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Acquisitions, Entry and Innovation in Network Industries

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Abstract

Why do so many high-priced acquisitions of entrepreneurial firms take place in network industries? We develop a theory of commercialization (entry or sale) in network industries showing that high equilibrium acquisition prices are driven by the incumbents' desire to prevent rivals from acquiring innovative entrepreneurial firms. This preemptive motive becomes more important when there is an increase in network effects. A consequence is higher innovation incentives under an acquisition relative to entry. A policy enforcing strict compatibility leads to more entry, but can be counterproductive by reducing bidding competition, thereby also reducing acquisition prices and innovation incentives.

Keywords: Acquisitions; commercialization; compatibility; entry; network effects; innovation; R&D; regulation.

JEL classification: L10; L15; L26; L50; L86; O31.

"Companies like Cisco, Intel and Microsoft recognize the threat posed by nimble young firms getting technologies to market at unimaginable speeds," says Red Herring's Brian Taptich. "And they're willing to pay extremely high premiums to protect their franchises."

-Economist (1999)

1 Introduction

In the last decade, several acquisitions of entrepreneurial firms at high prices have taken place in industries with network effects. Table 1 lists the ten largest majority acquisitions completed by Google, eBay, or Yahoo, where the target was founded later than 2000. A striking example is eBay's acquisition of Skype Technologies at $3.8 billion in 2005, only two years after it was founded by the entrepreneurs Janus Friis and Niklas Zennström.

Target	Founded	Acquired	Acquirer	Price
Skype Technologies	2003	2005	eBay	$3866 million
YouTube	2005	2006	Google	$1539 million
dMarc Broadcasting	2002	2006	Google	$1238 million
AdMob	2006	2009	Google	$750 million
Right Media	2003	2007	Yahoo!	$679 million
StubHub	2001	2007	Yahoo!	$310 million
Zimbra	2003	2007	Yahoo!	$300 million
BlueLithium	2004	2007	Yahoo!	$252 million
EachNet	2000	2003	eBay	$150 million
Maven Networks	2002	2008	Yahoo!	$141 million

Table 1: The 10 largest majority acquisitions completed by Google, eBay, or Yahoo! before 2008 where the target was founded later than 2000. Source: Capital IQ.

But what can explain the prevalence of acquisitions of entrepreneurial firms at high prices in network industries? How do they affect the innovation incentives for entrepreneurial firms? And should compatibility policy account for the market for entrepreneurial firms?

To address these issues, we develop a theory of commercialization and innovation in industries with network effects. Central to our theory is that (i) the commercialization mode of the entrepreneurial firm (entry or sale) does not only depend on the profitability of entry, but also on externalities associated with ownership of an innovation developed by the entrepreneurial firm, and (ii) the value of gaining a competitive advantage in the industry depends on the strength of networks effects.

We show that high equilibrium acquisition prices are driven by a desire to prevent rivals from obtaining innovations. Network effects amplify the preemptive motive for acquisitions, thereby leading to higher acquisition prices and innovation incentives for entrepreneurial firms, but to less entry. The intuition is as follows. The value of acquiring an entrepreneurial firm for an incumbent increases in network effects both because acquiring the firm gives the acquirer a lead over rivals, and because not acquiring it reduces the profits as rivals gain a lead. When the network effects increase, both reasons for acquiring an entrepreneurial firm become more important and the acquisition prices increase. Furthermore, the equilibrium acquisition price increases more than the entry valuation, thus making the entrepreneurial firm prefer being

acquired instead of entering the industry.

The business press contains numerous accounts of the mechanism we describe. One example is Apple's acquisition of the music site Lala.com. BusinessWeek (2010) described the acquisition as follows:

> "Late last year, Apple entered the bidding for the online music site Lala.com, after Google and several other potential acquirers had gotten involved. The company moved unusually quickly, closing the deal in a few weeks, rather than the more typical two to three months. It was clear that Apple didn't want to lose out again, and especially not to Google".

The possibility of being acquired in a bidding contest between incumbents can act as a strong incentive for innovation. As network effects amplify the acquisition price more than the profits from entering, acquisitions can be particularly important for innovation incentives in network industries.

This has implications for compatibility policy. One example where the competition authorities explicitly required compatibility to facilitate entry into an industry was the Cisco-Tandberg merger approved by the European Commission in 2010. Cisco is a company that provides networking equipment, data centers, and video conferencing solutions while Tandberg was a vendor of video conferencing products. The merger was approved on the condition that Cisco divested its protocol for video conferencing. The intention of the European Commission was explicitly to increase compatibility to facilitate market entry.[1] This is in line with a general understanding in the literature on network effects that mandating compatibility is desirable. As argued by Farrell and Klemperer (2007) in their survey of the literature on network effects: "inefficient incompatible competition is often more profitable than compatible competition, especially for dominant firms with installed-base or expectation advantages. Thus firms probably seek incompatibility too often. We therefore favor thoughtfully pro-compatibility public policy".

Accounting for the market for entrepreneurial firms, however, shows that too much compatibility can be counterproductive by reducing acquisition prices and innovation incentives. Increasing the degree of compatibility makes products more similar in the eyes of consumers as less emphasis is put on network size. An increase in compatibility benefits non-acquirers as they benefit from the acquiring incumbent's network. The acquiring incumbent, on the other hand, receives a smaller benefit since non-acquirers have smaller sales. Consequently, the equilibrium acquisition price is reduced since increased compatibility reduces the profit of the acquirer as well as increases the profits of non-acquirers. This, in turn, reduces the innovation incentives.

At the same time, however, increased compatibility still increases the amount of entry, despite reducing the entry profits. The reason is that the acquisition price will decrease even more in compatibility than entry profits, since increased compatibility does not only reduce the acquirer's profit but also increases the non-acquirers' profit.

While this points out a potential drawback of too much compatibility, we also show that compatibility can be an important tool for promoting entry and ensuring bidding competition

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[1]The European Commission noted that the "structural remedy facilitates market entry or expansion irrespective of where the competitor or its target customers are located". Source: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/377.

for entrepreneurial firms in the long run: a cost of monopolization is a reduction in innovation incentives because of a lack of bidding competition for innovative entrepreneurial firms. This suggests that mandating a too strict or too weak compatibility policy when an active market for entrepreneurial firms exists could be counterproductive.

We have outlined the paper as follows. In the next section, we relate our paper to the literature. We set up our model in Section 3 and Section 4 contains our main analysis: strong network effects favor acquisitions over entry (Subsection 4.1) and lead to high acquisition prices (subsection 4.2) and to acquisitions promoting innovation incentives (subsection 4.3). In Section 5, we extend our model to consider the optimal compatibility policy in the presence of acquisitions and argue that too strict or too weak a compatibility policy can harm the innovation incentives. We provide a discussion of extensions in Section 6 and conclude in Section 7.

2   Relation to the literature

Our paper contributes to the literature on network effects (see Economides (1996) or Farrell and Klemperer (2007) for an overview) by developing a model of competition in network industries that allows for innovation efforts by an independent entrepreneurial firm and that endogenously determines whether an acquisition of the entrepreneurial firm or entry into the industry takes place. In essence, our theory combines elements from the literature on network effects with the literature on commercialization routes of innovations by outside entrepreneurs.

In the literature on network effects, papers such as Farrell and Saloner (1985), Farrell and Saloner (1986), Katz and Shapiro (1992) and Church and Gandal (1996) have studied how expectations and installed bases can lead to too fast or too slow movement to a new technology. In particular, installed bases could work as an entry barrier to new technologies, thereby delaying a shift to a superior standard. Our setting is separate from these papers by allowing incumbents to acquire the entrepreneurial firm as a way of deterring entry. We also allow the entrepreneurial firm to innovate prior to entry. This makes it possible for us to show that increased network effects can lead to less entry but more acquisitions of entrepreneurial firms and that this, in turn, can stimulate the entry of new technologies by increasing the reward to innovating for entrepreneurial firms.[2]

Our paper is also closely related to the literature on R&D incentives and compatibility policy in network industries. In particular, our paper relates to Kristiansen (1998) and Cabral and Salant (2010), which both provide mechanisms for why compatibility can reduce innovation incentives. Kristiansen (1998) studies R&D rivalry between firms and finds that network effects can cause firms to introduce incompatible technologies too early. Firms can mutually agree on compatibility to reduce the incentives to introduce technologies too early. Cabral and Salant (2010) study evolving technologies and standards and point out that only having one standard can lead to a free-riding problem in R&D: one firm developing for the standard also benefits

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[2]From a formal perspective, our model is related to Cremer et al. (2000) and Malueg and Schwartz (2006) who study asymmetries in the Katz and Shapiro (1985) model in terms of installed base. The asymmetry on which we focus is a process improvement developed by an entrepreneurial firm leading to lower marginal costs for the possessor of the innovation. However, one could equally well view our innovation as providing a quality improvement or in a fixed way shifting expectations the same way as would an exogenous installed base of consumers (as the installed base works in Cremer et al. (2000) and Malueg and Schwartz (2006)).

other firms with the same standard. Having two competing standards (less compatibility) improves the innovation incentives because now firms with different standards compete with each other in terms of R&D. We differ by focusing on how compatibility affects the innovation incentives for entrepreneurial firms. In our setting, compatibility reduces innovation incentives by reducing the equilibrium acquisition price and thus, the reward for innovating. Thereby, we can derive predictions on how compatibility does not only affect innovation incentives, but also how innovations are commercialized.

The literature on the commercialization of innovations has shown that commercialization by sale (or by licensing) is more likely when entry costs are high, the entrepreneurial firm lacks complementary assets, brokers facilitating trade are available, the expropriation problem associated with asset transfers is low, and the intensity of product market competition is high (Anton and Yao (1994), Gans and Stern (2000), Gans and Stern (2003), Gans et al. (2002), and Norbäck and Persson (2009)). We add to this literature by examining how network effects and compatibility affect the commercialization route and equilibrium acquisition prices. This allows us to gain a better understanding of how market-specific characteristics such as network effects affect the commercialization mode and also allows us to study how compatibility policy in an industry can affect the commercialization route of innovations.

3   A model of acquisitions, entry and innovation in network industries

We analyze a model of acquisitions, entry and innovation in an oligopoly market characterized by network effects. The structure of the game is illustrated in Figure 1. In stage one, an entrepreneurial firm undertakes an effort to discover an innovation. In stage two, the entrepreneurial firm decides whether to enter the market or put itself up for sale through an auction where n symmetric incumbents are the bidders. There could then be exits of incumbent firms. In stage three, product market competition takes place between the firms in the network industry, one of which has the innovation. The game is solved in a standard fashion though backward induction.

3.1   Stage 3: product market competition

The final stage of the game is the product market competition stage where firms compete in oligopoly. Consumers make their purchase decisions based on the expected sizes of each firm's network (number of consumers). Define the strength of the network effect as $z \in [0,1]$, where $z = 0$ corresponds to no network effects. One firm owns an innovation of quality $k \in R^+$. The innovation was developed by the entrepreneurial firm in stage one, and the owner is now either the entrant or an incumbent that acquired the entrepreneurial firm in stage two.

Firm j chooses an action x_j to maximize $\pi_j(x_j, x_{-j}, l, k, z) - \tau$, which depends on its own action x_j, its rivals' actions x_{-j}, the owner of the innovation, l, the quality of the innovation, k, network effects, z and an operating fixed cost, τ.

We make the assumption that given the expectations of network sizes, there exists a unique Nash equilibrium in actions: $\mathbf{x}^*(l, k, z) = \{x_j^*(l, k, z), x_{-j}^*(l, k, z)\}$. The reduced-form prod-

1. Innovation: The entrepreneurial firm chooses innovation effort ρ

(ρ increases the probability of discovering an innovation of quality k.)

Success

Failure

2. Commercialization:
Acquisition/entry and exit game

Acquisition by an incumbent firm $i \in \mathcal{I}$

Entry by the entrepreneurial firm e

Potential exits by non-acquiring incumbents

$-i \in \mathcal{I}$

$i \in \mathcal{I}$

Potential exits by non-acquiring incumbents

$l = i$

$l = e$

$l = 0$

3. Product market interaction:
Oligopoly

$$x_A(i,k,z) \qquad x_E(e,k,z) \qquad x_N(0,z)$$
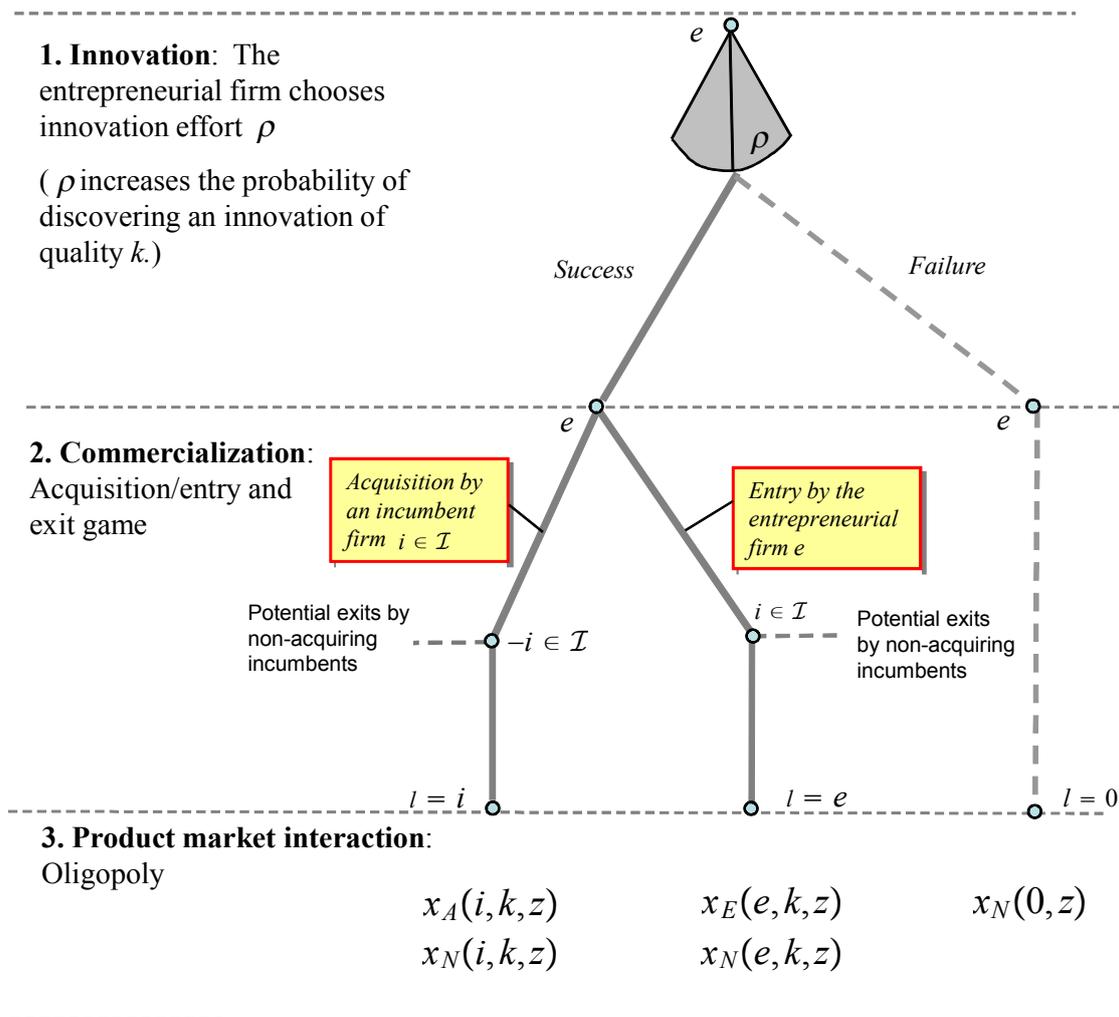$$x_N(i,k,z) \qquad x_N(e,k,z)$$

Figure 1: The timing of the game.

uct market profit function for firm j can then be defined as $\pi_j(l) - \tau = \pi_j(l, k, z) - \tau = \pi_j(\mathbf{x}^*(l, k, z), l, k, z) - \tau$. As incumbent firms are symmetric, we only need to keep track of two types of ownership: entry into the market ($l = e$) and sale to an incumbent ($l = i$). There are then three types of firms, the entering entrepreneurial firm ($h = E$), the acquiring incumbent ($h = A$) and non-acquiring incumbents ($h = N$), with reduced form profit functions $\pi_A(i) - \tau$, $\pi_E(e) - \tau$ and $\pi_N(l) - \tau$. For future reference, denote the profits of an incumbent firm if the entrepreneurial firm did not manage to discover the innovation for each of the n incumbent firms in the market as $\pi_N(0) - \tau = \pi_N(\mathbf{x}^*(0, z), z) - \tau$.

