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INNOVATION OF NETWORK GOODS. A NON-INNOVATING FIRM WILL GAIN

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Abstract

We consider duopolists innovating and producing a good subject to network externalities, so that the reservation price of a consumer increases with aggregate consumption. The post-innovation network consists of two compatible sub-networks, with increased network valuation of the new product. When the non-innovating firm enjoys a larger profit than when neither firm innovates, free-riding on the winner's network as a public good arises. With such a network spillover, duopolists may underinvest in innovation.

JEL Classification: D21, D62, L15, L63.

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The "third industrial revolution" has seen rapid product innovation, especially in the telecommunication and computer industries. In both these industries consumers value the features ("quality") of the product, and also the size of the network. Take telephones as an example. The dream of a wireless phone is over one hundred years old. But a mobile phone integrated in the general telephone network became technically feasible only in the 1980s, in the form of a car phone.[1] Portable phones later appeared, but the initial models were too heavy to be carried in a pocket or purse. Nevertheless, the network gains were substantial, as calls were not restricted to people sitting in a car. Once the weight was reduced from, say 3 kg, to 0.1 kg, mobile phones became increasingly popular, "connecting people" efficiently. Small differences in features of mobile phones (e.g., duration of batteries and memory for addresses) became important to consumers.[2] A new stage of competition is appearing, revolving around the switch from the GSM standard to the 3G standard. The new standard will offer services which were unprofitable or unavailable under the GSM standard, but will continue to allow communication with phones using the old standard.

A key property of mobile phones is their high compatibility across different brands and models.[3] Use of mobile phones is thus subject to positive network externalities. This raises the question of how quality affect profits and consumers, and whether firms innovate enough.

Many aspects of goods subject to network externalities have been studied. The best studied aspect arises in the adoption decisions of consumers—a consumer who uses the goods benefits other consumers (Rohlfs (1974), Oren and Smith, (1981), Farrell and Saloner (1985, 1986), Katz and Shapiro (1985, 1986), Economides (1996)). The externality is most apparent when a critical mass is needed to sustain the market (Oren and Smith (1981), Dybvig and Spatt (1983)). A Nash equilibrium could then have no one buy the good, whereas another, Pareto-superior, Nash equilibrium could have many consumers buy the good.

Some work also considers the behavior of firms when one firm's R&D either harms or benefits other firms. Negative externalities arise across firms when one firm's new product is incompatible with the products of other firms (e.g. Katz and Shapiro (1986)).

Other work considers patent races. Loury (1979) and Lee and Wilde (1980) show that when the winner of a race controls the whole market, firms may overinvest in R&D. This result, which is most apparent in tournament models of R&D, is also examined by Delbono and Denicolo (1991). The absence of these rent-seeking opportunities may lead a monopolist to innovate less than would firms in an initially competitive industry (Arrow (1962)). Dasgupta and Stiglitz (1980) clarify the effects of market structure, showing that the market

[1] As an example, we refer to the Finnish ARP-system.

[2] These differences contributed to large changes in the market shares of different firms. Nokia raised its market share from 28% in 1999, to 31% in 2000 and 35% in 2001. Ericsson, which initially enjoyed a strong reputation and experience in telecommunication, saw its market share decline to about 9% in 2001.

[3] Ericsson customers can call Nokia customers and vice versa.

structure and competition for innovations are simultaneous processes without any causal link.

Positive externalities appear when knowledge is a public good: knowledge is costly to produce, but cheap to reproduce. Any one …rm may therefore innovate less than is socially optimal. d'Aspremont and Jacquemin (1988) consider the behavior of oligopolists when the R&D e¤ort of one …rm reduces its own production costs, and also reduces the costs of its competitors. They …nd, surprisingly, that Research Joint Ventures can either increase or reduce innovation, and can lead to higher pro…ts but lower consumer surplus. Katsoulacos and Ulph (1998) compare the behavior of …rms in a Research Joint Venture to the behavior of independent …rms. They …nd that the spillovers associated with joint ventures are at least as high as those associated with the alternative arrangement.

We consider a di¤erent externality arising from innovation. If one …rm innovates and produces a good that increase sales among some consumers, then another …rm, selling to a di¤erent group of consumers, may see its demand increase.

