt{2t(2t - \gamma)} - t$ and $\sqrt{2t(2t - \gamma)} - t \leq \Delta q$ because the pair of pricing regime and compatibility is the incumbent's best response to the entrant's compatibility choice. Therefore, even if we consider the simultaneous choices of pricing regime and compatibility, we obtain a non-monotonic effect of quality difference on the incumbent's pricing regime.

Figure 3: Total surplus comparison



$t(3t - \Delta q)/(3t - 2\Delta q)$ in the first region or $\gamma > t(3t - \Delta q)/(3t + \Delta q)$ in the second region, otherwise, the total surplus under personalized pricing is higher. Comparing total surplus to the incumbent's decision highlights how this disconnect persists, suggesting that some form of price regulation may improve efficiency but may also be difficult to implement effectively as there is some alignment along with clear differences in pricing regime preferences.

5 The Incumbent's Unilateral Compatibility Choice

In the previous section, we assume that compatibility choices are individual. Now, we assume that the incumbent can determine the degree of *common*, industry-wide, compatibility between the two networks. We denote the common compatibility as $\delta = \delta_E = \delta_I$. We also consider the incentive of firm I to manipulate δ in order to deter entry by firm E because the unilateral choice of δ allows firm I to control the competitive environment more easily.

5.1 Uniform Pricing for the Incumbent

Using the demand system in the previous section, we now have that:

$$d_I = \frac{1}{2} + \frac{(q_I - p_I) - (q_E - p_E)}{2(t - \gamma(1 - \delta))}, \quad d_E = \frac{1}{2} + \frac{(q_E - p_E) - (q_I - p_I)}{2(t - \gamma(1 - \delta))}.$$

Considering the pricing subgame equilibrium, where δ is taken as given, we have that:

$$\begin{aligned} p_{cj}^* &= t - \gamma(1 - \delta) + \frac{q_j - q_k}{3}, \\ d_{cj}^* &= \frac{1}{2} + \frac{q_I - q_E}{6(t - \gamma(1 - \delta))}, \\ \pi_{cj}^*(\delta) &= \frac{(q_j - q_k + 3(t - \gamma(1 - \delta)))^2}{18(t - \gamma(1 - \delta))}, \\ CS_c^* &= v - \frac{5t}{4} + \frac{\gamma(3 - \delta)}{2} + \frac{q_I + q_E}{2} + \frac{(q_I - q_E)^2 t}{36(t - \gamma(1 - \delta))^2}. \end{aligned}$$

where $j, k = I, E, j \neq k$) and subscript c (*common*) indicates results in this section.

In terms of compatibility, we see that the incumbent prefers industry-wide compatibility under uniform pricing:

Proposition 5. *If the incumbent controls the degree of common compatibility and uses a uniform price, then it chooses $\delta^U = 1$.*

This result is natural given that compatibility mitigates uniform price competition in markets with network effects (Farrell and Saloner, 1992).

Entry deterrence The above compatibility choice can change if we consider the incumbent's incentive to deter entry. We consider the entry decision across the three possible cases. First, if $F < \pi_{cE}^*(0)$, then the entrant always enters the market regardless of $\delta \in [0, 1]$. Second, if $\pi_{cE}^*(0) \leq F < \pi_{cE}^*(1)$, then the entrant enters the market if $\delta > \bar{\delta}$, such that $F = \pi_{cE}^*(\bar{\delta})$; otherwise (if $\delta \leq \bar{\delta}$), it does not enter the market. Lastly, if $\pi_{cE}^*(1) \leq F$, then the entrant never enters the market. Given this, we see that the incumbent's compatibility decision is the following:

Proposition 6. *When the entrant incurs a fixed cost F , the incumbent's compatibility decision is as follows. If entry costs are low, then the incumbent prefers compatibility*

($\delta = 1$) so that entry occurs and competition is soft: if $F < \pi_{cE}^U(0)$, then the incumbent chooses $\delta = 1$. Under intermediate entry costs, the incumbent prefers incompatibility which deters entry: if $\pi_{cE}^*(0) \leq F < \pi_{cE}^U(1)$, then the incumbent sets $\delta \leq \bar{\delta}$ to deter entry. Lastly, if entry costs are high, then the incumbent's compatibility choice is irrelevant as entry will not occur. In sum, the incumbent deters entry if and only if $F \geq \pi_{cE}^*(0)$.