Define the quality of the innovation by its effect on reduced-form profits.

Definition 1 $d\pi_A(i)/dk > 0$, $d\pi_E(e)/dk > 0$, and $d\pi_N(l)/dk < 0$.

Our focus is on high-quality innovations. A central assumption of our model is that the reduced-form profit for the possessor of an innovation is strictly increasing in the strength of the network effects, while increased network effects strictly decrease the rivals' profits.

Assumption 1 *The quality of the innovation k is sufficiently high for stronger network effects to create an advantage of possessing the innovation: $k > \widetilde{k}$ such that $d\pi_A(i)/dz > 0$, $d\pi_E(e)/dz > 0$, and $d\pi_N(l)/dz < 0$.*

This assumption captures an important dynamic in network industries: getting a lead on rivals in terms of quality is more important when network effects are strong. We are not the first to make this claim. Liebowitz and Margolis (2001) argue that quality largely explains success in software markets, which suggests that higher quality attracts more users and that the effect on market share and profits is then larger the stronger are the network effects. Farrell and Katz (1998) argue that network effects amplify the advantage of owning an innovation if expectations of network sizes track quality, or if consumers have rational expectations and the innovation gives the acquirer a higher quality product. Empirical evidence is also available: Tellis et al. (2009) show that the presence of network effects enhances the effect of quality on market share using data from 19 markets with network effects.

To further support Assumption 1, let us now show that this assumption holds when the quality of the innovation k is sufficiently high in the linear Cournot model with network effects outlined in Katz and Shapiro (1985).

3.1.1   The linear Cournot model

Suppose that firms compete in a homogenous goods Cournot industry. First, consumers make their purchase decisions based on the expected size of each firm's network. Second, firms set the quantities to produce, taking consumers' expectations as given. Following Katz and Shapiro (1985), we focus on a Fulfilled Expectations Cournot equilibrium where consumers' expected size of the networks corresponds to firms' optimal output decisions.

Formally, let $\bar{q}_j$ denote the expected size of firm j's network and let $\bar{q}_{-j}$ be the combined expected size of firm j's competitors' networks. Denote total aggregate output as $Q = \sum_j q_j$. Then, firm j faces a price of

$$P_j = a + z\bar{q}_j - Q \tag{1}$$

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where once more the strength of the network effects is given by $z \in [0, 1]$.

Firms maximize profits $\pi_j - \tau = (P_j - \delta_j)q_j - \tau$, where δ_j is firm j's marginal costs. The firm possessing the innovation (an incumbent or the entrepreneurial firm) is assumed to have a marginal cost of $\delta_j = \delta - k$, whereas all other firms have marginal costs equal to $\delta_j = \delta$. Taking consumers' expectations $\bar{q}_j$ as given, firms' optimal outputs are given from the first-order conditions

$$\frac{\partial \pi_j}{\partial q_j} = P_j - \delta_j - q_j^* = 0, \forall j. \tag{2}$$

Solving for Nash-outputs we obtain $q_j(l, \bar{q}_j, \bar{q}_{-j})$. Assuming that consumers' expectations are correct, $q_j = \bar{q}_j$ and $\bar{q}_{-j} = \bar{q}_{-j}$, equation (1) and equation (2) can be used to solve for Cournot outputs consistent with fulfilled consumer expectations (omitting k and z for brevity): $q^*(l) = \{q_j^*(l), q_{-j}^*(l)\}$. From equation (2), the reduced-form profit function for firm j is then $\pi_j(l) - \tau = [P_j(l) - \delta_j] q_j^*(l) - \tau = [q_j^*(l)]^2 - \tau$.

We can now study how the reduced form profit functions of the different firm types $\pi_A(i)$, $\pi_E(e)$ and $\pi_N(l)$ respond to changes in z. We have the following lemma:

Lemma 1 *In the linear Cournot model with fulfilled consumer expectations, when the quality of the innovation is sufficiently high, $k > \widetilde{k}$, stronger network effects increase the profit when possessing the innovation while decreasing the profit of non-acquiring incumbents: $d\pi_A(i)/dz > 0$, $d\pi_E(e)/dz > 0$, and $d\pi_N(l)/dz < 0$.*

Proof. See Appendix A. ∎

To see the intuition, differentiate $\pi_h(l)$ with respect to z to obtain.

$$\frac{d\pi_h(l)}{dz} = \left[\underbrace{q_h^*(l)}_{\text{Direct effect}} - \underbrace{\frac{dq_{-h}^*(i)}{dz}}_{\text{Strategic effect}} \right] q_h^*(l). \tag{3}$$

The first term within the bracket, $\frac{\partial P_h(l)}{\partial z} = q_h^*(l)$, represents a direct price effect which is positive since consumers' willingness to pay increases at stronger network effects. The second term within the bracket $-\frac{dq_{-h}^*(l)}{dz} = \frac{dP_h(l)}{dq_{-h}} \frac{dq_{-h}^*(l)}{dz}$ represents the strategic price effect arising from the change in price from the induced change in the output of competitors from stronger network effects. The sum of the direct and strategic price effect times a firm's output determines the total effect in equation 3.

With symmetric firms, it is easily shown that the direct effect of stronger consumer willingness to pay will always dominate, and firms' profits will increase under stronger network effects. The possession of the innovation, however, introduces an asymmetry between firms, which benefits the possessor at the expense of a non-possessor.

To see this, consider Figure 2 (i) and assume that we have a duopoly. In the benchmark equilibrium D^0, network effects are absent $z = 0$ and the innovation quality is set to zero $k = 0$. Firms have identical sales $q_h^0 = q_h^0$, where q_h^0 is the output for the possessor of the innovation $h = \{E, A\}$ (the entrepreneurial firm or an acquiring incumbent) and q_N^0 is the output for the non-acquiring incumbent. Since an innovation with positive quality $k > 0$ reduces the marginal cost for the possessor, this firm can credibly commit to a higher output, shifting up its reaction

function from $R_h^0(q_N)$ to $R_h(q_N)$ along the reaction function of the non-acquirer $R_N(q_N)$. The equilibrium shifts from the symmetric equilibrium D^0 to the asymmetric equilibrium D. In D, the possessor produces a higher output than the non-acquiring incumbent, $q_h^D(l) > q_N^D(l)$.

Figure 2 (ii) depicts how firms change their equilibrium sales. Adding network effects $z > 0$ shifts out firms' reaction functions: at a given output of the competitor, firms are willing to sell more when the consumers' willingness to pay increases. But firms also become more sensitive to changes in the competitor's output: the reaction function of the non-acquirer becomes flatter, while the reaction function of the possessor becomes steeper. This mirrors the fact that consumers are more attracted to a network with a larger number of expected customers (larger expected sales), and expansion by the competitor is met by a larger reduction in own output to mitigate a fall in the firm's product price. When the innovation is of sufficiently high quality, this will give the possessor of the innovation a competitive edge since consumers will prefer the low-cost firm with a larger customer base. Comparing the Nash-equilibrium with network effects in point D^* with that without network effects in D, we see that the output of the possessor will increase in the presence of network effects, while the output of the non-acquiring incumbent will decrease. This illustrates how the non-acquiring incumbent could face a negative strategic effect in equation (3) (since the possessor expands, $-\frac{dq_{-N}^*(l)}{dz} < 0$), while the possessor (the entrepreneurial firm or an acquiring incumbent) faces a positive strategic effect in equation (3), (since the non-acquirer reduces its output, $-\frac{dq_{-A}^*(l)}{dz} > 0$).

In the Appendix, we show that the direct effect always dominates the strategic effect for the possessor, $\frac{d\pi_h(l)}{dz} > 0$ for $h = \{A, E\}$. The opposite, $\frac{d\pi_N(l)}{dz} < 0$, holds for a non-acquiring incumbent, if the combination of innovation quality and network strength is sufficiently high. The latter is shown in Figure 3, once more using the duopoly case. The downward sloping locus $\hat{z}(k)$ depicts combinations of the size of the innovation (k) and network effects (z) where $\frac{d\pi_N(l)}{dz} = 0$. Above (below) this locus, the non-acquirer's profit decreases (increases) in network strength. At some $\widetilde{k}(l) = 0$, we have $\frac{d\pi_N(l)}{dz} = 0$ and thus $\frac{d\pi_N(l)}{dz} < 0$ holds for $\widetilde{k}(l) > 0$ and $z \in [0, z^{\max}(\widetilde{k}(l))]$, where $z^{\max}(\widetilde{k}(l))$ is the highest network strength consistent with positive profits of a non-acquiring incumbent.

3.2 Stage 2: the commercialization mode (entry/sale)

Consider now stage 2 in Figure 1. If the entrepreneurial firm fails in coming up with an innovation, the market is entry stable with profits of incumbents exceeding fixed operating costs while entrants cannot cover the entry cost F (so we have $\pi_N(0) - \tau > 0$ for all n firms in the market). Given a successful innovation, however, there is *first* an entry-acquisition game where the entrepreneurial firm can decide either to sell the innovation to one of the incumbents or enter the market at a fixed cost, F. Given the mode of commercialization of a successful innovation, non-acquiring incumbents potentially *then* exit the market.

The firm in possession of the innovation is assumed to always make positive profits. Let $\underline{k}$ be defined from $\pi_E(e) - \tau = F$. We assume the quality of the innovation k to be sufficiently large $k > \underline{k}$, so that $\pi_A(l) - \tau > 0$ and $\pi_E(e) - \tau - F > 0$ hold. Let $n(l)$ be the number of incumbent firms. Non-acquiring incumbents will exit until the total number of firms on the

(i) The Nash-equilibrium:

(adding the innovation without network effects)

$\mathcal{R}_N = \Lambda - 2q_N$

45°

q_h^D

D

q_h^0

D^0

$\mathcal{R}_h = \frac{\Lambda+k}{2} - \frac{1}{2}q_N$

q_N^D q_N^0

$\mathcal{R}_h^0 = \frac{\Lambda}{2} - \frac{1}{2}q_N$

(ii) The Nash-equilibrium:

(adding network effects)

D^*

45°

q_h^*

$\mathcal{R}_N = \Lambda - (2-z)q_N$

q_h^D

D

$\mathcal{R}_h = \frac{\Lambda+k}{2-z} - \frac{1}{2-z}q_N$

D^0

q_N^* q_N^D

$\mathcal{R}_N = \Lambda - 2q_N$

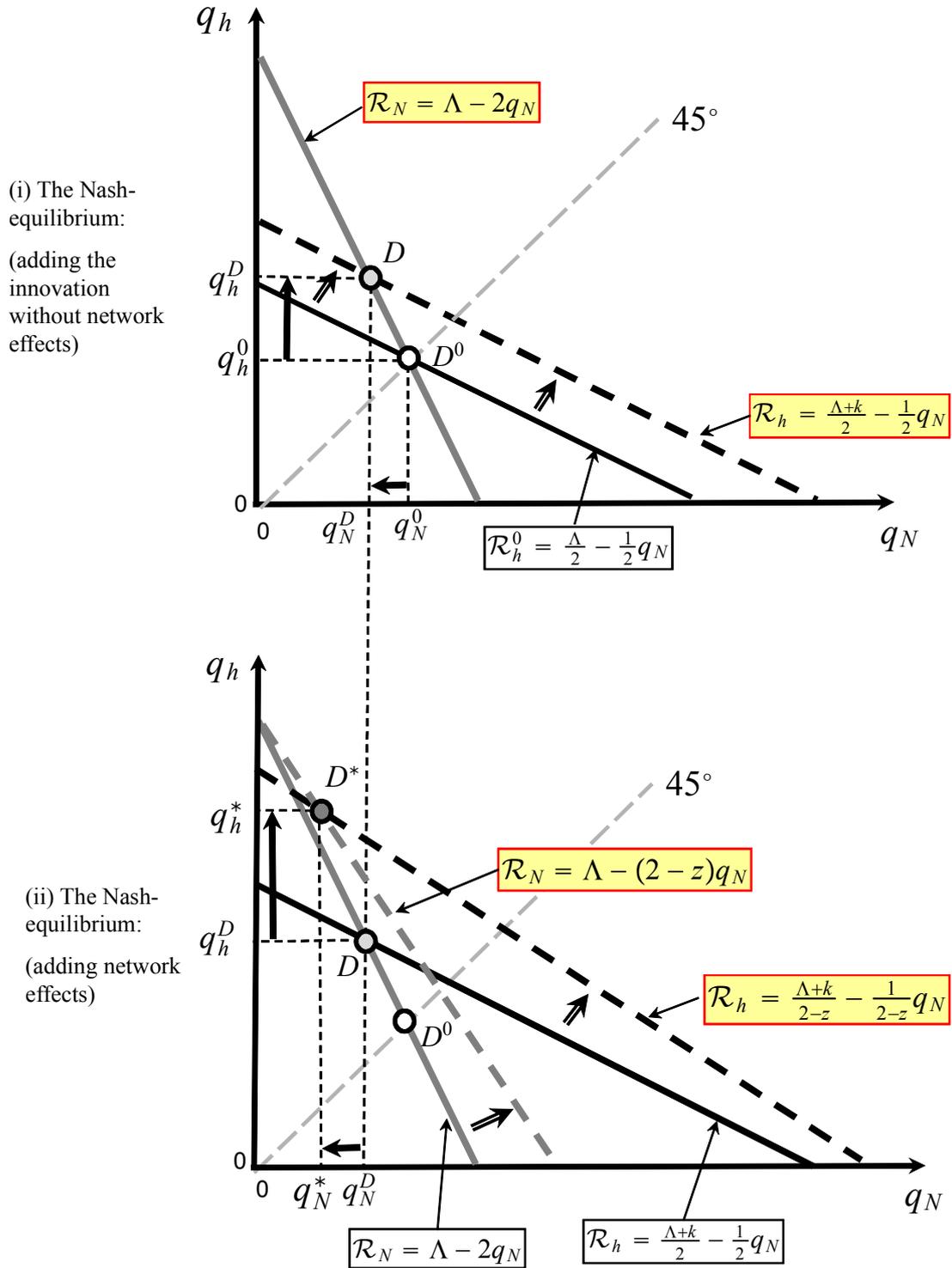$\mathcal{R}_h = \frac{\Lambda+k}{2} - \frac{1}{2}q_N$

Figure 2: Illustrating the reaction functions. Part (i) shows how the innovation shifts the symmetric Nash-equilibrium without the innovation D^0 to D. Part (ii) shows how network effects create an even more asymmetric equilibrium D^*.
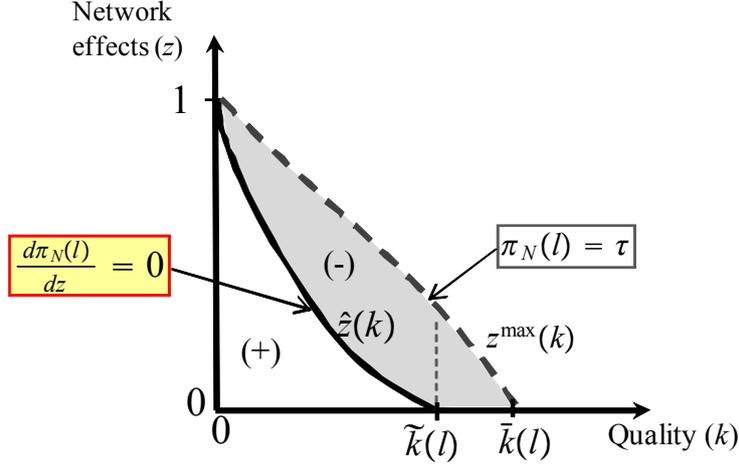
Figure 3: Illustrating how the sign of $d\pi_N(l)/dz$ varies with the quality of the innovation k and network effects z.

market $M(l)$ fulfils the *exit condition*:

$$\pi_N(l : M(l)) - \tau > 0, \qquad \pi_N(l : M(l) + 1) - \tau < 0, \qquad (4)$$

where $M(i) = n(i)$ and $M(e) = n(e) + 1$, where $n(l) \leq n$.