In considering an innovation, we therefore consider two ways in which it can increase consumer demand. First, consumers directly bene…t. For example, consumers may be willing to pay more for a lighter mobile phone, and will also use it more.[4] Second, the bene…t of each consumer increases with the number of other consumers who use the new product. Valuation of the network may increase for all consumers even if unit sales are constant. The crucial di¤erence between the two quality dimensions is that the …rm can better and more directly control the …rst one.

We shall see, as have others, that because duopolists e¤ectively engage in a rent-seeking contest (with a successful …rm winning sales at the expense of the other …rm), they may spend too much on innovation. But we shall also see that the externalities generated by innovation may lead the duopolists to spend less on innovation than the level that would maximize aggregate pro…ts or social welfare. That is, a …rm which does not innovate can bene…t from an innovation by the other …rm that increases aggregate demand, and therefore increases demand for the products of both …rms.[5] In contrast to much of the literature, we show that a loser in the innovation race pro…ts from the other …rm's success. For the sake of exposition, the argument is …rst presented in the main text using the simplest framework. The Appendix extends the argument to consider downward sloping demand.

Recent market competition between Nokia and Ericsson illustrates the issues we consider. Nokia developed mobile phones with better batteries, shapes, and other features. Though that reduced Ericsson's market share and pro…ts, Nokia's innovations may have helped Ericsson survive through the network e¤ect between consumers.

[4] Bental and Spiegel (1995) call this a traditional quality improvement.

[5] A related topic, the public good nature of standards, is discussed by Kindleberger (1983).

1 Assumptions

1.1 Products

Two …rms, j and k, initially produce identical products which are subject to network externalities in consumption. One feature of the product, f_o, is of equal value to all consumers. Each consumer buys just one good.

Firms can invest in developing a product with an additional feature, f_n, resulting in improved quality.

1.2 Consumers

Consumers are of two types, A and B. The number of type-i consumers is x_i. Each type-B consumer has zero willingness to pay for the new feature, but values the old feature at f_o. Each type-A consumer values the old feature at f_o and the new feature at $f_n > 0$. Consumers are thus heterogeneous in that type-A consumers value the new feature, whereas type-B consumers do not. But, as will be elaborated below, all consumers equally value the network.[6] The total number of consumers is $x_B + x_A = 1$. The number of consumers of each type is …xed.

The new product generates a larger network externality than does the old product. The di¤erence may arise because the users of the new product are more active. As an example, consider mobile phones which supplemented wired phones. Consumers who use only wired phones bene…t from the introduction of wireless phones because they can connect to those. As another example, consider an improved mobile phone weighing 100 grams instead of 3 kilograms. As the light phone is carried more easily, the users of the older type bene…t from users of the new product.

In the spirit of Katz and Shapiro (1985), we consider equilibria where expectations of consumers are ful…lled. To simplify notation in the following, we do not distinguish between expected and realized network sizes; we assume that the expectations are realized in equilibrium.

The network externality from each old phone is v. The network externality from each new phone is v_n, with $v_n > v$. When only old phones are used, the willingness to pay for an old phone by each consumer is

$$f_o + v(x_B + x_A) = f_o + v: \tag{1}$$

If type-A consumers use new phones while all type-B consumers use old phones, the willingness to pay for a new phone by each type-A consumer is

$$u_A = f_o + f_n + vx_B + v_n x_A: \tag{2}$$

[6] de Palma and Leruth (1996) make similar assumptions, in a di¤erent context. They consider consumers who di¤er in their willingness to pay for the externality within the same network. Here we consider a model where consumers' willingness to pay for the network varies.

The willingness to pay by each type-B consumer (who continues to use an old phone) is

$$u_B = f_o + vx_B + v_n x_A: \qquad (3)$$

These assumptions imply an externality: the user of an old phone benefits when others consume new phones. We structure our model to focus on externalities arising from improved product quality rather than from an increase in the number of users. Our assumptions, relaxed in the Appendix, ensure that in equilibrium all consumers buy a phone; an innovation induces type-A consumers to buy new instead of old phones.

1.3 Firms

The firms engage in an R&D race to develop the new feature. Both may succeed, both may fail, or only one may succeed. The probability that firm i innovates is α_i, which lies between 0 and 1. Firms are symmetric.