When the entry cost is moderate, the incumbent can choose partial incompatibility to deter entry because the choice reduces the entrant's entry profit. Thus, unlike in the case of individual compatibility decisions, Propositions 2 and 4, we see that entry can be deterred with imperfect compatibility, opposed to fully siloing.

If we compare the threshold values of F , $\pi_E^U(\delta_E^{Ud}, 0)$, and $\pi_{cE}^U(0)$, in Propositions 2 and 6 we see that $\Delta q \geq \Delta q^d$, $\delta_E^{Ud} = 0$ and then $\pi_E^U(\delta_E^U, 0) = \pi_{cE}^U(0)$. That is, when $\Delta q \geq \Delta q^d$, whether compatibility is selected independently by the entrant and incumbent or by the incumbent at the industry level does not influence firm I 's decision for entry deterrence. When $\Delta q < \Delta q^d$, $\delta_E^{Ud} = 1$ and then we need to compare $\pi_E^U(\delta_E^{Ud}, 0) = \pi_E^U(1, 0)$ with $\pi_{cE}^U(0)$. Because $\pi_{cE}^U(0) = \pi_E^U(0, 0)$, which is lower than $\pi_E^U(1, 0)$, firm E has a higher chance to enter the market if it makes its own independent compatibility choice under the uniform pricing regime.

5.2 Personalized Pricing for the Incumbent

We consider the case where the incumbent is able to use personalized prices to consumers. As in the previous section, we assume that personalized prices are private, secret, and ineffective in influencing the expectations of consumers for the network sizes. Using the demand system in the previous section, we now have:

$$d_I = \frac{1}{2} + \frac{p_E - q_E + q_I}{2(t - \gamma(1 - \delta))}, \quad d_E = \frac{1}{2} + \frac{q_E - q_I - p_E}{2(t - \gamma(1 - \delta))}.$$

The incumbent supplies consumers at $x \in [0, d_I)$, and the entrant supplies at $x \in [d_I, 1]$. The price schedule of the incumbent under p_E is

$$p_I(x) = \begin{cases} t(1 - 2x) + \frac{t(p_E - q_E + q_I)}{t - \gamma(1 - \delta)} & \text{for } x \in [0, d_I), \\ 0 & \text{for } x \in [d_I, 1]. \end{cases}$$

Solving the entrant's profit maximization problem, $\max_{p_E} p_E d_E$, reveals that

$$\begin{aligned} d_{cE}^p &= \frac{1}{4} + \frac{q_E - q_I}{4(t - \gamma(1 - \delta))}, \quad p_{cE}^p = \frac{q_E - q_I + t - \gamma(1 - \delta)}{2}, \\ \pi_{cE}^p(\delta) &= \frac{(q_E - q_I + t - \gamma(1 - \delta))^2}{8(t - \gamma(1 - \delta))}. \end{aligned}$$

This generates the incumbent's equilibrium price schedule and the resulting equilibrium:

$$\begin{aligned} p_{cI}^p(x) &= \begin{cases} 2\left(\frac{3}{4} - x\right)t + \frac{t(q_I - q_E)}{2(t - \gamma(1 - \delta))} & \text{for } x \in [0, d_I^p], \\ 0 & \text{for } x \in [d_I^p, 1], \end{cases} \\ d_{cI}^p &= \frac{3}{4} + \frac{q_I - q_E}{4(t - \gamma(1 - \delta))}, \\ \pi_{cI}^p(\delta) &= \frac{t(q_I - q_E + 3(t - \gamma(1 - \delta)))^2}{16(t - \gamma(1 - \delta))^2} \\ &= \frac{9t}{16} + \frac{t(q_I - q_E)(q_I - q_E + 6(t - \gamma(1 - \delta)))}{16(t - \gamma(1 - \delta))^2}, \\ CS_c^p &= v - t + \frac{\gamma(3 + \delta)}{4} + \frac{q_I + q_E}{2} + \frac{\gamma(1 - \delta)(q_E - q_I)}{4(t - \gamma(1 - \delta))}. \end{aligned}$$

Comparing these results to the case of uniform pricing, we first see that the incumbent (entrant) is better-off (worse-off) when the incumbent uses personalized pricing. In addition, we see that under symmetric quality, $q_E = q_I$, consumers are worse-off with personalized prices unless differentiation is very large or compatibility is high ($t > 3\gamma(1 - \delta)$). These results are not surprising as personalized pricing gives the incumbent an advantage at extracting surplus.