The commercialization process is depicted as an auction with externalities. This is an auction, studied in among others Jehiel and Moldovanu (1999) and Jehiel and Moldovanu (2000), where the bidders' valuations depend on the outcome if the bidder does not win the auction. The n incumbents simultaneously post bids, and the entrepreneurial firm then either accepts or rejects these bids. If the entrepreneurial firm rejects these bids, it will enter the market. Each incumbent announces a bid, b_i, for the innovation. $\mathbf{b} = (b_1, ..b_i.., b_n) \in R^n$ is the vector of these bids. Following the announcement of $\mathbf{b}$, the innovation can be sold to one of the incumbents at the bid price, or remain in the ownership of entrepreneurial firm e. If more than one bid is accepted, the bidder with the highest bid obtains the innovation. If there is more than one incumbent with such a bid, each bidder obtains the innovation with equal probability. The acquisition is solved for Nash equilibria in undominated pure strategies. There is a smallest amount ε chosen such that all inequalities are preserved if ε is added or subtracted.

There are three different valuations:

- $v_{ii} = [\pi_A(i) - \tau] - \lambda(i)[\pi_N(i) - \tau]$ is the value of obtaining k for an incumbent, when otherwise a rival incumbent would obtain k. The first term shows the profit when possessing the innovation k. The second term shows the expected profit if a rival incumbent obtains k, where $\lambda(i)$ is the probability of remaining in the market as a non-acquirer if an incumbent acquisition occurs.

- $v_{ie} = [\pi_A(i) - \tau] - \lambda(e)[\pi_N(e) - \tau]$ is the value of obtaining k for an incumbent, when otherwise the entrepreneurial firm would keep it. The profit for an incumbent of not obtaining innovation k is different because of the change of identity of the firm that would

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otherwise possess the assets. $\lambda(e)$ is the probability of remaining in the market as a non-acquirer if entry occurs.

- $v_e = \pi_E(e) - \tau - F$ is the value for the entrepreneurial firm of keeping an innovation with quality k and entering the market

We can now proceed to solve for the Equilibrium Ownership Structure (EOS). Since incumbents are symmetric, valuations v_{ii}, v_{ie} and v_e can be ordered in six different ways, as shown in Table 2.

Lemma 2 *Equilibrium ownership l^*, acquisition price S^* and the reward R_E are described in Table 2.*

Inequality:	Definition:	Ownership l^*:	Acquisition price, S^*:	Reward, R_E :
$I1$:	$v_{ii} > v_{ie} > v_e$	i	v_{ii}	v_{ii}
$I2$:	$v_{ii} > v_e > v_{ie}$	i *or* e	v_{ii}	v_{ii} or v_e
$I3$:	$v_{ie} > v_{ii} > v_e$	i	v_{ii}	v_{ii}
$I4$:	$v_{ie} > v_e > v_{ii}$	i	v_e	v_e
$I5$:	$v_e > v_{ii} > v_{ie}$	e	.	v_e
$I6$:	$v_e > v_{ie} > v_{ii}$	e	.	v_e

Table 2: The equilibrium ownership structure, the acquisition price and the reward.

Proof. See the Appendix. ∎

Lemma 2 shows that when one of the inequalities $I1$, $I3$, or $I4$ holds, k is obtained by one of the incumbents. Under $I1$ and $I3$, the acquiring incumbent pays the acquisition price $S = v_{ii}$, and $S = v_e$ under $I4$. When $I5$ or $I6$ holds, the entrepreneurial firm retains its assets. When $I2$ holds, there exist multiple equilibria. The last column summarizes the reward R_E accruing to the entrepreneurial firm as a result of discovering an innovation.

3.3 Stage 1: innovation by the entrepreneurial firm

Prior to the acquisition or entry stage, the entrepreneurial firm undertakes an effort to discover an innovation by selecting the probability $\rho \in [0, 1]$ of discovering the innovation. Let the effort cost $y(\rho)$ be an increasingly increasing function in the success probability: $y'(\rho) > 0$ and $y''(\rho) > 0$. The expected net profit of undertaking an effort to discover an innovation is thus $\bar{\Pi}_E = \rho R_E(l) - y(\rho)$. The optimal success probability as a function of the reward $\rho^*(R_E)$ is implicitly given from the first-order condition

$$\frac{d\bar{\Pi}_E}{d\rho} = R_E(l) - y'(\rho^*(l)) = 0, \tag{5}$$

with the associated second-order condition (omitting the ownership variable l) equal to $\frac{d^2\Pi_E}{d\rho^2} = -y''(\rho) < 0$. As shown by the following Lemma (obtained by using the implicit function theorem), the entrepreneurial firm's innovation incentives (the optimal success probability) are increasing in the reward.

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Lemma 3 *The equilibrium probability of successfully innovating in stage 1 increases with the reward:* $d\rho^*(l)^*/dR_E > 0$.

4   The effects of network effects

Having set up and solved the model, we now perform comparative statics with respect to network effects, z. To simplify the following analysis, we start out by assuming *large-scale* and *market-neutral* entry.

Assumption 2 *The following holds:*

(i) Large-scale entry: the entrepreneurial firm and the acquirer attain a symmetric market position when exposed to the same market conditions: $\pi_A(i) = \pi_E(e)$ *when* $N(i) = N(e)$.

(ii) Market-neutral entry: the quality of the innovation is sufficiently high so that in a market absent network effects, $z = 0$, *entry by the entrepreneurial firm leads to the exit of one incumbent:* $k \in (\bar{k}(e), \bar{k}(i))$ *where* $\bar{k}(l)$ *is defined as* $\pi_N(l, \bar{k}(l)) = 0$ *for* $l = \{e, i\}$.

(iii) $\widetilde{k} > \bar{k}(e)$.

Large scale entry is illustrated in Figure 4 (i), which depicts the reduced-form profit for the entrepreneurial firm (if entry occurs), $\pi_E(e) - \tau$, and the profit of an acquiring incumbent (if an acquisition takes place), $\pi_A(i) - \tau$, absent network effects, $z = 0$. Both profits increase in the quality of the innovation. When quality is low, $k \in (\underline{k}, \bar{k}(e))$, the acquiring incumbent will earn a higher profit, $\pi_A(i) - \tau > \pi_E(e) - \tau$, due to the concentration effect. At higher quality $k \geq \bar{k}(e)$, these profits are equalized, $\pi_A(i) - \tau = \pi_E(e) - \tau$. To see why, consider Figure 4 (ii). Absent network effects, the profit of a non-acquiring incumbent $\pi_N(l)$ is decreasing in the quality of the innovation. At $k = \bar{k}(e)$, $\pi_N(e) = \tau$ holds and entry by the entrepreneurial firm then leads to the exit of one incumbent firm.

The concentration effect implies that the profit for a non-acquirer under an acquisition will exceed its profit under entry, $\pi_N(e) - \tau < \pi_N(i) - \tau$. Therefore, the exit of a non-acquiring incumbent demands a higher quality under a sale, i.e. $\bar{k}(i) > \bar{k}(e)$. As shown in Figure 4 (iii), it then follows that in region $k \in (\bar{k}(e), \bar{k}(i))$, entry is market-neutral and does not change the total number of firms in the industry which remains at n firms. In this region, an acquiring incumbent and the entrepreneurial firm would obtain the same product market profit $\pi_A(i) - \tau = \pi_E(e) - \tau$, while a non-acquiring incumbents would obtain the same profit regardless of the ownership of the innovation, $\pi_N(e) - \tau = \pi_N(i) - \tau$. Note also that for a larger quality than $\bar{k}(i)$, additional exits occur. However, the number of firms in the market is the same under entry and sale.

Figure 4 (iv) adds network effects under market-neutral and large-scale entry. Once we have a sufficiently large quality $k > \tilde{k} > \bar{k}(e)$, Lemma 1 is fulfilled, $\frac{d\pi_N(i)}{dz} = \frac{d\pi_N(e)}{dz} < 0$. Initially, we will focus on varying network strength in the region $z \in (0, z^{\max}(k))$ for $k > \tilde{k} \in (\bar{k}(e), \bar{k}(i))$, where $z^{\max}(k)$ is the largest network strength at which a non-aquiring incumbent makes a positive profit. That is, we will assume that the quality of the innovation is sufficiently large to simultaneously generate exit of an incumbent under entry, while creating a sufficiently asymmetric market so that the profit of a non-acquirer decreases when the network effects increase.
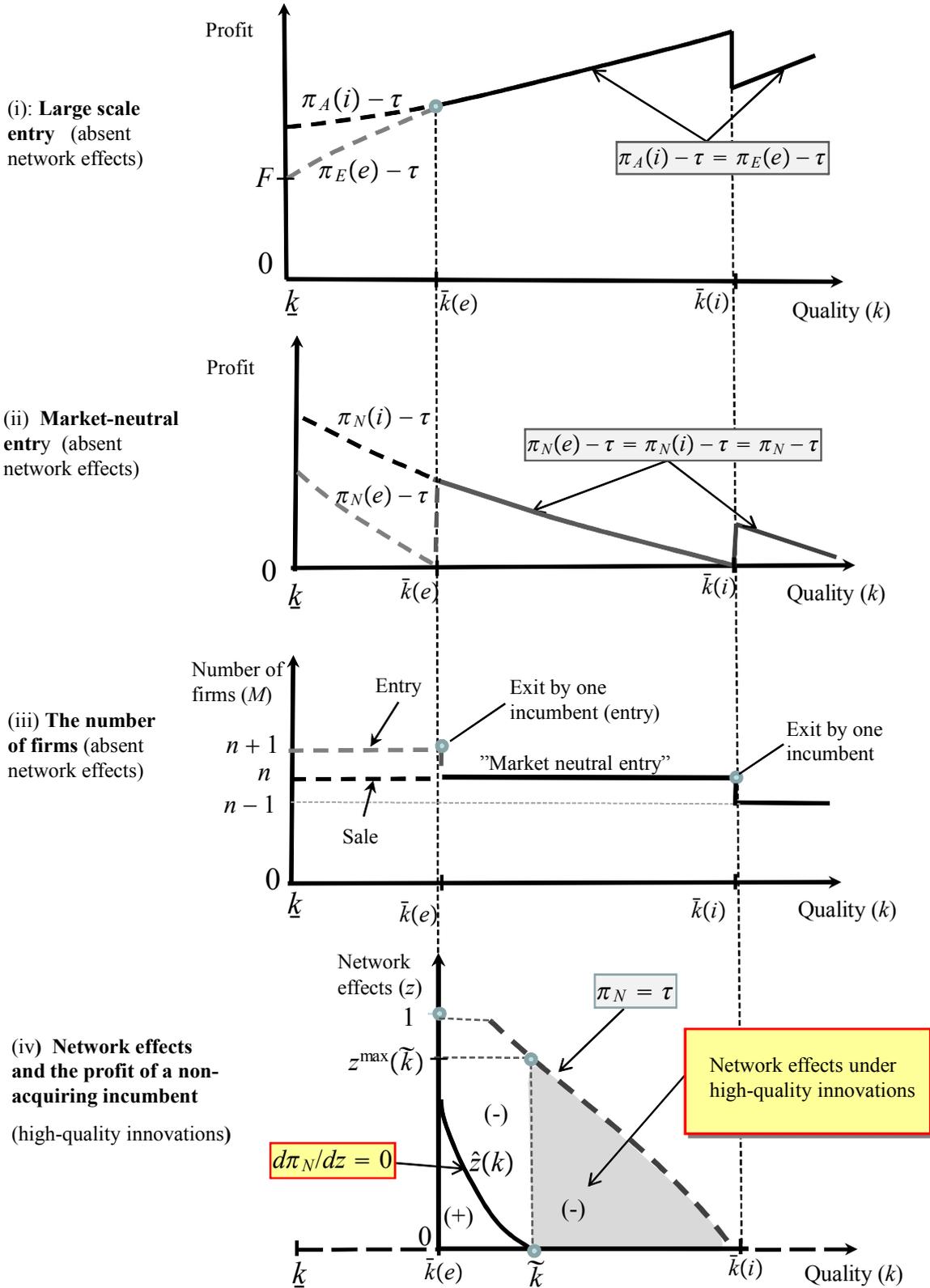
(i): Large scale entry (absent network effects)

Profit

$\pi_A(i) - \tau$

F

$\pi_E(e) - \tau$

$\pi_A(i) - \tau = \pi_E(e) - \tau$

$\underline{k}$ $\bar{k}(e)$ $\bar{k}(i)$ Quality (k)

(ii) Market-neutral entry (absent network effects)

Profit

$\pi_N(i) - \tau$

$\pi_N(e) - \tau = \pi_N(i) - \tau = \pi_N - \tau$

$\pi_N(e) - \tau$

$\underline{k}$ $\bar{k}(e)$ $\bar{k}(i)$ Quality (k)

(iii) The number of firms (absent network effects)

Number of firms (M)

Entry   Exit by one incumbent (entry)

Exit by one incumbent

$n + 1$

n "Market neutral entry"

$n - 1$

Sale

$\underline{k}$ $\bar{k}(e)$ $\bar{k}(i)$ Quality (k)

(iv) Network effects and the profit of a non-acquiring incumbent

(high-quality innovations)

Network effects (z)

1

$z^{\max}(\widetilde{k})$

$\pi_N = \tau$

Network effects under high-quality innovations

$(-)$

$dπ_N/dz = 0$

$\hat{z}(k)$

$(+)$ $(-)$

0

$\underline{k}$ $\bar{k}(e)$ $\widetilde{k}$ $\bar{k}(i)$ Quality (k)

Figure 4: Illustrating large-scale and market-neutral entry. Part (i) illustrates large-scale entry and how the reduced profit functions of posessors of the innovation vary with k. Part (ii) depicts market neutral entry, showing that the profits of non-acquiring incumbents decrease in k. Part (iii) illustrates that we have entry neutrality in the middle region. Part (iv) depicts the exact region on which we focus where Assumption 1 and Assumption 2 hold.