Without loss of generality, if only one firm innovates, we call it firm j, and call firm k the unsuccessful firm. An innovating firm produces two goods, one good with only the old feature, and one good with both the old and the new features. A non-innovating firm produces only the good with the old feature.

If neither firm innovates then both sell old phones to all consumers, dividing the market equally.

If a new phone is developed, then new phones will be sold to type-A consumers, and old phones will be sold (at a lower price) to type-B consumers. We shall suppose that the market for old phones is equally divided between the firms: each sells $x_B=2$. If j innovates while k does not, j sells to all type-A consumers. The non-innovating firm thus loses customers (half of the type-A consumers). But since use of the new good by type-A consumers benefits type-B consumers, the willingness to pay for the old good by type-B consumers increases.

Firms must decide how much to spend on research and development, and how much to produce of each type of good, after realizing the outcomes of the R&D efforts. Marginal production cost is zero. Thus, maximizing profits in period 2 is equivalent to maximizing revenue.

2 Prices

2.1 No firm develops new phones

Suppose first that no firm develops new phones. Then the market price, p_o^f must be equal across the two old products. And since we suppose that all consumers equally value old phones, the marginal consumer is also the average consumer:[7]

$$p_o^f = f_o + v(x_B + x_A): \qquad (4)$$

[7] For discussioin of a hedonic price, which is standard in the literature, see Katz and Shapiro (1985).

Were price greater than $f_o + v(x_B + x_A)$, no consumer would buy. Were price less than $f_o + v(x_B + x_A)$, neither …rm would be maximizing pro…ts.[8]

2.2 One …rm develops new phone

Suppose that one …rm develops a new phone, with new phones sold to type-A consumers and old phones sold to type-B consumers. Then two conditions hold for pro…t maximization. First the price of an old phone generates zero consumer surplus, or $p_o = f_o + vx_o + v_n x_n$. Of course, the market price of an old phone is higher than when no new phones are produced, generating the possibility of free-riding by …rms.

Second, the price of a new phone must make a type-A consumer indi¤erent between consuming an old and a new phone:

$$f_o + f_n + vx_B + v_n x_A - p_n = f_o + vx_B + v_n x_A - p_o = 0. \tag{5}$$

Of course, the price of the new phone exceeds the price of an old phone. This generates the gain to a …rm of innovating when its competitor does not.

The relations between the market price for old phones when no new phones are available (p_o^f) and for old phones when new phones are available (p_o), and for new phones (p_n) are

$$p_o^f = f_o + v(x_B + x_A); \tag{6}$$

$$p_o = f_o + vx_B + v_n x_A; \tag{7}$$

and

$$p_n = f_o + f_n + vx_B + v_n x_A. \tag{8}$$

Recall that all consumers of each type are identical, and so the demand curve by each type of consumer is perfectly elastic at his willingness to pay for a phone. Therefore goods will be sold to all consumers. We suppose for simplicity that the marginal cost of production is zero, so that in period 2 a …rm's pro…ts equals its revenues. These revenues are

1. If neither …rm sells a new phone, each earns

$$\pi^f = \frac{1}{2}p_o^f. \tag{9}$$

2. If …rm j sells a new phone and …rm k does not, then …rm j earns

$$\pi_j = x_{jo}p_o + x_A p_n \tag{10}$$

$$= \frac{1}{2}x_B[f_o + v(x_{jo} + x_{ko}) + v_n x_A] \tag{11}$$

[8] As the consumer surplus equals zero, so do the hedonic prices.

$$+x_A[f_o + f_n + v(x_{jo} + x_{ko}) + v_n x_A];$$

where $x_{jo} + x_{ko} = x_B = 1 - x_A$. Firm k, which sells only old phones, splits the market for type-B consumers. It earns

$$\pi_k = \frac{1}{2} x_B [f_o + v(x_{jo} + x_{ko}) + v_n x_A]: \tag{12}$$

2.3 Both firms innovate

If both firms sell new phones, each gets half the market for type-A consumers and type-B consumers. Each earns

$$\pi^s = \frac{1}{2} x_B p_o + \frac{1}{2} x_A [f_o + f_n + v x_B + v_n x_A]: \tag{13}$$

3 Free riding and innovation

We now turn to determine spending in period 1 on research and development. Two effects are at play. First, a firm which develops a new phone while the other firm does not enjoys high profits from selling new phones to type-A consumers. This generates a rent-seeking contest. Second, as mentioned above, a firm which sells new phones increases demand for old phones by type-B consumers, thereby increasing the profits of the other firm which sells old phones. This generates free riding by the firms.