Turning to the compatibility subgame, we obtain the following result for the incumbent's selection of industry-wide compatibility under personalized pricing:

Proposition 7. *The incumbent's optimal compatibility decision is to ensure industry-wide compatibility ($\delta^p = 1$), benefiting the entrant if $\Delta q < \sqrt{t(t - \gamma)}$, otherwise harming it.*

We see that the incumbent faces a tradeoff, much like in the base model, if the entrant has a quality advantage that is not too large. If the entrant has a quality advantage, then the incumbent prefers compatibility because industry-wide compatibility mitigates

price competition, benefiting both firms when the entrant's quality advantage is not significant ($\Delta q < \sqrt{t(t - \gamma)}$). However, the entrant's quality advantage is significant ($\Delta q > \sqrt{t(t - \gamma)}$), the demand loss through compatibility dominates the gain from price increase because per-unit profit is higher as the quality advantage becomes stronger.

Entry deterrence The above compatibility choice can change if we consider the incumbent's incentive to deter entry. Indeed we see that both siloing and partial incompatibility are possible:

Proposition 8. *If the entrant's quality advantage is small, $0 \leq \Delta q \leq t - \gamma$, then the incumbent chooses compatibility if entry costs are low, otherwise siloing occurs and entry is deterred: if $F < \pi_{cE}^p(0)$, then $\delta = 1$, otherwise $\delta = 0$. Similarly, when $t - \gamma < \Delta q < t$, the incumbent chooses compatibility if entry costs are low, otherwise entry is deterred with partial incompatibility: if $F < \pi_{cE}^p(\bar{\delta}^p)$, then $\delta = 1$, otherwise $\delta \leq \bar{\delta}^p$. Lastly, if $t \leq \Delta q$, then the incumbent chooses compatibility ($\delta = 1$) and the entrant does not enter if and only if $F \geq \pi_{cE}^p(1)$.*

If we compare the threshold values of F , $\pi_E^p(0, 0)$, and $\pi_{cE}^p(0)$ from Propositions 4 and 8 we see that the values are the same. That is, $\pi_E^p(0, 0) = \pi_{cE}^p(0)$ so that the mode for how compatibility is set within the industry does not influence firm I 's decision for entry deterrence.

Labor Market As in the previous section, we can add technology specialists to the model who contributes by improving product quality. In contrast with the comparative statics in the case of personalized pricing here, we can numerically show that $q_E^* - q_I^* < 0$ and $\delta = 1$ is optimal for the incumbent if $t = \tau = 1$ and $g < 1$. The incumbent has an incentive to mitigate the labor market competition and compatibility mitigates competition for consumers which weakens the incentives to acquire specialists. Also, under the parametric example, we have that $\partial CS_c^* / \partial \delta > 0$ because the quality difference between the two firms diminishes we see less harmful personalized prices for consumers.

As in Section 4.2, if we consider the labor market under uniform pricing, the quality levels q_I and q_E are the same in equilibrium because of the firm symmetry. Then, firm I choose compatibility in equilibrium.

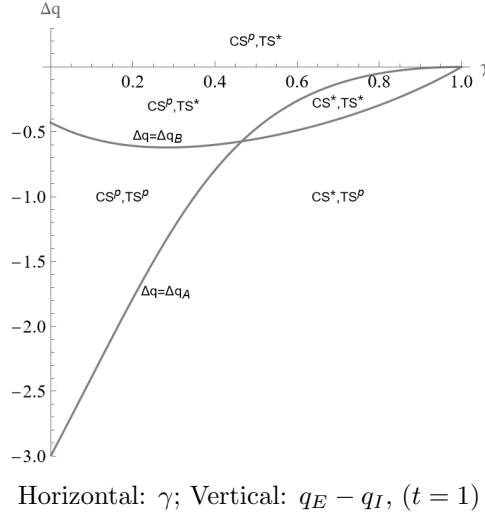
5.3 The Optimal Pricing Regime

Now consider the base model (without the labor market or entry costs), where the incumbent chooses which pricing regime to use when it can subsequently choose the level of common compatibility between the two networks. When the incumbent can choose the common compatibility, it always choose personalized pricing because it can always choose the more profitable compatibility choice under each of both pricing regimes. Thus, the competitive advantage through personalized pricing always prevails.