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We consider these assumptions to be reasonable, and refer the sceptical reader to sections 6.1 and 6.3 where we examine network effects with innovations of lower quality ($k < \tilde{k}$) and market neutral entry $k \in (\bar{k}(e), \bar{k}(i))$ as well as non-market neutral entry, $k \in (0, \bar{k}(e))$. Furthermore, section 6.2 allows for exits at strong network effects, $z \geq z^{\max}(k)$, and "tipping": such strong network effects that only one firm can be active in the market.

4.1 Network effects promote acquisitions over entry

Let us now show that strong network effects can induce the entrepreneurial firm to sell the innovation instead of entering the market. Using Assumption 2, incumbents' valuations become:

$$v_{il} = \begin{cases} v_{ie} = \pi_A(i) - \left(\frac{n-1}{n}\right) \pi_N(e), \\ v_{ii} = \pi_A(i) - \pi_N(i). \end{cases} \tag{6}$$

where $v_{ie} > v_{ii}$ since the probability of remaining in the market for a non-acquiring incumbent is lower under entry, $\lambda(i) = 1 > \lambda(e) = \frac{n-1}{n} > 0$.

From Lemma 2, commercialization by sale occurs as a unique equilibrium if and only if $v_{ie} > v_e$ or $v_{ii} > v_e$ or both. It is then convenient to define the *net value of preemption* as $\Delta_{PE}(z) = v_{ii} - v_e$ and the *net value of entry deterrence* as $\Delta_{ED}(z) = v_{ie} - v_e$. These net values simply compare an incumbent's valuation to the minimum price at which the entrepreneurial firm will sell its innovation to an incumbent. Using Assumption 2, it follows from equation (6) that the net value of entry-deterrence and preemption can be written as

$$\begin{aligned} \Delta_{ED}(z) &= v_{ie} - v_e = F - \left(\frac{n-1}{n}\right) \pi_N(e), \text{ and} \\ \Delta_{PE}(z) &= v_{ii} - v_e = F - \pi_N(i). \end{aligned} \tag{7}$$

The profit as a possessor of the innovation vanishes in equation (7) since the profit of an acquiring incumbent equals that of the entrepreneurial firm under entry, $\pi_A(i) = \pi_E(e)$. To proceed, define cut-off levels for network strengths z^{PE} from $\Delta_{PE}(z^{PE}) = 0$ and z^{ED} from $\Delta_{ED}(z^{ED}) = 0$, and note that $z^{ED} < z^{PE}$ since $\Delta_{ED}(z) > \Delta_{PE}(z)$ from $v_{ie} > v_{ii}$. We can then state the following proposition:

Proposition 1 *Under Assumptions 1 and 2 and under the existence of z^{PE} and z^{ED}, entry takes place if $z \in (0, z^{ED})$, an entry deterring acquisition at price $S^* = v_e$ takes place for $z \in [z^{ED}, z^{PE})$ and a preemptive acquisition at price $S^* = v_{ii}$ occurs for $z \in [z^{PE}, z^{\max})$. Thus, an increase in z makes an acquisition more likely.*

The proposition is proved and illustrated in Figure 5, which solves the acquisition entry game as a function of the network effect, z. When network effects are weak, $z \in (0, z^{ED})$, the net value for entry deterrence is negative $\Delta_{ED}(z) = v_{ie} - v_e < 0$, i.e. an incumbent's entry deterring valuation v_{ie} is lower than the entry value of the entrepreneurial firm, v_e. In this region, the entrepreneurial firm will choose to enter the market ($l^* = e$).

What happens if there is an increase in the network effects? Differentiate the net value of entry deterrence $\Delta_{ED}(z)$ in z to obtain

$$\frac{d\Delta_{ED}}{dz} = v'_{ie,z} - v'_{e,z} = -\left(\frac{n-1}{n}\right) \frac{d\pi_N(e)}{dz} > 0. \tag{8}$$
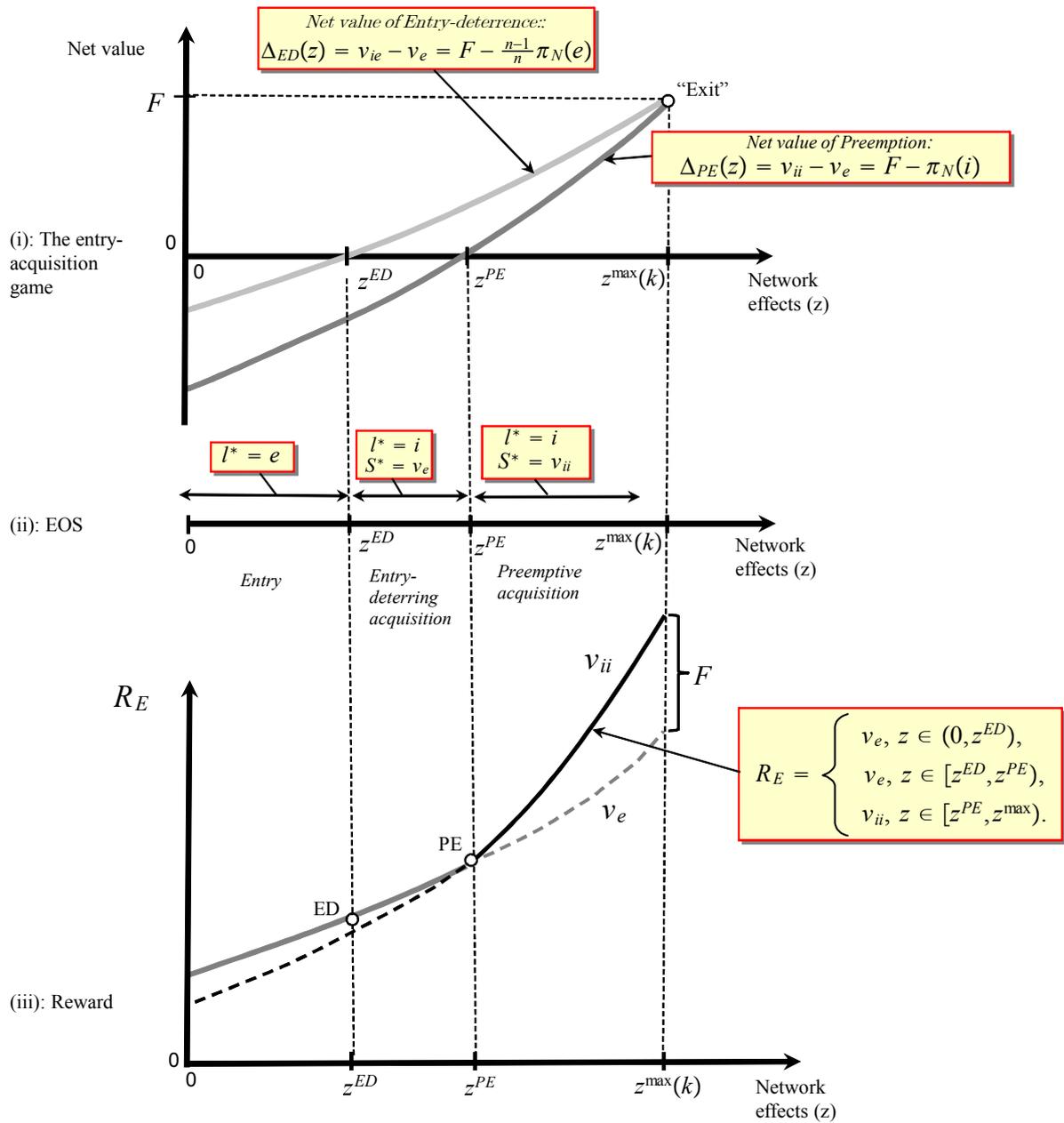
Figure 5: Network effects in an industry affect the entry/acquisition decision, the equilibrium acquisition price and the innovation reward. Part (i) illustrates the upward sloping net value of preemption and the net value of entry deterrence. Part (ii) illustates for what values of z entry that an entry deterring acquisition, or a preemptive acquisition, takes place. Part (iii) illustrates the effects on the reward from increasing network effects.

Thus, the entry deterring valuation of an incumbent v_{ie} increases more than the entrepreneurial firm's value of entry v_e when there is an increase in the network effect. The first term in $v_{ie} = \pi_A(i) - \left(\frac{n-1}{n}\right)\pi_N(e)$ increases by the same amount as the first term in $v_e = \pi_E(i) - F$, since the acquiring incumbent and the entrepreneurial firm have the same increase in profit from Assumption 2 ($\pi_A(i) = \pi_E(e)$). However, since the profit of a non-acquirer $\pi_N(e)$ decreases in z, there is an additional increase in the incumbent's valuation such that $dv_{ie}/dz > dv_e/dz$. Thus, since an incumbent's net value of entry deterrence $\Delta_{ED}(z) = v_{ie} - v_e$ is increasing in z, an entry deterring acquisition at the acquisition price $S^* = v_e$ occurs at $z = z^{ED}$ where $\Delta_{ED}(z^{ED}) = 0$ (shown in Figure 5 (ii)). Other incumbents will not preempt a rival acquisition in the region $z \in (z^{ED}, z^{PE})$, since the net value of preemption is negative, $\Delta_{PE} = v_{ii} - v_e < 0$. Thus, the entrepreneurial firm will be acquired ($l^* = i$) at the price $S^* = \pi_E(e) - F$ in this region.

What if the network effects increase even further? Since a stronger network effect decreases the profit of a non-acquiring incumbent under an incumbent acquisition, the net value of preempting rivals also increases. Differentiating the net gain of preemption Δ_{PE} in z we obtain

$$\frac{d\Delta_{PE}}{dz} = v'_{ii,z} - v'_{e,z} = -\frac{d\pi_N(i)}{dz} > 0. \tag{9}$$

As shown in Figure 5(i), increasing the network effect into the region $z \in [z^{PE}, z^{\max}(k))$ leads to a strictly positive net value of preemption: $\Delta_{PE}(z) = v_{ii} - v_e > 0$. This induces a bidding war between incumbents driving the equilibrium acquisition price above the entry value for the entrepreneurial firm, $S^* = v_{ii} = \pi_A(i) - \pi_N(i) > v_e$. The entrepreneurial firm will be acquired ($l^* = i$) at the acquisition price $S^* = v_{ii}$ in this region.

4.2 Network effects increase the acquisition prices and the acquisition premium

Given that an acquisition takes place, how do network effects affect the equilibrium acquisition price? Network effects have a dual effect on the equilibrium preemptive acquisition price: the acquisition price increases in network effects both because the bidders find the innovation gained through the acquisition to be more valuable and because they want to prevent rivals from acquiring the entrepreneurial firm. Under an entry deterring acquisition, the acquisition price is affected by network effects in the same way as network effects affect the profitability of entry.

This holds because if an entry deterring acquisition takes place, the equilibrium acquisition price is $S^* = v_e = \pi_E - F$. Since the acquisition price then equals the entry value, it follows that for low or medium network strength $z \in (0, z^{ED})$, we obtain

$$\frac{dS^*}{dz} = \frac{d\pi_E}{dz} = \frac{dv_e}{dz} > 0. \tag{10}$$

If a preemptive acquisition takes place at strong network effects $z \in [z^{PE}, z^{\max})$, the equilibrium acquisition price is $S^* = v_{ii} = \pi_A - \pi_N(i)$. It follows from Assumption 1 that the effect

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of network effects on the acquisition price is:

$$\frac{dS^*}{dz} = \frac{dv_{ii}}{dz} = \underbrace{\frac{d\pi_A}{dz}}_{+} - \underbrace{\frac{d\pi_N(i)}{dz}}_{-} > 0. \tag{11}$$

The equilibrium acquisition price under a preemptive acquisition increases because i) the profits if the entrepreneurial firm is acquired increase in network effects ($d\pi_A/dz > 0$), and ii) the profits if the incumbent is forced to compete with a rival that acquired the entrepreneurial firm decrease in the network effects ($d\pi_N(i)/dz < 0$). Thus, the acquisition premium (the acquisition price paid by an incumbent in a preemptive acquisition net the entry value of the firm) is also increasing in network effects. As shown in Figure 5(iii), the acquisition premium is given by $\Delta_{PE} = v_{ii} - v_e$, which by equation (9) is also increasing in z when the network effects are sufficiently large.

Proposition 2 *Under Assumptions 1 and 2 and under the existence of z^{PE} and z^{ED}, the following holds:*

(i) the entry value of the entrepreneurial firm v_e and the acquisition price under a sale S^* increase when the network effects increase,

(ii) when a preemptive acquisition occurs for strong network effects $z \in [z^{PE}, z^{\max})$, the acquisition price $S^* = v_{ii}$ increases more than the reservation price v_e. This increases the acquisition premium $v_{ii} - v_e$.

Proposition 2 provides an explanation for why acquisition prices can be so high in network industries: acquiring an entrepreneurial firm gives an incumbent a larger lead over rivals at the same time as preventing a rival from acquiring the entrepreneurial firm becomes more important. Bidding competition as incumbents expect rivals to acquire the entrant ensures that the bid equals the full valuation v_{ii}.

4.3   Acquisitions promote innovation incentives in network industries

We have seen that stronger network effects tend to promote acquisitions over entry and amplify acquisition prices more under a preemptive acquisition than under an entry deterring acquisition. But how do these effects feed back into the entrepreneurial firm's innovation incentives?

Proposition 3 *Under Assumptions 1 and 2 and the existence of z^{PE} and z^{ED}, under preemptive acquisitions ($z \in [z^{PE}, z^{\max})$), entrepreneurial firms face stronger innovation incentives than under entry-deterring acquisitions or under entry, i.e. $\rho^*(i) > \rho^*(e)$.*

To prove this, we make use of Figure 5 (iii) which depicts the reward $R_E(l)$ as a function of network strength z. When the network strength is low $z \in (0, z^{ED})$, entry will take place and the reward is $R_E(e) = v_e = \pi_E(e) - F$. From Assumption 1, $R_E(e)$ is increasing in network effects and from Lemma 3, the innovation efforts increase when the reward for innovation increases. The same holds if an entry deterring acquisition occurs in region $z \in [z^{ED}, z^{PE})$ since $R_E(i) = S^* = v_e$.

When the network effects increase further, $z \in [z^{PE}, z^{\max})$, a preemptive acquisition occurs. In this region, bidding competition among incumbents for the entrepreneurial firm causes the reward for innovation to be strictly greater than the reward for innovation under entry or an entry-deterring acquisition: $R_E(i) = v_{ii} > v_e = R_E(e)$. Since the probability of success $\rho^*(l)$ is increasing in the reward $R_E(l)$, it directly follows from Lemma 3 that there will be a higher probability of success if there is bidding competition for the entrepreneurial firm and a preemptive acquisition occurs. This is illustrated in Figure 5 (iii), which shows that preemptive incumbent acquisitions of entrepreneurial firms substantially increase the innovation incentives for entrepreneurial firms.

Proposition 3 thus provides an explanation for the fast innovation pace in network industries: entrepreneurial firms know that they can get a large reward for innovating if they are acquired by an incumbent competing with other incumbents to acquire them.

5   Compatibility policy in the presence of a market for entrepreneurial firms

5.1   Incorporating compatibility

The required level of compatibility between products is often used in network industries to achieve policy goals so as to ensure sufficient entry into an industry. To account for this, we start by extending our model to account for both network effects and varying degrees of compatibility. Let the degree of compatibility between firms' products be measured by $c \in [0, 1]$, where $c = 0$ means that each firm's product only benefits from its own network (incompatibility) and $c = 1$ means that each firm's product benefits from the networks of all products sold (full compatibility).