Lemma 1 A firm earns higher profits if it develops a new phone than if it does not.

This means that $\pi_j > \pi^f$. The difference between the two values generates the rent extraction effect, or increases the profitability of R&D.

Definition 1 Define $v_n^c = \left(\frac{1}{1-x_A}\right)[f_o + 2v - v x_A]$. We call this the critical valuation of the network.

Lemma 2 The free-riding incentive $\pi_k > \pi^f$ arises if $v_n > v_n^c$.

The proof follows from developing $\pi_k > \pi^f$ and noting that $x_B = 1 - x_A$. QED

A firm which fails in developing a new phone thus earns higher profits if the competing firm does develop a new phone. Why? Though the firm will sell nothing to type-A consumers, the type-B consumers to whom it sells old phones benefit from the spillover of the network created by the rival firm, and so have a greater willingness to pay. The network effect will dominate if $v_n > \frac{1}{1-x_A}[f_o + 2v - v x_A]$. If the inequality holds, $\pi_k > \pi^f$, and one firm may want to free-ride on the other firm's efforts on innovation.

Lemma 3 The critical valuation of the network v_n^c increases with x_A.

The greater the number of type-A consumers, the more sales the non-innovating firm loses to the innovating firm. To compensate, the network valuation by the type-B consumers must be sufficiently high to increase their willingness to pay a higher price. Obviously, a necessary condition for free-riding in innovation is that $v_n > v$.

Lemma 4 A firm which sells new phones earns higher profits when it is the sole seller of new phones: $\pi_j > \pi^s$.

Proof:

$$\pi_j - \pi^s = \frac{1}{2} x_A (f_o + f_n + v x_B + v_n x_A) > 0. \tag{14}$$

Note that $\pi_j - \pi^s$ increases with the number of the type-A consumers. In the following, we shall call $\pi_j - \pi^s$ the single-success margin.

Lemma 5 A firm enjoys higher revenue when both firms innovate than when its rival innovates and it does not: $\pi^s > \pi_k$.

This follows from the observation that in both cases the network is enhanced and each consumer's willingness to pay for a phone increases. When both firms innovate, they share the market for new phones, which are sold at a high price. We thus have $\pi_k = \frac{1}{2} x_B p_o < \pi^s$.

3.1 Spending on R&D

In period 1, firm i chooses α_i, the probability that it innovates. Each firm's success in R&D is independent of the other's, so both may succeed, both may fail, or only one may succeed. The probability that firm j succeeds while firm k fails is $\alpha_j(1 - \alpha_k)$. The probability that both succeed is $\alpha_j \alpha_k$. Let the cost of effort which yields success with probability α_i be $\frac{1}{2} h \alpha_i^2$ for $i = j, k$ and $h > 0$.

The ex ante expected profits of firm i over two periods are V_i. Firm j maximizes its expected profits over two periods

$$V_j = \alpha_j(1 - \alpha_k)\pi_j + (1 - \alpha_j)\alpha_k \pi_k + \alpha_j \alpha_k \pi^s + (1 - \alpha_j)(1 - \alpha_k)\pi^f - \frac{1}{2} h \alpha_j^2. \tag{15}$$

The same holds for firm k. The first-order condition (which determines the reaction function) for firm j is

$$\alpha_j = -\frac{(\pi_k - \pi^f) + (\pi_j - \pi^s)}{h} \alpha_k + \frac{\pi_j - \pi^f}{h}. \tag{16}$$

The inequalities $(\pi_k > \pi^f)$ and $\pi_j > \pi^s$ imply that $\partial \alpha_j / \partial \alpha_k < 0$. R&D efforts are thus strategic substitutes.