Proposition 9. *If the incumbent chooses the degree of common compatibility between the two networks, then the incumbent always chooses personalized pricing.*

For a social planner interested in total surplus or consumer surplus, we compare the consumers surpluses and total surpluses in the two pricing regimes when $\Delta q \geq 0$, $CS_c^p(1) - CS_c^*(1)$ and $TS_c^p(1) - TS_c^*(1)$.

Figure 4: Surplus comparisons



We find that the consumer surplus under personalized pricing is higher than under uniform pricing if and only if $\Delta q > 3(3\gamma t - \sqrt{t(4t^3 - 12\gamma t^2 + 21\gamma^2 t - 4\gamma^3)})/(2(t - \gamma)) \equiv \Delta q_A$. Also, the total surplus under uniform pricing is higher if $\Delta q > (t - \gamma)(9t^2 - 6\sqrt{2t(2t^3 + 8\gamma t^2 + 14\gamma^2 t - 15\gamma^3)})/(7t^2 + 22\gamma t - 20\gamma^2) \equiv \Delta q_B$ (see Figure 4).

6 Conclusion

As technology improves, competing firms are increasingly able to implement advanced strategies to give them an edge up against the competition. We consider the connection between pricing regimes, compatibility choice, and entry deterrence when two horizontally and vertically differentiated firms compete in a market with direct network effects. Our work reveals that an incumbent can use both pricing and compatibility strategies to deter entry and that the interplay between these decisions is nontrivial and often misaligned across agents with both siloing or full compatibility existing as optimal outcomes. This makes policy recommendations difficult but one overarching result is that allowing the incumbent to choose its pricing regime and have unilateral power over the industry-wide compatibility level is often suboptimal for the entrant, consumers, and total surplus. Thus, our work suggests that all agents, consumers and competing firms, should have a say in the compatibility decisions made within industries and that outright bans or mandates may not be helpful.

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Appendix of Proofs

Proof of Lemma 1: The first-order conditions lead to the reaction functions:

$$\begin{aligned}\frac{\partial \pi_I}{\partial p_I} &= \frac{t - \gamma(1 - \delta_E) - q_E + q_I + p_E - 2p_I}{2t - \gamma(2 - \delta_E - \delta_I)} = 0 \\ \Rightarrow p_I(p_E) &= \frac{t - \gamma(1 - \delta_E) - (q_E - q_I) + p_E}{2}, \\ \frac{\partial \pi_E}{\partial p_E} &= \frac{t - \gamma(1 - \delta_I) + q_E - q_I + p_I - 2p_E}{2t - \gamma(2 - \delta_E - \delta_I)} = 0 \\ \Rightarrow p_E(p_I) &= \frac{t - \gamma(1 - \delta_I) + (q_E - q_I) + p_I}{2}.\end{aligned}$$

The reaction functions imply that choosing compatibility shifts the rival's reaction function upward, allowing the choosing firm to set a higher price. The reaction functions lead to $(j, k = I, E, j \neq k)$:

$$\begin{aligned}p_j(\delta_j, \delta_k) &= t - \gamma + \frac{(q_j - q_k) + \gamma(\delta_j + 2\delta_k)}{3}, \quad d_j(\delta_j, \delta_k) = \frac{3t - \gamma(3 - 2\delta_k - \delta_j) + (q_j - q_k)}{6t - 3\gamma(2 - \delta_E - \delta_I)}, \\ \pi_j(\delta_j, \delta_k) &= \frac{(3t - \gamma(3 - 2\delta_k - \delta_j) + (q_j - q_k))^2}{9(2t - \gamma(2 - \delta_E - \delta_I))}, \\ CS(\delta_E, \delta_I) &= v - \frac{(5t - 2\gamma(2 - \delta_E - \delta_I))K}{18(2t - \gamma(2 - \delta_E - \delta_I))^2},\end{aligned}$$

where $K \equiv (3t - \gamma(3 - 2\delta_E - \delta_I) - (q_E - q_I))^2 + (3t - \gamma(3 - \delta_E - 2\delta_I) + (q_E - q_I))^2$. \square