In stage 3, firm j chooses an action x_j to maximize its direct product market profits $\pi_j(x_j, x_{-j}, l, k, z, c) - \tau$, which now also depend on the degree of compatibility, c. Given the expectations of network sizes, assume that a unique Nash equilibrium in actions $\mathbf{x}^*(l, k, z, c) = \{x_j^*(l, k, z, c), x_{-j}^*(l, k, z, c)\}$ exists, allowing us to define the reduced form profit function for firm j as $\pi_j(l) = \pi_j(\mathbf{x}^*(l, k, z, c), l, k, z, c) - \tau$. We impose the following assumption:

Assumption 3 *Increased compatibility levels the playing field by reducing the advantage of possessing the innovation developed by the entrepreneurial firm:* $\frac{d\pi_A(i)}{dc} < 0$, $\frac{d\pi_E(e)}{dc} < 0$, *and* $\frac{d\pi_N(l)}{dc} > 0$.

This effect is termed "leveling" in the literature (Katz and Shapiro (1985), Farrell and Saloner (1992), Malueg and Schwartz (2006) and Farrell and Klemperer (2007)). Empirical evidence suggests that leveling takes place: Liu et al. (2008) document that increasing compatibility in the memory card market reduces the effect of installed bases on price premiums while larger installed bases increase price premiums. In other words, there appear to be network effects in the memory card market but the price premiums they allow are reduced when the degree of compatibility increases.

5.1.1 The linear Cournot model

For clarity, let us consider how compatibility can be incorporated in the linear Cournot model of Katz and Shapiro (1985). Consider the linear Cournot model with network effects developed in Section 3.1 and extend it to allow for compatibility between firms' networks. Firm j now faces a price of

$$P_j = a + z(\bar{q}_j + c\bar{q}_{-j}) - Q. \tag{12}$$

The term $c\bar{q}_{-j}$ captures how much firm j benefits from the quantities sold by rivals. Setting $c = 0$, we have returned to the linear Cournot model developed in Section 3.1. Observing expectations, firms maximize profits $\pi_j = (P_j - \delta_j)q_j - \tau$, where δ_j is firm j's marginal costs. Following the steps in Section 3.1, the reduced-form profit function for firm j is $\pi_j(l) - \tau = [P_j(l) - \delta_j] q_j^*(l) = [q_j^*(l)]^2 - \tau$.

We can now study how the reduced form profit functions $\pi_A(i) - \tau$, $\pi_E(e) - \tau$ and $\pi_N(l) - \tau$ respond to changes in c to obtain the following lemma.

Lemma 4 *For sufficiently high-quality innovations, increased compatibility levels the playing field by reducing the advantage of acquiring the entrepreneurial firm: $\frac{d\pi_A}{dc} < 0$, $\frac{d\pi_E}{dc} < 0$, and $\frac{d\pi_N(l)}{dc} > 0$ for $k > \check{k}$.*

Proof. See Appendix A. ∎

Lemma 4 gives the conditions under which Assumption 3 holds in the linear Cournot model with network effects and fulfilled consumer expectations. To see this, differentiate the reduced form profit functions with respect to c to obtain

$$\frac{d\pi_h(l)}{dc} = \left[\Psi_{-h}^*(l) - \frac{dq_{-h}^*(l)}{dc} \right] q_h^*. \tag{13}$$

The first term within the bracket $\partial P_h(l)/\partial c = \Psi_{-h}^*(l) = zq_{-h}^*$ represents a direct price increase as consumers' willingness to pay increases when compatibility increases. The second term in the expression $\frac{dP_h(l)}{dq_{-h}} \frac{dq_{-h}^*(l)}{dc} = -\frac{dq_{-h}^*(l)}{dc}$ represents the strategic price effect arising from the change in price from the induced change in the output of competitors from increased compatibility.

Due to the possession of the innovation, a possessor has a larger network than a non-acquiring incumbent. However, the direct effect of an increase in compatibility now benefits non-acquiring incumbents more than a possessor because consumers in the smaller network of a non-acquirer now benefits from the acquiring incumbent's/entrepreneurial firm's larger network, $\Psi_{-N}^*(l) > \Psi_{-A}^*(l)$.

To examine the strategic effect, it is instructive to once more examine a duopoly setting. Figure 6 uses equilibrium D^* from Figure 2 (ii) as a benchmark, where an innovation of high quality is present under network effects, $z > 0$, but networks are not compatible. This creates a highly asymmetric market with the low cost possessor attracting most customers. Introducing compatibility $c > 0$ shifts out firms' reaction functions due to the increase in the willingness to pay of consumers. However, this will disproportionately benefit the smaller non-possessor since this firm's product attains compatibility with the larger firm's network. The gain for the large firm is limited due to the network size of the smaller firm. Comparing the Nash-equilibrium
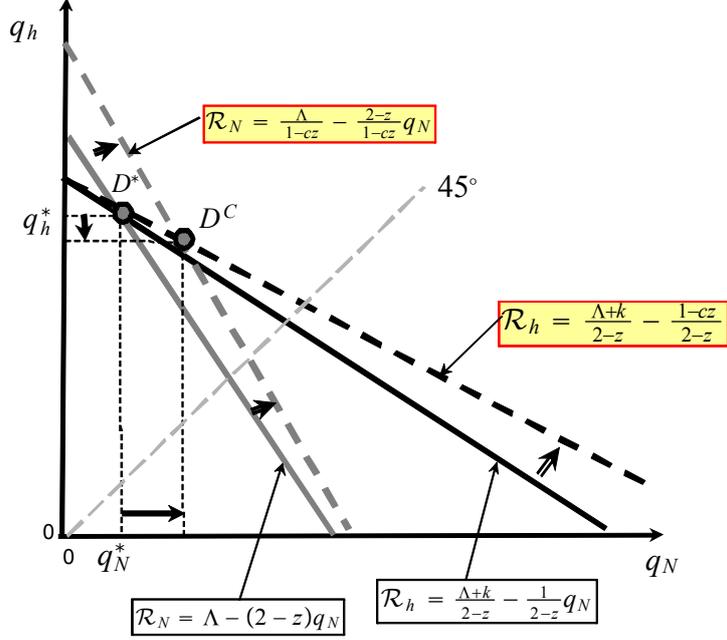
Figure 6: Illustrating how reaction functions respond to increases in compatibility.

without compatibility in point D^* with that with compatibility in D^C, we see that the output of the non-acquirer has increased while that of the possessor has decreased.

In the Appendix, we show that non-acquiring incumbents always gain from higher compatibility. For sufficiently high quality of innovations $k > \overline{k}$, the possessor's profit decreases as the compatibility increases from low levels. We also derive the range of compatibility under which larger compatibility reduces the profit of the possessor of the innovation.

5.2 Increased compatibility leads to more entry but reduced innovation incentives

We now perform comparative statics with respect to c to study how compatibility affects the entry/acquisition decision, equilibrium acquisition prices and innovation incentives. Required compatibility is often motivated in the policy arena by its effect to promote entry. We show that indeed more entry takes place for higher compatibility, but this comes at the expense of reduced innovation incentives under preemptive acquisitions.

Recall incumbents' net values of an acquisition in equation (7). Differentiating these net values in c, we obtain :

$$\frac{d\Delta_{ED}(c)}{dc} = v'_{ii,c} - v'_{e,c} = -\left(\frac{n-1}{n}\right)\frac{d\pi_N(e)}{dc} < 0, \text{ and}$$
$$\frac{d\Delta_{PE}(c)}{dc} = v'_{ii,c} - v'_{e,c} = -\frac{d\pi_N(i)}{dc} < 0.$$

The net value of entry deterrence and preemption, $\Delta_{PE}(c)$ and $\Delta_{ED}(c)$, are decreasing in compatibility since non-acquiring incumbents gain from increased compatibility. This is illustrated in Figure 7(i). If we assume that the combination of the quality of the innovation and the strength of network effects is sufficiently high to support a sale under bidding competition ab-

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sent compatibility, we can define cut-off levels for compatibility c^{PE} from $\Delta_{PE}(c^{PE}) = 0$ and c^{ED} from $\Delta_{ED}(c^{ED}) = 0$, where $c^{ED} < c^{PE}$ since $\Delta_{ED}(c) > \Delta_{PE}$.

As illustrated by Figure 7 (i), preemptive acquisitions occur at low levels of compatibility $c \in (0, c^{ED})$ since $\Delta_{PE}(c) = v_{ii} - v_e > 0$. This induces a bidding war between incumbents driving the equilibrium acquisition price above the entry value for the entrepreneurial firm, $S^* = v_{ii} = \pi_A(i) - \pi_N(i) > v_e$. However, as we increase the compatibility, incumbents' value of preempting other incumbents becomes smaller than the reservation price and leads to a negative net value, $\Delta_{PE}(c) < 0$. Since the net value of entry deterrence is higher than the net value of preemption from the concentration effect of an acquisition, incumbents' value of deterring entry remains higher than the reservation price for the entrepreneurial firm at medium compatibility, $\Delta_{ED}(c) > 0$ for $c \in (c^{PE}, c^{ED})$. Thus, an entry deterring acquisition at the acquisition price $S^* = v_e$ occurs in this region. However, when compatibility is very high, $c \in (c^{ED}, 1)$, incumbents' valuations are lower than the reservation price. In this region, the entrepreneurial firm will thus choose to enter the market.

Proposition 4 *Under Assumptions 1, 2 and 3, and the existence of c^{PE} and c^{ED}, a preemptive acquisition at price $S^* = v_{ii}$ occurs for $c \in (0, c^{PE})$, an entry deterring acquisition at price $S^* = v_e$ takes place for $c \in [c^{PE}, c^{ED})$ and entry takes place if $c \in (c^{ED}, 1)$. Thus, an increase in compatibility c makes entry more likely and an acquisition under bidding competition less likely.*

From Lemma 3, we know that the probability of success $\rho^*(l)$ is increasing in the reward to innovation, $R_E(l)$. It directly follows that innovation incentives always decrease in compatibility, regardless of the entry mode. An increase in compatibility when the entrepreneurial firm is acquired under bidding competition will drastically reduce the probability of success $\rho^*(l)$. Figure 7 (iii) depicts the reward $R_E(l)$ as a function of compatibility c. When compatibility is low, such that $c \in [0, c^{PE})$, a preemptive acquisition occurs at $S^* = v_{ii}$. Then, the reward to innovation $R_E(l) = v_{ii}$ will decrease in c both because the profits when acquiring the entrepreneurial firm decrease and because the profits when forced to compete with a rival that acquired the entrepreneurial firm increase:

$$\frac{dS^*}{dc} = \frac{dv_{ii}}{dc} = \underbrace{\frac{d\pi_A}{dc}}_{-} - \underbrace{\frac{d\pi_N(i)}{dc}}_{+} < 0. \tag{14}$$

The acquisition premium $S^* = v_{ii} - v_e$ will decrease more than the reservation price:

$$\frac{dS^*}{dc} - \frac{dv_e}{dc} = -\underbrace{\frac{d\pi_N(i)}{dc}}_{+} < 0. \tag{15}$$

Hence, the negative effect on innovation incentives of increased compatibility is greater if a preemptive acquisition takes place. We get more entry, but at the cost of reduced acquisition prices which reduce the innovation incentives for entrepreneurial firms.

Corollary 2 *Under Assumptions 1, 2 and 3, and the existence of c^{PE} and c^{ED}, increased compatibility reduces the reward to innovation for the entrepreneurial firm $\frac{dR_E(l)}{dc} < 0$ which*
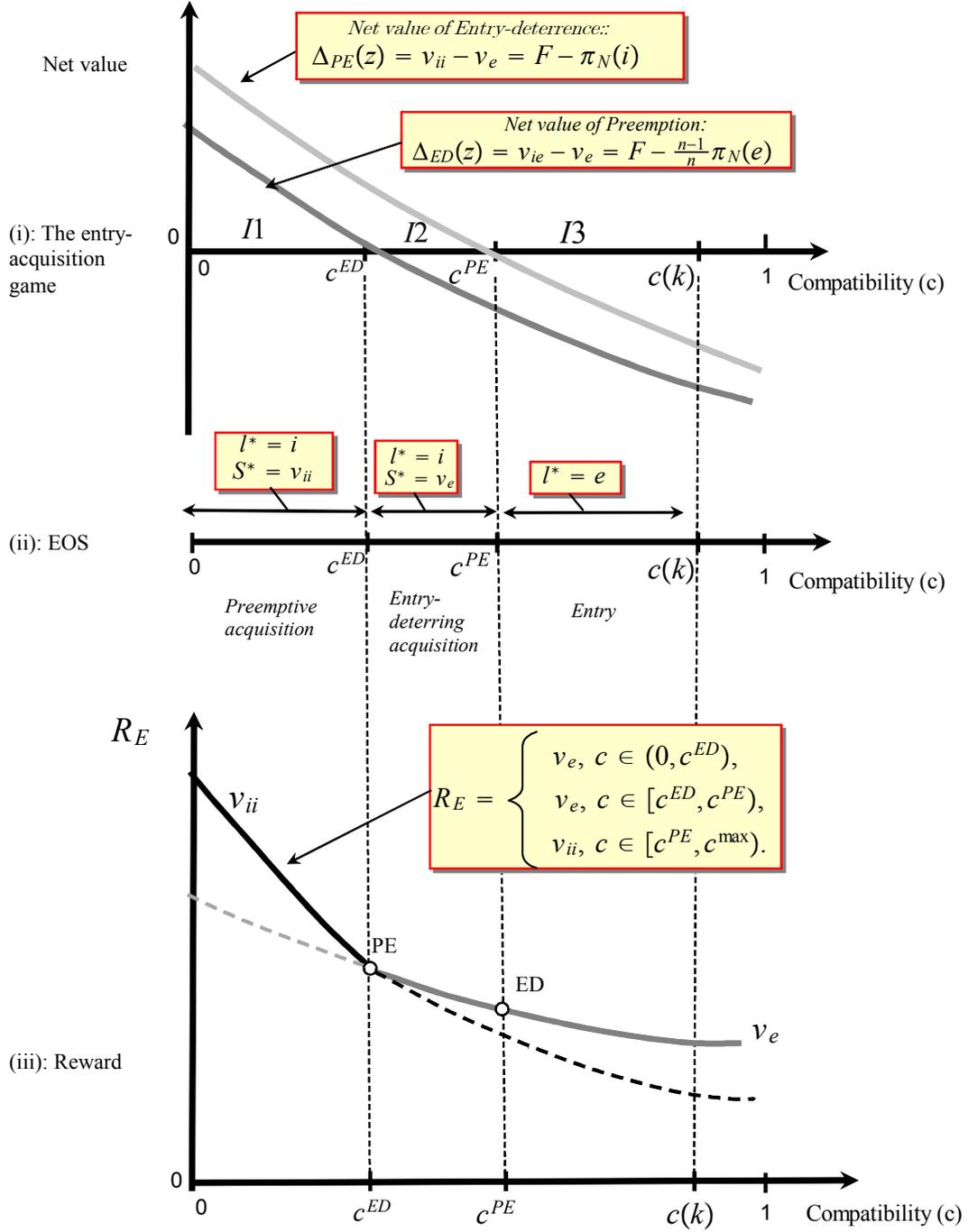
Figure 7: The compatibility policy affects the entry/acquisition decision, the equilibrium acquisition price and the innovation reward. Part (i) illustrates the downward sloping net value of preemption and the net value of entry deterrence. Part (ii) illustrates for what values of c entry an entry deterring acquisition or a preemptive acquisition takes place. Part (iii) illustrates the effects on the reward of increasing compatibility.

reduces the effort to innovate and the probability of successful innovation. This negative effect tends to be the strongest when the entrepreneurial firm is acquired under bidding competition.