Three mutually reinforcing mechanisms make the innovation efforts α_j and α_k strategic substitutes. First, the free-riding incentive $\pi_k > \pi^f$ works in this direction. Second, the effect of the single-success margin, $\pi_j > \pi^s$ consists of two elements. In the profit function, the single-success profit π_j increases with R&D spending by its rival. Moreover, the effect of the simultaneous-success profit π^s is the opposite (positive), as it becomes more likely that both will succeed.

Suppose that $0 < \alpha^N < 1$.[9]. Then under symmetry, the Nash equilibrium satisfies

$$\alpha^N = \alpha_j^N = \alpha_k^N = \frac{\pi_j - \pi^f}{h + (\pi_k - \pi^f) + (\pi_j - \pi^s)}. \qquad (17)$$

Thus, spending on R&D is subject to two opposing effects. The rent-extraction effect increases profits from innovation. If the network valuation of the new product is sufficiently large, the free-riding effect reduces a firm's benefit from innovation.

The rent-extraction effect (see Lemma 1) operates through two channels, the term $\pi_j - \pi^f$ in the numerator, and the single-success revenue $\pi_j - \pi^s$ in the denominator. The free-riding effect operates through $\pi_k - \pi^f$ in the denominator.

4 Social welfare

This section examines the socially optimal level of R&D. We consider firms developing a product (such as a phone), where development can be independently undertaken at two places. The social planner can assign development to both laboratories (firms) or to one laboratory only. We consider both the cases where the planner can and cannot require a successful firm to share its innovation with the other firm.

4.1 Sharing innovations

Suppose first that the planner assigns the research task to two laboratories, and requires any innovation to be shared. Expected social welfare is then

$$W_2^s = 2\left[\alpha_j \alpha_k \pi^s + \alpha_j (1 - \alpha_k)\pi^s + \alpha_k (1 - \alpha_j)\pi^s + (1 - \alpha_j)(1 - \alpha_k)\pi^f\right] \qquad (18)$$

$$- \frac{1}{2} h \alpha_j^2 - \frac{1}{2} h \alpha_k^2.$$

The three first terms represent the social return under success and information sharing; the fourth term represents the social return under failure. Under symmetry, the socially optimal effort for each firm is

$$\alpha_2^s = \frac{2(\pi^s - \pi^f)}{h + 2(\pi^s - \pi^f)}. \qquad (19)$$

[9] In all the equilibria we study, $\alpha > 0$. We also suppose that R&D is sufficiently costly to make $\alpha < 1$

Consider next whether it would be socially desirable to restrict the development effort to a single laboratory, thereby avoiding possible duplication. With two laboratories, the probability that at least one of the laboratories succeeds is $[\alpha_2^s]^2 + 2(1 - \alpha_2^s)\alpha_2^s$. Were this success probability achievable at a lower cost by assigning development to a single laboratory, that choice would increase profits (which here equal social welfare): firms would earn the same revenue at lower cost or earn a higher revenue at the same cost. The condition for a single assignment to be socially optimal given information sharing is

$$\frac{1}{2}h\left([\alpha_2^s]^2 + 2(1 - \alpha_2^s)\alpha_2^s\right)^2 < 2\left[\frac{1}{2}h[\alpha_2^s]^2\right]. \tag{20}$$

This holds when $\alpha_2^s > 2 - \sqrt{2}$. Verbally, if the optimal effort devoted to R&D is high, optimality requires that only one firm do R&D .[10]

4.2 Private information

Suppose the planner cannot require information sharing. Suppose, however, that the planner can require the firms to coordinate their joint research effort. This appears natural when the focus is on the analysis of free riding. Since firms extract all consumer surplus, in our model maximizing social welfare is the same as maximizing joint profits: $W_2^p = 2V_j$. Imposing symmetry, $\alpha_j = \alpha_k$, the socially optimal value of α satisfies

$$\alpha_2^p = \frac{\left(\pi_j - \pi^f\right) + (\pi_k - \pi^f)}{h + 2(\pi_k - \pi^f) + 2(\pi_j - \pi^s)}. \tag{21}$$

We find that whether firms overinvest or underinvest in R&D is determined by opposing incentives. The standard rent extraction mechanism induces firms to overinvest. The public-good aspects of innovation tends to make firms spend too little on R&D.