Proof of Proposition 1: Differentiating the profit functions from Lemma 1 implies that (1) $\partial \pi_I^*(\delta_I, \delta_E)/\partial \delta_I > 0$, (2) $\partial^2 \pi_j^*(\delta_j, \delta_k)/\partial \delta_j^2 > 0$ ($j = E, I$), and (3)

$$\frac{\partial \pi_E^*(\delta_E, \delta_I)}{\partial \delta_E} = \frac{\gamma(t - \gamma(1 - \delta_E) - (q_E - q_I))(3t - \gamma(3 - \delta_E - 2\delta_I) + (q_E - q_I))}{9(2t - \gamma(2 - \delta_E - \delta_I))^2}.$$

Note that (1) and (2) imply that $\delta_I^U = 1$. In addition, (2) and (3) imply that $\delta_E = 0$ or $\delta_E = 1$ is optimal. Given that $\delta_I = 1$, $\pi_E^*|_{\delta_E=1} > \pi_E^*|_{\delta_E=0}$ if and only if $q_E - q_I < \sqrt{2t(2t - \gamma)} - t$. \square

Proof of Proposition 2: Note that $\partial \pi_E^*(\delta_E, \delta_I)/\partial \delta_I > 0$ regardless of δ_E and δ_I . Therefore, firm I will choose $\delta_I = 0$ if its objective is to successfully deter entry. If $\delta_I = 0$, then we derive the optimal δ_E for firm E by noting that $\pi_E^*(1, 0) > \pi_E^*(0, 0)$ if

and only if

$$\Delta q < \frac{2(3t - 2\gamma)\sqrt{t - \gamma} - 3(t - \gamma)\sqrt{2(2t - \gamma)}}{\sqrt{2(2t - \gamma)} - 2\sqrt{t - \gamma}} \equiv \Delta q^d.$$

That is, $\Delta q^d < \sqrt{2t(2t - \gamma)} - t$ which is the threshold value in Proposition 1. Those inequalities imply that firm E is less likely to choose compatibility ($\delta_E = 1$) if firm I chooses $\delta_I = 0$. We use δ_E^{*d} to express firm E 's choice that depends on Δq . We consider the entry decision across the two possible cases. First, if $F < \pi_E^*(\delta_E^{*d}, 0)$, then the entrant always enters the market. Second, if $\pi_E^*(\delta_E^{*d}, 0) \leq F$, the incumbent can deter entry by choosing $\delta_I = 0$. \square

Proof of Proposition 2: Anticipating the personalized prices, the entrant solves the profit maximization problem, $\max_{p_E} p_E d_E$, which leads to:

$$p_E^p = \frac{q_E - q_I + t - \gamma(1 - \delta_I)}{2}, \quad d_E^p = \frac{q_E - q_I + t - \gamma(1 - \delta_I)}{2(2t - \gamma(2 - \delta_E - \delta_I))},$$

$$\pi_E^p(\delta_E, \delta_I) = \frac{(q_E - q_I + t - \gamma(1 - \delta_I))^2}{4(2t - \gamma(2 - \delta_E - \delta_I))}.$$

This generates the incumbent's equilibrium price schedule and the resulting equilibrium:

$$p_I^p(x) = \begin{cases} (1 - 2x)t + \frac{\{t - \gamma(1 - \delta_I) - (q_E - q_I)\}t}{2t - \gamma(2 - \delta_E - \delta_I)} & \text{for } x \in [0, d_I^p], \\ 0 & \text{for } x \in [d_I^p, 1], \end{cases}$$

$$d_I^p = \frac{3}{4} + \frac{2(q_I - q_E) + \gamma(\delta_E - \delta_I)}{4(2t - \gamma(2 - \delta_E - \delta_I))},$$

$$\pi_I^p(\delta_I, \delta_E) = \frac{t(q_I - q_E + 3t - \gamma(3 - 2\delta_E - \delta_I))^2}{4(2t - \gamma(2 - \delta_E - \delta_I))^2}$$

$$= \frac{9t}{16} + \frac{t(2(q_I - q_E) + \gamma(\delta_E - \delta_I))(2(q_I - q_E) + 12t - \gamma(12 - 7\delta_E - 5\delta_I))}{16(2t - \gamma(2 - \delta_E - \delta_I))^2},$$

$$CS^p(\delta_E, \delta_I) = v - \frac{3t(q_I - q_E + 3t - \gamma(3 - 2\delta_E - \delta_I))^2}{8(2t - \gamma(2 - \delta_E - \delta_I))^2}$$

$$- \frac{(q_E - q_I + t - \gamma(1 - \delta_I))^2(5t - 2\gamma(2 - \delta_E - \delta_I))}{8(2t - \gamma(2 - \delta_E - \delta_I))}.$$