5.3 When is compatibility desirable?

Let us now make some remarks on compatibility policy and welfare. To this end, we add a stage zero where the government contemplates a policy which forces firms to make products compatible. To simplify the presentation, we make the following assumptions:

- Compatibility policy (henceforth denoted the C-policy) states that products are to be made compatible only if the innovation k succeeds (and the entrepreneurial firm commercializes the innovation in stage 2).

- If the entrepreneurial firm fails, the symmetric incumbents will not agree on compatibility, say, because of fixed costs of making the product compatible (which we normalize to zero).

- Let the innovation quality be sufficiently high and the network effects be sufficiently strong to have the entrepreneurial firm sell the innovation to an incumbent under preemptive bidding competition at price $S^* = v_{ii}$ in the absence of compatibility, $c = 0$. When the government imposes compatibility, it will use the minimum compatibility to enforce entry, i.e. $c = c^{PE} + \varepsilon \approx c^{PE}$.

Let us now compare the C-policy to a laissez-fair policy (henceforth denoted the L-policy) where no commitment to compatibility is made. The conventional welfare evaluation of M&As and market structures is typically made by comparing the sum of consumer surplus and profits in different market structures. We follow this approach. Denote the expected welfare under the L-policy as $\bar{W}(i) = \rho^*(i)W(i) + [1 - \rho^*(i)]W(0)$, where $W(i)$ is the welfare when the entrepreneurial firm is successful, and $W(0)$ is the welfare under a failure by the entrepreneurial firm. Similarly, denote the expected welfare under the C-policy $\bar{W}(e) = \rho^C(e)W^C(e) + [1 - \rho^C(e)]W(0)$, where $W^C(e)$ is the welfare under entry, and $W(0)$ is once more the welfare under a failure (where compatibility is not enforced).

Defining the difference in expected welfare $\bar{W}^{C-L} = \bar{W}(e) - \bar{W}(i)$, and rearranging terms, we obtain:

$$\bar{W}^{C-L} = \rho^C(e) \underbrace{\left[W^C(e) - W(0)\right]}_{(+):\text{ Entry with comp.}} - \rho^*(e) \underbrace{\left[W(i) - W(0)\right]}_{(+):\text{ Sale without comp}} \gtreqless 0 \tag{16}$$
$$\underbrace{}_{\text{Change in expected welfare}}$$

Even if the welfare is higher under compatibility, $W^C(e) > W(i)$, when the entrepreneurial firm succeeds, *expected* welfare can be reduced under the compatibility policy, $\bar{W}^{C-L} < 0$, since the probability of an innovation can be significantly lower under the C-policy, $\rho^C(e) < \rho^*(e)$. As shown in Corollary 2, the reason for this is the significant loss of revenue for the entrepreneurial firm arising from not being able to extract incumbents' full willingness to pay from selling the innovation under bidding competition. This can be seen by comparing the reward to innovation R_E for $c = 0$ and $c = c^{PE}$ in Figure 7(iii).

Let us now examine the effect on consumers, incumbents and the entrepreneurial firm. Note that

$$\bar{W}^{C-L} = \bar{C}S^{C-L} + \bar{\Pi}_I^{C-L} + \bar{\Pi}_E^{C-L}. \tag{17}$$

In (17), $\bar{C}S^{C-L} = \bar{C}S^C - \bar{C}S$ is the change in expected consumer surplus from adopting the C-policy, where $\bar{C}S(i) = \rho^*(i)W(i) + [1 - \rho^*(i)]W(0)$ and $\bar{C}S^C(e) = \rho^C(e)W(e) + [1 - \rho^C(e)]CS(0)$. Similarly, $\bar{\Pi}_I^{C-L} = \bar{\Pi}_I^C - \bar{\Pi}_I^L$ is the change in aggregate expected incumbent profits, with $\bar{\Pi}_I^L = \rho^*(i)\Pi_I(i) + [1 - \rho^*(i)]\Pi_I(0)$ and $\bar{\Pi}_I^C = \rho^C(e)\Pi_I^C(e) + [1 - \rho^C(e)]\Pi_I(0)$. Finally, $\bar{\Pi}_E^{C-L} = \bar{\Pi}_E^C(e) - \bar{\Pi}_E(i)$ is the change in expected net income for the entrepreneurial firm, where $\bar{\Pi}_E^C(e) \equiv \rho^C(e)v_e^C - y(\rho^C(e))$ and $\bar{\Pi}_E(i) \equiv \rho^*(i)v_{ii} - y(\rho^*(e))$, and where $v_e^C = v_e|_{c=c^{PE}}$ and $v_{ii}|_{c=0}$. We can then rewrite (17) as follows:

$$\bar{W}^{C-L} = \rho^C(e)\underbrace{[CS^C(e) - CS(0)]}_{(+):\text{ Entry with comp.}} - \rho^*(i)\underbrace{[CS(i) - CS(0)]}_{(+):\text{ Sale without comp}} + \tag{18}$$

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}_{\text{Change in expected consumer surplus, } \bar{C}S^{C-L} \lesseqgtr 0}$$

$$\rho^*(i)\underbrace{[\Pi_I(0) - \Pi_I(i)]}_{(+):\text{ Sale with } c=0} - \rho^C(e)\underbrace{[\Pi_I(0) - \Pi_I^C(e)]}_{(+):\text{ Entry with } c>0} +$$

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}_{\text{Change in expected incumbent profits, } \bar{\Pi}_I^{C-L} \lesseqgtr 0}$$

$$\underbrace{\left[\bar{\Pi}_E^C(e) - \bar{\Pi}_E(i)\right]}_{\text{Loss for entrepreneurial firm, } \bar{\Pi}_E^{C-L} < 0}$$

Analyzing this expression, we get the following result.

Proposition 5 *Suppose that the government imposes a compatibility policy (C-policy) to promote entry. This will:*

(i) lower the reward for the entrepreneurial firm, and the probability of a successful innovation, $\rho^C(e) < \rho^*(e)$,

(ii) lead to either an increase or a decrease in expected total and consumer welfare.

To see the intuition, observe that equation (18) is split into three parts. As shown by the first line in equation (18), the expected consumer surplus can be lower under the C-policy than under the L-policy. Consumers are better off from the C-policy if the entrepreneurial firm succeeds, since concentration is lower and products are compatible, $CS^C(e) > CS(i)$. But once more, because compatibility reduces the bidding competition and the acquisition prices, the innovation is less likely to succeed under the C-policy, $\rho^C(e) < \rho^*(i)$.

The second line in equation (18) displays the aggregate profits of incumbents. The first term shows the expected loss when the entrepreneurial firm commercializes the innovation by selling to an incumbent under bidding competition under the L-policy, $S^* = v_{ii}$. The aggregate profit when the entrepreneurial firm commercializes by sale is $\Pi(i) = (n-1)\pi_N(i) + \pi_A(i) - v_{ii} = n\pi_N(i)$, whereas the aggregate incumbent profit under a failure is $\Pi(0) = n\pi_N(0)$. Since the innovation reduces the profits for non-acquiring incumbents, we have $\Pi(0) - \Pi(i) = n[\pi_N(0) - \pi_N(i)] > 0$. The second term of the second line shows the corresponding loss in aggregate profits when the entrepreneurial firm commercializes by entry under the C-policy,

where $\Pi^C(e) = n\frac{(n-1)}{n}\pi_N^C(e) = (n-1)\pi_N^C(e)$, and $\Pi(0) - \Pi^C(e) = \pi_N^C(e) + n\left[\pi_N(0) - \pi_N^C(e)\right]$, where the first terms illustrates the exit of one incumbent under entry. The expected loss due to an acquisition by an incumbent can be larger since (i) the probability of success is significantly higher under a sale, $\rho^*(i) > \rho^C(e)$ and (ii) the loss in aggregate profit can be lower under entry with enforced compatibility. The latter follows from $\Pi(i) - \Pi^C(e) = \pi_N^C(e) - n[\pi_N^C(e) - \pi_N(i)]$, which can be positive since compatibility improves a non-acquiring incumbent's competitive position $\pi_N^C(e) > \pi_N(i)$. Thus, aggregate profits for incumbents could then be higher under compatibility even when entry leads to the exit of one incumbent.

Finally, the third line in (18) displays the effect on the entrepreneurial firm. As shown in Figure 7 (iii), it directly follows that the entrepreneurial firm must be worse off from the C-policy since the reward to innovation is reduced, $v_e^C < v_{ii}$.

5.4 The long-run effects of compatibility: preserving bidding competition

Ex-ante asymmetries between incumbents could make compatibility more desirable. While earlier in this section, we pointed out a potential drawback of too much compatibility in the short run, we can also show that compatibility could be an important tool for promoting entry and ensuring bidding competition for entrepreneurial firms in the long run. A cost of monopolization in network industries could be a reduction in innovation incentives because of a lack of bidding competition for innovative entrepreneurial firms.

To see this, let us first consider how our results on how network effects affect acquisition prices and how the commercialization mode would be affected by the presence of ex-ante asymmetric incumbents. Suppose that there is initially one larger more efficient incumbent d and $n-1$ less efficient symmetric incumbents. The dominating incumbent could be created by acquisitions of previous innovations. The valuations for acquiring the entrepreneurial firm will then differ between incumbents and the auction game will, in general, be tedious to solve. A sufficient condition for an acquisition, however, is that the net value of an entry deterring acquisition for incumbent firm d is positive:

$$v_{ie}^d - v_e = \left[\pi_A^d(i) - \pi_E(e) + F\right] - \pi_N^d(e) > 0. \tag{19}$$

As long as $d\pi_A^d/dz$ is not sufficiently lower than $d\pi_E/dz$, network effects will be conducive to acquisitions by firm d if $d\pi_N^d(l)/dz$ is negative. If Assumptions 1 and 2 are fulfilled for the other incumbent firms $i \neq d$, a stronger network effect can imply an acquisition under biding competition where incumbent d bids the other incumbents' preemptive value, v_{ii}. If we allow ex-ante asymmetries between less efficient incumbents, the exit game could also look different: the least efficient firm would know that it would exit if it did not acquire the entrepreneurial firm and hence, an acquisition would tend to be the equilibrium outcome if entry triggers exit.

Why is it then that ex-ante asymmetries between incumbents could make compatibility more desirable? The reason is that if the incumbent d is dominating ex-ante and if the innovation quality is not too high, it could be the case that the profits of its rivals will decrease in network effects irrespective of who ends up owning the innovation.

Proposition 6 *With asymmetric incumbents, increased compatibility can benefit a smaller firm*

and therefore strengthen the bidding competition between incumbents over entrepreneurial firms.

In terms of equation (3), this occurs if the leading firm has a very low marginal cost ex-ante and this cost advantage over rivals prevails if a rival wins the auction (or if the entrepreneurial firm enters the market). Then, the direct effect of stronger network effects would be limited for rivals even when they own the innovation. This might imply that rivals' profits always decrease in network effects, $\frac{d\pi_{A-d}}{dz} < 0$ and $\frac{d\pi_E}{dz} < 0$. The dominating incumbent d would tend to obtain the innovation at a very low price and monopolize the market. Since equation (13) shows that increased compatibility can benefit a smaller firm (as this firm gets a larger direct profit increase from access to a larger rival network), increased compatibility could be beneficial by either ensuring profitable entry or guaranteeing a bidding competition between incumbents.

This suggests that a medium level of compatibility is likely to be desirable: too high a level of compatibility could reduce the innovation efforts as shown in Section 5.3, while too low a level of compatibility could lead to asymmetric incumbents which weakens the bidding competition for entrepreneurial firms.

6 Discussion and extensions

6.1 Innovations of lower quality

A central assumption in our model is that innovations are of sufficiently high quality. Suppose that we relax this assumption. First, consider innovations that generate market-neutral entry, $k \in (\bar{k}(e), \tilde{k})$. As shown in Figure 4 (iv), increasing the network strength from a very low initial level, $z \in [0, \tilde{z}(k))$, will increase the profit of a non-acquirer, $\frac{d\pi_N}{dz} > 0$. Only when network effects become larger than the critical value $\tilde{z}(k)$ do we observe a decrease in the profit of a non-acquiring incumbent, $\frac{d\pi_N}{dz} < 0$. As shown in Figure 8(i), this will make the locus for the net value of preemption $\Delta_{PE}(z) = v_{ii} - v_e = F - \pi_N(i)$ and the net value of entry deterrence $\Delta_{ED}(z) = v_{ie} - v_e = F - \frac{n-1}{n}\pi_N(e)$ U-shaped in network strength z. Both loci are then downward-sloping when $z \in (0, \tilde{z}(k))$ and increasing when $z \in (\tilde{z}(k), z^{\max}(k))$. As shown in Figure 8(ii), entry will then take place for medium network strengths, whereas acquisitions occur at both low and very high network strengths.

6.2 Additional exits and tipping

What if we increase the network effects beyond $z^{\max}(k)$? When $z = z^{\max}(k)$ holds, $\Delta_{PE}(z) = \Delta_{ED}(z) = F$ since $\pi_N(l) = 0$. If we increase the network slightly from $z^{\max}(k)$, one incumbent will exit. The remaining non-acquiring firm will make positive profits. This implies that the net value of entry-deterrence and preemption is reduced by $\pi_N(l) > 0$. As shown in Figure 8, this can lead to the commercialization mode shifting from acquisition to entry: that is, we might have $\Delta_{PE}(z^{\max}(k)) = \Delta_{ED}(z^{\max}(k)) = F > 0$ while $\Delta_{PE}(z^{\max}(k) + \varepsilon) = F - \pi_N(i) < 0$ and $\Delta_{ED}(z^{\max}(k) + \varepsilon) = F - \left(\frac{n-1}{n}\right)\pi_N(e) < 0$. While exits could lead to entry, it is still true that when the network effects become sufficiently large, acquisitions under bidding competition will take place.

Net value of Entry-deterrence::
$$\Delta_{ED}(z) = \begin{cases} F - (\frac{n-1}{n})\pi_N(e), & z \in (0, z^{\max}], \\ F - (\frac{n-2}{n})\pi_N(e), & z \in (z^{\max}, 1] \end{cases}$$

Net value of Preemption:
$$\Delta_{PE}(z) = \begin{cases} F - \pi_N(i), & z \in [0, z^{\max}(k)), \\ F - (\frac{n-1}{n})\pi_N(i), & z \in [z^{\max}(k), 1). \end{cases}$$

Net value

"Exit"

(i): The entry-acquisition game

0

0    $z^{PE'}$ $z^{ED'}$ $\hat{z}(k)$ z^{ED} z^{PE} $z^{\max}(k)$ 1   Network effects (z)

PE acq.   ED acq.   Entry   Entry   ED acq.   PE acq.   Entry   ED acq.   PE acq.