To see these effects at work, compare, the first-best level of spending, α_2^p, to the Nash–equilibrium level, α^N. The terms $\pi_k - \pi^f$ in α_2^p capture the free-riding effect. The remaining difference between α_2^p and α^N reflects the rent extraction effects, and captures the overinvestment incentive. The key element is the non-innovating firm's profits, π_k, when the rival innovates. For overinvestment to appear, the firm which fails in developing a new phone must profit sufficiently from sales of new phones by its rival.

The free-riding effect dominates if $\alpha^N < \alpha_2^p$. This holds if

$$h > \left(\pi_j - \pi^f\right) - (\pi_j - \pi^s) - (\pi_k - \pi^f) + \frac{\left(\pi_j - \pi^f\right)(\pi_j - \pi^s)}{(\pi_k - \pi^f)}.$$

Intuitively, if R&D is highly costly, a firm finds it profitable to free ride on the rival's network.

[10] This result follows from the convexity of the cost function. Were development costs described by a different cost function, for example $c(\alpha) = -\alpha - \log(1 - \alpha)$, social optimality would have both firms do R&D.

We so far considered symmetric equilibria in R&D. With only one of two firms doing R&D and without information sharing, social welfare is

$$W_1^p = \alpha_j(\pi_j + \pi_k) + (1 - \alpha_j)2\pi^f - \frac{1}{2}h\alpha_j^2.$$

The optimal R&D effort at one firm is then

$$\alpha_1^p = \frac{\pi_j - \pi^f + (\pi_k - \pi^f)}{h} > \alpha_2^p.$$

Whether assigning R&D to one firm is socially efficient, however, obviously depends on the technology of innovation. With one firm, duplication is eliminated, but increasing marginal cost of R&D may make such an allocation excessively costly. A planner may therefore want both firms to do R&D, particularly if fixed costs are low. The socially optimal allocation of R&D is then determined by whether W_1^p is greater or less than W_2^p.

5 Monopoly

Consider a monopolist who extracts all consumer surplus, so maximizing profits maximizes social welfare. If, however, market entry is sufficiently inexpensive, it makes sense to compare R&D under monopoly with R&D under duopoly. We ask under what condition a monopolist chooses the socially optimal level of R&D. A monopolist's expected profits are

$$V_j = \alpha_j 2\pi^s + (1 - \alpha_j)2\pi^f - \frac{1}{2}h\alpha_j^2. \tag{22}$$

A monopolist's spending on R&D is then

$$\alpha^M = \frac{2(\pi^s - \pi^f)}{h}. \tag{23}$$

We find

Proposition 1 If type-A consumers are numerous, then a monopolist invests more on R&D than would each duopolist.

Proof. The result follows from noticing that $d(\pi^s - \pi^f)/dx_A > 0$.

We cannot exclude the possibility that a monopolist spends more on R&D than duopolists jointly spend, $2\alpha^N$. The welfare implications of monopoly are therefore ambiguous. If the duopolists' spending on R&D exceeds the socially optimal level, then the monopolist would spend too much. If the duopolists free ride and underinvest, then a monopolist's spending could lie closer to the social optimum.

6 Conclusion

Many countries have been waiting for the introduction of 3G phones, with introductions repeatedly delayed. A potential explanation is discussed in our paper: …rms may free ride on the customer network of their competitors.

Preference uncertainty is an extension worth exploring. Suppose …rms are uncertain ex ante whether consumers will like the new feature or not. With 3G-mobile phones this is a billion dollar question: if consumers do not like the Nokia version, the market structure may change. If consumers like the Sony version, we may see a Sony-Ericsson comeback.

Lastly, it may not be quality uncertainty in the traditional sense which is relevant. One might also ask whether uncertainty about the network e¤ect complicates the industry equilibrium.

7 Appendix: Downward-sloping demand

We saw that the non-innovating firm may gain from an innovation by the other firm. We also saw that with inelastic demand the firms may underinvest. We now extend this result to consider downward-sloping demand.