\square

Proof of Proposition 3: To determine the effect of compatibility, we derive the fol-

lowing partial derivatives:

$$\begin{aligned}\frac{\partial \pi_E^p}{\partial \delta_E} &= -\frac{\gamma(q_E - q_I + t - \gamma(1 - \delta_I))^2}{4(2t - \gamma(2 - \delta_E - \delta_I))^2} < 0, \\ \frac{\partial \pi_I^p}{\partial \delta_I} &= \frac{t\gamma(q_E - q_I - t + \gamma - \gamma\delta_E)(q_I - q_E + 3t - \gamma(3 - 2\delta_E - \delta_I))}{4(2t - \gamma(2 - \delta_E - \delta_I))^3}.\end{aligned}$$

Note that $q_E - q_I + t - \gamma(1 - \delta_I) > 0$ and $q_I - q_E + 3t - \gamma(3 - 2\delta_E - \delta_I) > 0$ whenever the outcome is an interior solution so that we have $\delta_E^p = 0$ since $\frac{\partial \pi_E^p}{\partial \delta_E} < 0$. Given this result, $\frac{\partial \pi_I^p}{\partial \delta_I}$ generates two cases: it is always non-negative if $t - \gamma \leq q_E - q_I$ or it is always negative if $q_E - q_I < t - \gamma$. Therefore, $\delta_I^p = 1$ if and only if $t - \gamma \leq q_E - q_I$. Note that if $q_E - q_I = t - \gamma$ and $\delta_E^p = 0$, then $d_E^p = d_I^p = 1/2$. So, if the demand for the incumbent is smaller than that for the entrant, the incumbent chooses compatibility $\delta_I^p = 1$. \square

Proof of Proposition 5: Comparative statics reveal that $\partial \pi_{c_j}^*(\delta)/\partial \delta > 0$, $\partial^2 \pi_{c_j}^*(\delta)/\partial \delta^2 > 0$, $\partial p_{c_j}^*/\partial \delta > 0$ for $j = I, E$. Thus, the incumbent selects $\delta^U = 1$. \square

Proof of Proposition 7: To determine the compatibility decision, we partially differentiate π_{cI}^p , π_{cE}^p , and CS_c^p with respect to δ and obtain the following:

1. If $q_E - q_I \equiv \Delta q < 0$, then $\frac{\partial \pi_{cE}^p}{\partial \delta} > 0$, $\frac{\partial \pi_{cI}^p}{\partial \delta} < 0$, and $\frac{\partial CS_c^p}{\partial \delta} > 0$,
2. If $0 \leq \Delta q < \frac{(t - \gamma(1 - \delta))^2}{t}$, then $\frac{\partial \pi_{cE}^p}{\partial \delta} > 0$, $\frac{\partial \pi_{cI}^p}{\partial \delta} \geq 0$, and $\frac{\partial CS_c^p}{\partial \delta} > 0$,
3. If $\frac{(t - \gamma(1 - \delta))^2}{t} \leq \Delta q < t - \gamma(1 - \delta)$, then $\frac{\partial \pi_{cE}^p}{\partial \delta} > 0$, $\frac{\partial \pi_{cI}^p}{\partial \delta} \geq 0$, and $\frac{\partial CS_c^p}{\partial \delta} < 0$,
4. If $t - \gamma(1 - \delta) \leq \Delta q$, then $\frac{\partial \pi_{cE}^p}{\partial \delta} \leq 0$, $\frac{\partial \pi_{cI}^p}{\partial \delta} > 0$, and $\frac{\partial CS_c^p}{\partial \delta} < 0$.

The comparative statics reveal three important cases. First, if the incumbent has a quality advantage, then compatibility helps the disadvantaged entrant at the expense of the incumbent. As a result, the incumbent prefers siloing in this case. Second, if the entrant has a slight quality advantage, then both the incumbent's and entrant's profits improve from compatibility. This case is much like the case of uniform pricing. Third, if the entrant has a substantial quality advantage, then greater compatibility aids the incumbent's profit at the expense of the entrant. We check the profits of the entrant under the two cases: $\delta = 0$ and $\delta = 1$. The difference between $\pi_{cE}^p(0)$ and $\pi_{cE}^p(1)$ is positive if and only if $\Delta q > \sqrt{t(t - \gamma)}$. \square