$l^* = i$ / $S^* = v_{ii}$ $l^* = i$ / $S^* = v_e$ $l^* = e$ $l^* = i$ / $S^* = v_e$ $l^* = i$ / $S^* = v_{ii}$ $l^* = e$ $l^* = i$ / $S^* = v_e$ $l^* = i$ / $S^* = v_{ii}$

(ii): EOS

0    $z^{PE'}$ $z^{ED'}$ $\hat{z}(k)$ z^{ED} z^{PE} $z^{\max}(k)$ $z^{ED''}$ $z^{PE''}$ 1   Network effects (z)

R_E

v_{ii}

"Exit"   PE"

v_{ii}

v_e

PE

v_e

v_{ii} PE'

$$R_E = \begin{cases} v_{ii}, & z \in (0, z^{PE'}), \\ v_e, & z \in [z^{PE'}, z^{PE}), \\ v_{ii}, & z \in [z^{PE}, z^{\max}(k)], \\ v_e, & z \in (z^{\max}(k), z^{PE''}) \\ v_{ii}, & z \in [z^{PE''}, 1]. \end{cases}$$

(ii): Reward

0

0    $z^{PE'}$ $\hat{z}(k)$ z^{PE} $z^{\max}(k)$ $z^{PE''}$ 1   Network effects (z)
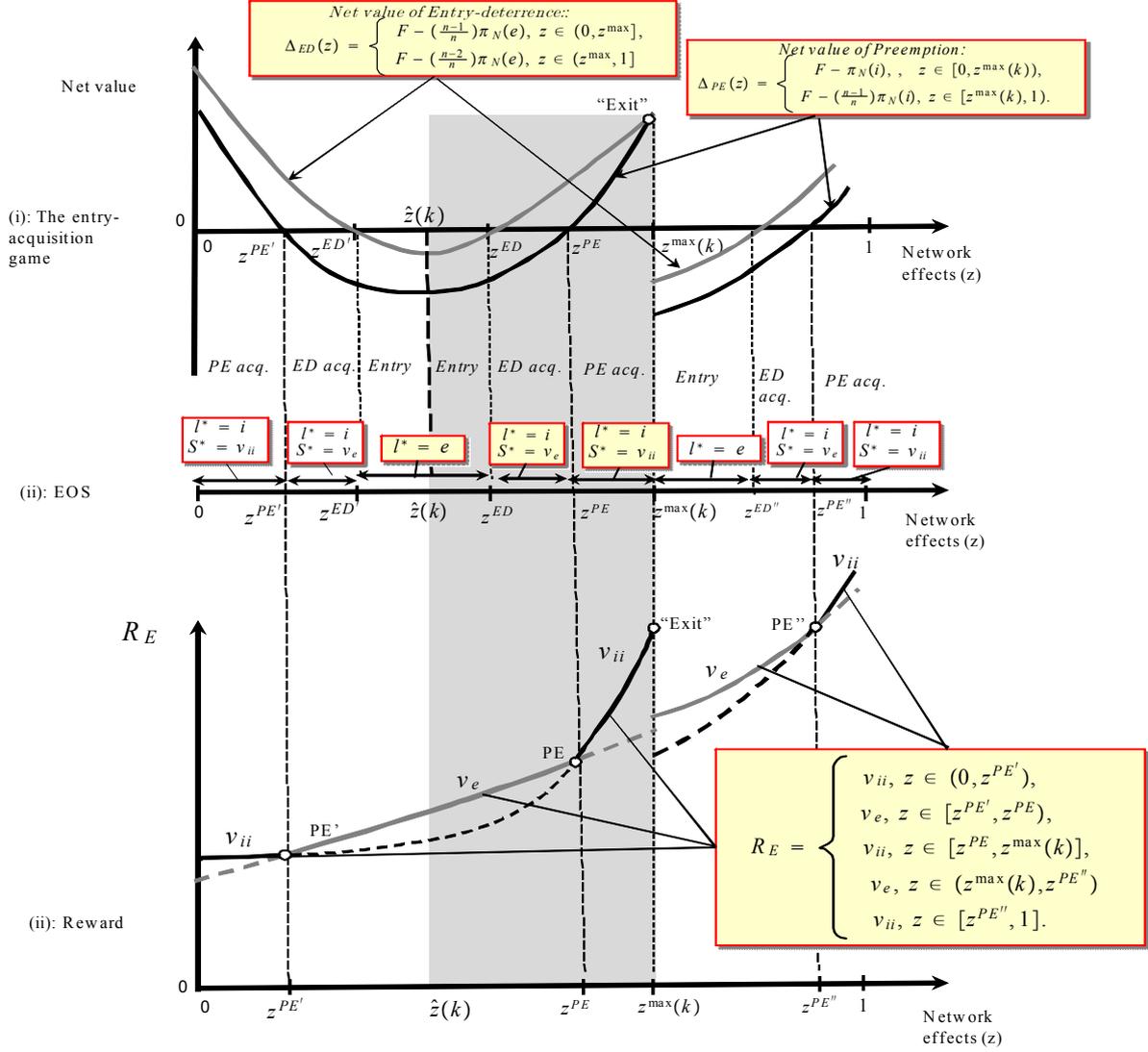
Figure 8: Illustrating the solution to the game when allowing for low-quality innovations. Part (i) illustrates the net value functions, which are now U-shaped. Part (ii) illustrates that for low quality innovations, we can have acquisitions when the network effects are weak. Part (iii) illustrates how the reward function varies across all commercialization modes.

But what if the combination of network strength and innovation quality creates such a strong position for the possessor that only the possessor will make positive profits, $\pi_N(l) = 0$? Under such "tipping", we immediately see that a preemptive acquisition will take place since $\Delta_{PE} = \Delta_{PE} = F > 0$.

6.3   Entry is not market neutral

Market structure neutral entry says that the number of firms in the industry is the same before and after entry. If the number of firms is allowed to vary, our results could be affected. Suppose that entry leads to a less concentrated market structure, i.e. if an acquisition occurs, n firms are active in the market, whereas if entry occurs, $n+1$ firms are active. To this end, replace the assumption of market structure neutral entry with the assumption that entry occurs without the exit of incumbents. Now $\pi_A(i)$ can differ from $\pi_E(e)$.

Since all incumbents remain in the market, the net value of preemption $\Delta_{PE}(z) = v_{ii} - v_e$ and the net value of entry deterrence $\Delta_{ED}(z) = v_{ie} - v_e$ are now increasing in z only if

$$v'_{il,z} - v'_{e,z} = \left[\frac{d\pi_A(i)}{dz} - \frac{d\pi_E(e)}{dz} \right] - \frac{d\pi_N(l)}{dz} > 0. \tag{20}$$

The major change is that the effects on the entrant and the acquirer of an increase in the network effect can differ: $d\pi_A/dz \neq d\pi_E/dz$. As long as $d\pi_A/dz$ is not sufficiently lower than $d\pi_E/dz$, equation (20) will hold since $d\pi_N(l)/dz$ is negative. Our main results that stronger network effects (i) promote acquisitions over entry, (ii) generate bidding competition between incumbents increasing the reward to innovation, and (iii) promote innovation incentives, will thus also hold when entry is not market neutral.

6.4   Other selling mechanisms and licensing

In our setup, an acquisition takes place through a sealed-bid first price auction with externalities. The motivation for this is that we believe that it well captures bidding competition between incumbents when acquisitions are used to gain access to new innovations. But potential rents from using a more sophisticated mechanism are foregone. Jehiel and Moldovanu (1999) have shown that sophisticated mechanisms might be needed to maximize the revenues in auctions with externalities. It might be that all firms in the industry need to provide some transfers to the seller. However, it is likely that more complicated mechanisms require the entrepreneurial firm to have an unrealistically strong commitment power (Jehiel and Moldovanu (2000)).

Our results should be robust to incorporating licensing of the innovation instead of a full acquisition of the entrepreneurial firm. If the entrepreneurial firm licenses the innovation to only one incumbent, then licensing equals an acquisition in our model and our results go through unchanged. Such a setting is natural when the innovation consists of an indivisible asset such as human capital. If the entrepreneurial firm licenses the innovation to a large number of incumbents or licenses the innovation and simultaneously enters the industry, our results could be weakened. The seller must now determine how many licenses to sell. Allowing the seller to commit to the number of licences to sell, Katz and Shapiro (1986) show that there exists an equilibrium where some potential buyers are left without a licence. Consider a setting where

the entrepreneurial firm can decide how many licences r to licence if not entering. Let $\pi_A(i, r)$ denote the profit of a buyer of a licence when there are r licenses for sale. Let $\pi_N(i, r)$ be the profit of a firm not buying a licence. Licensing by the entrepreneurial firm gives the profit $\Omega = r [\pi_A(i, r) - \pi_N(i, r)]$. For simplicity, treating r as continuous, the optimal number of licenses is:

$$\Omega'_r = \underbrace{[\pi_A(i, r) - \pi_N(i, r)]}_{(+)} + r \left[\pi'_{A,r}(i, r) - \pi'_{N,r}(i, r) \right] = 0. \tag{21}$$

In the Linear Cournot model, it can be shown that $\pi'_{A,r}(i, r) - \pi'_{N,r}(i, r) < 0$, $\pi'_{A,r}(i, r) < 0$ and $\pi'_{N,r}(i, r) < 0$, since more licenses increase aggregate output and lower the product market price, which affects a larger firm more adversely. Assuming that $\Omega''_{rr} < 0$ and m is sufficiently large, there exists an optimal $r^* < m$.

How does an increase in network effects affect the choice between licensing and entry? Define $\Omega^*(r^*) \equiv r^* [\pi_A(i, r^*) - \pi_N(i, r^*)]$. This gives:

$$
\begin{aligned}
\frac{d\Omega^*}{dz} &= \Omega'_r \frac{dr^*}{dz} + \frac{\partial \Omega^*}{\partial z} \\
&= r^* \left[\frac{d\pi_A(i, r^*)}{dz} - \frac{d\pi_N(i, r^*)}{dz} \right]
\end{aligned} \tag{22}
$$

since $\Omega'_r = 0$ from (21). So, we could have that $\frac{d\Omega^*}{dz} > \frac{dv_e}{dz} > 0$ since $\frac{d\pi_N(i, r^*)}{dz} < 0$. Hence, allowing for multiple licences to be sold, higher network effects are conducive to selling multiple licences rather than entering the market.

7   Concluding remarks

We have shown that network effects amplify the preemptive motive for acquisitions of entrepreneurial firms by increasing the relative benefit of winning the bidding competition among incumbents. This, in turn, leads to strong incentives to innovate to be acquired. We have also established that increased compatibility in network industries with a market for entrepreneurial firms can be counterproductive by lowering the equilibrium acquisition prices of entrepreneurial firms by reducing the relative advantage of acquiring entrepreneurial firms.

Our findings suggest that policy makers should put more emphasis on acquisitions of entrepreneurial firms when considering implementing compatibility requirements. A careful analysis of the effects of increased compatibility on bidding competition over innovative entrepreneurial firms in the short run is warranted as too much compatibility can have negative effects on acquisition prices and thereby depress innovation incentives. In the long run, however, more emphasis should be put on preserving the bidding competition for entrepreneurial firms: a cost of monopolization in network industries is a removal of bidding competition for entrepreneurial firms. Consequently, an intermediate level of required compatibility is likely to be optimal.

Our model also gives rise to several empirically testable predictions: (i) the ratio of acquisitions to entry in network industries should be higher the stronger are the network effects, (ii) the implementation of policies increasing compatibility should decrease the ratio of acquisitions to entry and reduce the pace of innovation in the short run, and (iii) total innovation output

(e.g. patents) by potential innovative entrants should be higher when network effects are strong. Testing these predictions seems a fruitful avenue for further research, as well as extending the model to allow for endogenously choosing compatibility, installed bases, sequential acquisitions, and systems competition.

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Appendix

A   Proof of Lemma 1 and 4

Here we will prove

- Lemma 1: with zero compatibility ($c = 0$) and with sufficiently high-quality innovations ($k > \widetilde{k}$), an increase in network effects amplifies the advantage of owning an innovation in the linear Cournot model: $\frac{d\pi_A}{dz} > 0$, $\frac{d\pi_E}{dz} > 0$, and $\frac{d\pi_N(l)}{dz} < 0$.

- Lemma 4: with sufficiently high-quality innovations ($k > \overline{k}$), increased compatibility levels the playing field by reducing the advantage of acquiring the entrepreneurial firm: $\frac{d\pi_A}{dc} < 0$, $\frac{d\pi_E}{dc} < 0$, and $\frac{d\pi_N(l)}{dc} > 0$.

A.1 Setup

We take as the starting point the model with both network effects (z) and compatibility (c) that was set up in Section 3 and extended in Section 5. Disregard fixed operating costs τ and recall that firm j faces a price of

$$P_j = a + z(\bar{q}_j + c\bar{q}_{-j}) - Q \tag{23}$$

and that taking consumer expectations as given, firms' optimal outputs are given from the first-order conditions

$$\frac{\partial \pi_j}{\partial q_j} = P_j - \delta_j - q_j^* = 0, \forall j. \tag{24}$$

The reduced-form profit function for firm j is

$$\pi_j(l) = [P_j(l) - \delta_j] q_j^*(l) = [q_j^*(l)]^2. \tag{25}$$

Differentiate the reduced-form profits in network strength and use the envelope theorem to get:

$$\frac{d\pi_j(l)}{dz} = \underbrace{\Psi_j^*(l)q_j^*(l)}_{DE} - \underbrace{\frac{dq_{-j}^*(i)}{dz}q_j^*(l)}_{SE}. \tag{26}$$

The network size is $\Psi_j^*(l) = q_j^*(l) + cq_{-j}^*(l)$. The first term $\frac{dP_j(l)}{dz}q_j^*(l) = \Psi_j^*(l)q_j^*(l)$ represents the direct effect (DE) on the profits of a higher price when the strength of the network increases, whereas the second term $\frac{dP_j(l)}{dq_{-j}}\frac{dq_{-j}^*(l)}{dz}q_j^*(l) = -\frac{dq_{-j}^*(l)}{dz}q_j^*(l)$ represents the strategic effect (SE) arising from the change in price from a changing output of competitors.

There are three types of firms ($h = \{E, A, N\}$), the entering entrant (E), the acquiring incumbent (A) and non-acquiring incumbents (N). The firm with the innovation thus has $\delta_A = \delta_E = \delta - k$, while $\delta_N = \delta$. From equation (23) and equation (24), the equilibrium outputs are:

$$q_h^*(l) = \frac{\Lambda[\varphi(\phi + n(l) - 2) - (n(l) - 1)]}{(1 - cz)[\phi^2 + (n(l) - 2)\phi - (n(l) - 1)]} \tag{27}$$

$$q_N^*(l) = \frac{\Lambda[\phi - \varphi]}{(1 - cz)[\phi^2 + (n(l) - 2)\phi - (n(l) - 1)]}, \tag{28}$$

where $\Lambda = a - \delta$ and $\varphi = 1 + \frac{k}{\Lambda}$ is a relative measure of the size of the innovation, where $\varphi'(k) > 0$. The variable $\phi = \frac{2-z}{1-cz}$ maps network strength z and compatibility c between networks to the strategic interaction between networks.

To show uniqueness, stability and existence of the Nash equilibrium, we consider a duopoly with one non-acquiring incumbent and one acquiring incumbent/entrant (it is tedious, but possible, to extend the proof to n non-acquiring incumbents). Using the assumption of market structure neutral entry (Assumption 2), $n(i) = n(e) = 2$, the optimal output for a non-acquirer is $q_N^* = \frac{\Lambda(\phi - \varphi)}{(1 - cz)(1 + \phi)(\phi - 1)}$, while the profit for the possessor is $q_h^* = \frac{\Lambda[\phi\varphi - 1]}{(1 - cz)(1 + \phi)(\phi - 1)}$ for $h = A, E$. As illustrated in Figure 6, which shows the Nash-Equilibrium under an acquisition, $\frac{d\mathcal{R}_h}{dq_N} = -1/\phi$ is the slope of the reaction function of the possessor of the innovation, whereas $\frac{d\mathcal{R}_h}{dq_N} = -\phi$ is the

slope of the reaction function of the non-acquirer. From this figure, $\phi > \varphi > 1$ is required for existence and $\phi > 1$ guarantees stability.

A.2 Proof of Lemma 1

We first show that under zero compatibility $(c = 0)$ and with sufficiently high quality innovations $(k > \widetilde{k})$, an increase in network effects amplifies the advantage of owning an innovation in the linear Cournot model: $\frac{d\pi_A}{dz} > 0$, $\frac{d\pi_E}{dz} > 0$, and $\frac{d\pi_N(l)}{dz} < 0$.