Recall that potential consumers are heterogenenous. We scale their mass to $N = 1$, and index consumers in declining order of their basic willingness to pay, f_o^i. This value is uniformly distributed on $[0; f_o]$, where f_o is thus the maximal basic willingness to pay for the old product: $f_o \geq f_o^i$. Define total willingness to pay when one good is available as

$$f_o^i + vx;$$

and v is a consumer's valuation of the network effect. Let the number of buyers be x, with $0 \leq x \leq 1$. Define the marginal consumer as the one with a net benefit of 0, so that $f_o^m + vx = p$.

To illustrate, consider a monopoly. The price p determines the quantity sold. Greater x brings into the market a marginal consumer with a lower basic willingness to pay. Clearly, $f_o^m = f_o(1 - x)$. A monopolist chooses p (or x) to maximize $\pi = px = [f_o^m + vx]x$, resulting in the profit-maximizing output

$$\hat{x} = \frac{f_o}{2(f_o - v)};$$

with $\frac{\partial \hat{x}}{\partial v} > 0$ and $\frac{\partial \hat{x}}{\partial f_o} < 0$.

Suppose instead that two firms produce perfect substitutes, so that the prices of the two goods must be identical. Output is $x = x_j + x_k$. Firms compete by price, but are constrained by their production capacities. As Kreps and Scheinkman (1983) show, this justifies the analysis in terms of Cournot-Nash quantity competition.[11] Cournot-Nash equilibrium outputs are

$$x_j = x_k = \frac{f_o}{3(f_o - v)};$$

with profits

$$\pi^f = \frac{f_o^2}{9(f_o - v)}:$$

7.1 No firm innovates

Suppose neither firm innovates, with each then earning π^f. We note that each duopolist produces less than would a monopolist. Joint output of the duopolists, however, exceeds the monopoly output.

[11] This view is most naturally motivated by high costs of changing capacities.

7.2 One …rm innovates

Suppose that one of the two …rms innovates. This divides the consumer mass $N = 1$ into two exclusive groups of consumers. Consumers in one group, say type A with size A, value the new phones more than old phones, and are therefore potential buyers of new phones. Consumers in the second group have mass $B = 1 - A$; these consumers place no value on using a new phone therefore would not buy one.[12] Consequently, some type-A consumers buy the new product while some of them buy the old product (and some may buy neither one).The marginal type-A consumer must be indi¤erent between buying the new and old product.

We will now determine how many type-A people and how many type-B people buy phones. We assume that product innovation increases the maximum basic willingness to pay by a type-A person to $f_o + f_n$. Then, the willingness to pay for new phones by type-A people is uniformly distributed on $[0; f_o + f_n]$. The maximum willingness to pay by a type-B person remains f_o. Type-A users and type- B users bene…t identically from the network e¤ect of the new product. As in the main text, the network valuation of the new product is $v_n > v$.

Consider an arbitrary type-A buyer, say a with location a on $[0; A]$. His basic willingness to pay for a new phone is $f_N^a = (1 - \frac{a}{A})(f_o + f_n)$. His basic willingness to pay for an old phone is $f_O^a = (1 - \frac{a}{A})f_o$. Let the prices and outputs of the new and old phones be (p_N, p_O) and $(x_N; x_O)$. Incorporating the network e¤ect, the marginal type-A consumer, say m, is indi¤erent between buying the new phone and the old phone, or his consumer surplus from the old and the new phones are equal:

$$f_N^m + v_n x_N + v x_O - p_N = f_O^m + v_n x_N + v x_O - p_O:$$

Substituting $f_N^m = (1 - \frac{m}{A})(f_o + f_n)$ and $f_O^m = (1 - \frac{m}{A})f_o$ we can can solve for sales of new phones. Sales are determined by the marginal type-A buyer, $x_N = m = A[1 - \frac{p_N - p_O}{f_n}]$. Solving for the price of the new phone gives

$$p_N = p_O + f_n - \frac{f_n}{A} x_N:$$

Note that the monopolistic producer of a new phone is constrained in pricing it by this indi¤erence condition. Indeed, if some type-A consumers buy old phones, then the marginal consumer of a new phone necessarily enjoys positive consumer surplus. Note that some type-A consumers may buy the old phone. The number of potential consumers for old phones is $1 - x_N$, including some type-A consumers and all type-B consumers. The demand schedule for old phones is kinked; beyond some quantity it must have the same slope, $-f_o$, as the demand when no innovation was available.