Because $\pi_h^* = [q_h^*]^2$ and $\frac{d\pi_h^*}{dz} = 2q_h^* \frac{dq_h^*}{dz}$, we can study how network effects affect profits by examining how optimal output changes with z. For simplicity, consider a duopoly. Straightforward differentiation yields:

$$\frac{dq_h^*}{dz} = \frac{\Psi_N[\phi \frac{\Psi_h}{\Psi_N} - 1]}{(1 - cz)[\phi^2 - 1]} > 0, \quad h = \{A, E\} \tag{29}$$

$$\frac{dq_N^*}{dz} = \frac{\Psi_N[\phi - \frac{\Psi_h}{\Psi_N}]}{(1 - cz)[\phi^2 - 1]} \lesseqqgtr 0 \tag{30}$$

since $\phi > 1$ and $\Psi_h = q_h^* + cq_{-h}^*$ is the size of the possessor's network while $\Psi_N = q_N^* + q_{-N}^*$ is the size of the non-acquirers' network. The relative network size is:

$$\frac{\Psi_h}{\Psi_N} = \frac{q_h^* + cq_N^*}{q_N^* + cq_h^*} = \frac{\frac{\phi\varphi - 1}{\phi - \varphi} + c}{1 + c\frac{\phi\varphi - 1}{\phi - \varphi}} > 1, \quad h = \{A, E\} \tag{31}$$

where the latter inequality follows from $\phi > \varphi > 1$. Hence, *it is always true that $\frac{d\pi_A^*}{dz} = 2q_A^* \frac{dq_A^*}{dz} > 0$ and $\frac{d\pi_E}{dz} = 2q_E^* \frac{dq_E^*}{dz} > 0$.*

Let us now turn to when $\frac{d\pi_N(l)}{dz} < 0$. From equation (30) and equation (31), we have

$$\phi - \frac{\Psi_h}{\Psi_N} = \frac{\Omega(c)}{1 + c\frac{(\phi\varphi - 1)}{(\phi - \varphi)}} \tag{32}$$

where $\Omega(c) = (\phi - c) + \frac{(\phi\varphi - 1)}{(\phi - \varphi)}(c - 1)$. It follows that the sign of $\frac{dq_N^*}{dz}$ in (30) and hence the sign of $\frac{d\pi_N(l)}{dz} > 0$ depend on the expression $\Omega(c) = (\phi - c) + \frac{(\phi\varphi - 1)}{(\phi - \varphi)}(c - 1)$. Note that $\frac{d\Omega}{dc} = (\phi + 1)\frac{\varphi - 1}{\phi - \varphi} > 0$, $\Omega(0) = \phi - \frac{\phi\varphi - 1}{\phi - \varphi} \lesseqqgtr 0$ and $\Omega(1) = \phi - c > 0$. Hence, there exists a $\tilde{c} \in (0, 1)$ for which $\frac{d\pi_N(l)}{dz} > 0$ holds for $c > \tilde{c}$. For $c = 0 < \tilde{c}$, we will now show that $\frac{d\pi_N(l)}{dz} < 0$ holds when $k > \widetilde{k}$.

Figure 9 gives a proof when networks are incompatible, $c = 0$. To derive this figure, we first insert $c = 0$ in (32) and solve the combination of relative size of the innovation φ and network interaction ϕ at which $\frac{d\pi_N(l)}{dz} = 0$. Denote this φ as $\hat{\varphi}(\phi) = \frac{\phi^2 + 1}{2\phi}$ and note that $\hat{\varphi}(\phi)$ is increasing in ϕ. This is shown in Figure 9 where $\hat{\varphi}(\phi)$ is depicted by the dotted line. It follows that for $\varphi > \hat{\varphi}(\phi)$, we have $\frac{d\pi_N(l)}{dz} < 0$, and for $\varphi < \hat{\varphi}(\phi)$, $\frac{d\pi_N(l)}{dz} > 0$. Note again that $\varphi < \phi$ is required for the existence of an equilibrium.

Figure 9 gives the inverse function $z^{-1}(\phi)$ that maps network parameter ϕ to network strength z, and maps the relative size of the innovation $\varphi = 1 + \frac{k}{\Lambda}$ to its actual size k. In the bottom left part of Figure 9, the dotted line shows combinations of network strength z
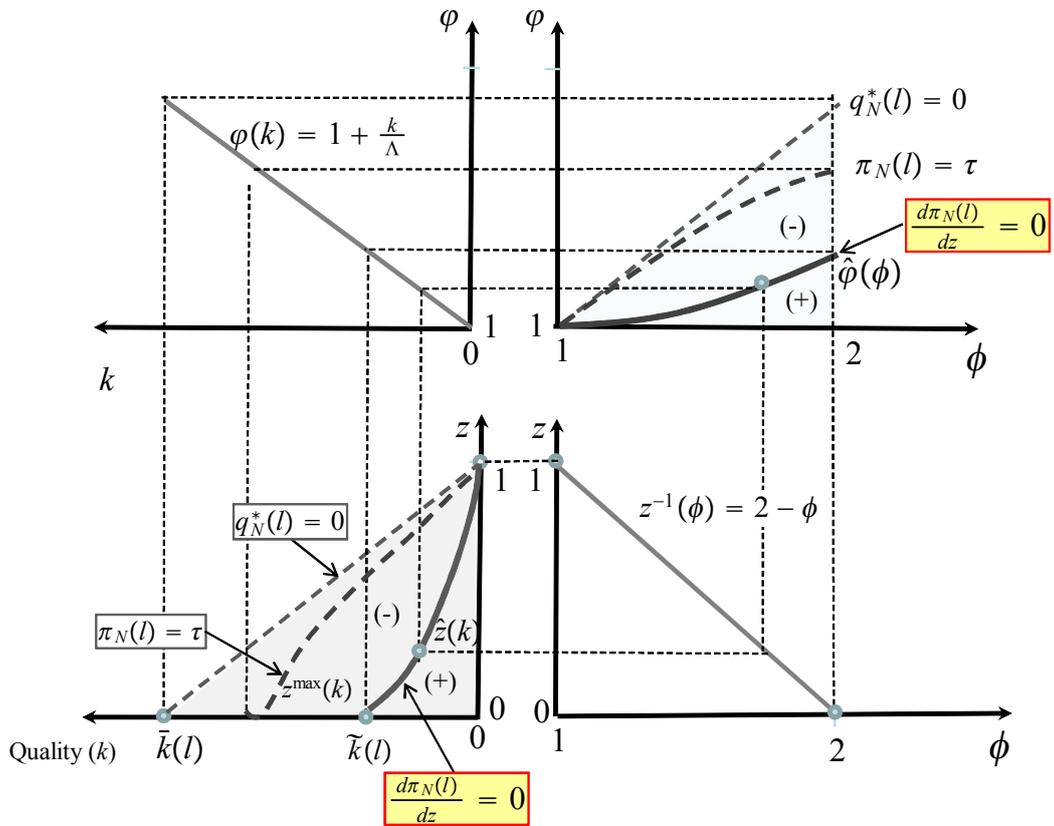
Figure 9: Illustrating the combination of parameter values for which non-acquiring incumbents' profits are reduced when there is an increase in the network effects.

and innovation size k at which $\frac{d\pi_N(l)}{dz} = 0$. Above the dotted line, $\frac{d\pi_N(l)}{dz} < 0$ holds, whereas $\frac{d\pi_N(l)}{dz} > 0$ holds below the dotted line. Since Lemma 1 assumes that $c = 0$, we have thus shown that $\frac{d\pi_N(l)}{dz} < 0$ holds when $k > \widetilde{k}$, where $\widetilde{k}$ is sufficiently large.

A.3   Proof of Lemma 4

Here we show that for sufficiently good innovations ($k > \overline{k}$), increased compatibility levels the playing field by reducing the advantage of acquiring the entrepreneurial firm: $\frac{d\pi_A}{dc} < 0$, $\frac{d\pi_E}{dc} < 0$, and $\frac{d\pi_N(l)}{dc} > 0$.

To explore the effect of increased compatibility, in a duopoly we have

$$\frac{dq_h^*}{dc} = \frac{zq_N[\phi - \frac{[\phi\varphi - 1]}{(\phi - \varphi)}]}{[\phi^2 - 1]}, \text{ and}$$

$$\frac{dq_N^*}{dc} = \frac{zq_N[\phi\frac{\phi\varphi - 1}{\phi - \varphi} - 1]}{(1 - cz)[\phi^2 - 1]} > 0.$$

It can be checked that $\frac{\phi\varphi - 1}{\phi - \varphi} > 1$ is always fulfilled and therefore it *is always true that* $\frac{dq_N^*}{dc} > 0$ *and* $\frac{d\pi_N(l)}{dc} > 0$. Next, recall that $\varphi'(k) > 0$. This implies that there exists a $\overline{k}$ such that $\phi < \frac{\phi\varphi(k) - 1}{\phi - \varphi(k)}$ when $k > \overline{k}$. Hence, for $k > \overline{k}$ it holds that $\frac{dq_h^*}{dc} < 0$ and that $\frac{d\pi_A}{dc} < 0$ and $\frac{d\pi_E}{dc} < 0$.

B   Proof of Lemma 2

First, note that $b_i \geq \max v_{il}$, $l = \{e, i\}$ is a weakly dominated strategy since no incumbent will post a bid equal to or above its maximum valuation of obtaining the innovation and that firm e will accept a bid, iff $b_i > v_e$.

B.1   Inequality I1

Consider equilibrium candidate $b^* = (b_1^*, b_2^*, ..., yes)$. Let us assume that incumbent $w \neq e$ is the incumbent that has posted the highest bid and obtains the innovation and firm $s \neq d$ is the incumbent with the second highest bid.

Then, $b_w^* \geq v_{ii}$ is a weakly dominated strategy. $b_w^* < v_{ii} - \varepsilon$ is not an equilibrium, since firm $j \neq w, e$ then benefits from deviating to $b_j = b_w^* + \varepsilon$, since it will then obtain the innovation and pay a price lower than its valuation of obtaining it. If $b_w^* = v_{ii} - \varepsilon$, and $b_s^* \in [v_{ii} - \varepsilon, v_{ii} - 2\varepsilon]$, then no incumbent has an incentive to deviate. By deviating to *no*, the entrepreneurial firm's payoff decreases since it foregoes a selling price exceeding its valuation, v_e. Accordingly, the entrepreneurial firm has no incentive to deviate and thus, b^* is a Nash equilibrium.

Let $b = (b_1, , , b_m, no)$ be a Nash equilibrium. Let incumbent h be the incumbent with the highest bid. The entrepreneurial firm will then say *no* iff $b_h \leq v_e$. But incumbent $j \neq e$ will have the incentive to deviate to $b' = v_e + \varepsilon$, since $v_{ie} > v_e$. This contradicts the assumption that b is a Nash equilibrium.

B.2   Inequality I2

Consider equilibrium candidate $b^* = (b_1^*, b_2^*, ..., y)$. Then, $b_w^* \geq v_{ij}$ is a weakly dominated strategy. $b_w^* < v_{ij} - \varepsilon$ is not an equilibrium since firm $j \neq w, e$ then benefits from deviating to $b_j = b_w^* + \varepsilon$, since it will then obtain the innovation and pay a price lower than its valuation of obtaining it. If $b_w^* = v_{ii} - \varepsilon$, and $b_s^* \in [v_{ii} - \varepsilon, v_{ii} - 2\varepsilon]$, no incumbent has an incentive to deviate. By deviating to no, the entrepreneurial firm's payoff decreases since it foregoes a selling price exceeding its valuation, v_e. Accordingly, the entrepreneurial firm has no incentive to deviate and thus, b^* is a Nash equilibrium.

Consider equilibrium candidate $b^{**} = (b_1^{**}, b_2^{**}, ..., no)$. Then, $b_w^* \geq v_{ie}$ is not an equilibrium since the entrepreneurial firm would then benefit by deviating to yes. If $b_w^* \leq v_e$, then no incumbent has an incentive to deviate. By deviating to yes, the entrepreneurial firm's payoff decreases since it then sells the innovation at a price below its valuation, v_e. The entrepreneurial firm has no incentive to deviate and thus, b^{**} is a Nash equilibrium.

B.3   Inequality I3

Consider equilibrium candidate $b^* = (b_1^*, b_2^*, ..., yes)$. Then, $b_w^* \geq v_{ii}$ is a weakly dominated strategy. $b_w^* < v_{ii} - \varepsilon$ is not an equilibrium since firm $j \neq w, e$ then benefits from deviating to $b_j = b_w^* + \varepsilon$, since it will then obtain the innovation and pay a price lower than its valuation of obtaining it. If $b_w^* = v_{ii} - \varepsilon$, and $b_s^* \in [v_{ii} - \varepsilon, v_{ii} - 2\varepsilon]$, then no incumbent has an incentive to deviate. By deviating to no, the entrepreneurial firm's payoff decreases, since it foregoes a selling price exceeding its valuation, v_e. Accordingly, the entrepreneurial firm has no incentive to deviate and thus, b^* is a Nash equilibrium.

Let $b = (b_1, ..., b_m, no)$ be a Nash equilibrium. The entrepreneurial firm will then say no iff $b_h \leq v_e$. But incumbent $j \neq e$ will then have the incentive to deviate to $b' = v_e + \varepsilon$, since $v_{ie} > v_e$. This contradicts the assumption that b is a Nash equilibrium.

B.4   Inequality I4

Consider equilibrium candidate $b^* = (b_1^*, b_2^*, ..., yes)$. Then, $b_w^* > v_e$ is not an equilibrium since firm w would then benefit from deviating to $b_w = v_e$. $b_w^* < v_e$ is not an equilibrium, since the entrepreneurial firm would then not accept any bid. If $b_w^* = v_e - \varepsilon$, then firm w has no incentive to deviate. By deviating to $b_j' \leq b_w^*$, firm j's, $j \neq w, e$, payoff does not change. By deviating to $b_j' > b_w^*$, firm j's payoff decreases since it must pay a price above its willingness to pay v_{ii}. Accordingly, firm j has no incentive to deviate. By deviating to no, the entrepreneurial firm's payoff decreases since it foregoes a selling price above its valuation, v_e. Accordingly, the entrepreneurial firm has no incentive to deviate and thus, b^* is a Nash equilibrium.

Let $b = (b_1, , , b_m, yes)$ be a Nash equilibrium. If $b_w \geq v_{ii}$, then firm w will have the incentive to deviate to $b' = b_w - \varepsilon$. If $b_w < v_{ii}$, the entrepreneurial firm will have the incentive to deviate to no, which contradicts the assumption that b is a Nash equilibrium.

Let $b = (b_1, ..., b_m, no)$ be a Nash equilibrium. The entrepreneurial firm will then say no iff $b_h \leq v_e$. But incumbent $j \neq d$ will have the incentive to deviate to $b' = v_e + \varepsilon$ since $v_{ie} > v_e$, which contradicts the assumption that b is a Nash equilibrium.

B.5 Inequalities I5 or I6

Consider equilibrium candidate $b^* = (b_1^*, b_2^*, ..., no)$, where $b_j^* < v_e \ \forall j \in J$. It then directly follows that no firm has an incentive to deviate and thus, b^* is a Nash equilibrium.

Then, note that the entrepreneurial firm will accept a bid iff $b_j \geq v_e$. But $b_j \geq v_e$ is a weakly dominating bid in these intervals, since $v_e > \max\{v_{ii}, v_{ie}\}$.