Consider an arbitrary buyer of the old good, say ab (because both type-A consumers and type-B consumers buy it) with location ab on $[0; 1 - x_N]$. His basic willingness to pay for the phone is $f_O^{ab} = (1 - x_N - ab)f_o$. Output of old

[12] Intuitively, we can think that A-people are talkative whereas the B-people are not.

phones is ab. We denote it by x_O. Moreover, the marginal consumer of the old product has zero consumer surplus:

$$f_o(1 - x_N - x_O) + v_n x_N + v x_O - p_O = 0.$$

This condition determines the price of the old product, expressed in terms of the outputs, $p_O = f_o(1 - x_N - x_O) + v_n x_N + v x_O$.

The innovating firm, say j, earns revenue from selling both new phones and old phones. The firm that does not innovate, firm k, earns revenue only from selling old phones.

Let the quantity of old phones sold by the innovating firm be x_{jo}; the quantity sold by the non-innovating firm is x_{ko}. Total unit sales of old phones is $x_O = x_{jo} + x_{ko}$. Profits are

$$\begin{aligned}\pi_j &= p_N x_N + p_O x_{jo}\\ \pi_k &= p_O x_{ko}.\end{aligned}$$

Inserting price schedules yields profit functions

$$\begin{aligned}\pi_j &= \left(f_o + f_n - \frac{Af_o + f_n}{A}x_N + v_n x_N + (v - f_o)(x_{jo} + x_{ko})\right)x_N + \\ &\quad (f_o(1 - x_N) - f_o(x_{jo} + x_{ko}) + v_n x_N + v(x_{jo} + x_{ko}))\,x_{jo}\\ \pi_k &= (f_o(1 - x_N) - f_o(x_{jo} + x_{ko}) + v_n x_N + v(x_{jo} + x_{ko}))\,x_{ko}\end{aligned}$$

The first-order conditions for maximization are

$$\begin{aligned}\frac{\partial \pi_j}{\partial x_N} &= f_o + f_n - 2\frac{Af_o + f_n}{A}x_N + 2v_n x_N + (v - f_o)(x_{jo} + x_{ko}) + (v_n - f_o)\,x_{jo} = 0\\ \frac{\partial \pi_j}{\partial x_{jo}} &= (v_n + v - f_o)x_N + f_o(1 - x_N) - (f_o - v)(2x_{jo} + x_{ko}) = 0\\ \frac{\partial \pi_k}{\partial x_{ko}} &= f_o(1 - x_N) - (f_o - v)(x_{jo} + 2x_{ko}) + v_n x_N = 0.\end{aligned}$$

The duopoly Cournot-Nash equilibrium outputs of old phones by firms k and j are

$$\begin{aligned}x_{jo} &= \frac{f_o + (v_n + 2v - 3f_o)\,x_N}{3(f_o - v)}\\ x_{ko} &= \frac{f_o + (v_n - v)\,x_N}{3(f_o - v)},\end{aligned}$$

where the output of new phones, x_N, is yet to be determined.

Lemma 6 If the innovating firm sells the new product, $(x_N > 0)$, the output of the non-innovating firm is higher than if no new product is sold.

The innovating firm may, instead, increase or reduce its sales of the old product, depending on the network valuation of the new product.

Lemma 7 If the network valuation of the new product is sufficiently large, $v_n > 3f_o - 2v$, the innovating firm produces more of the old product than each firm does when no firm innovates

This effect arises because firm j, which innovated, now has an additional gain from increasing its output of the old product. The network effect makes increased use of the old product, x_{jo}, increase demand for the new product, on which firm j has a monopoly. An opposing effect arises, however, when greater output of the old product reduces its price, and thereby the price of the new product.

Solving for the price of the old product, $p_O = \frac{f_o + (v_n - v)x_N}{3}$, the profit of the non-innovating firm k, is

$$\pi_k = \frac{[f_o + (v_n - v)x_N]^2}{9(f_o - v)}.$$

Note that the profit when no firm innovates is $[f_o]^2/(9(f_o - v))$, which is less than π_k.

Thus the non-innovating firm profits from an innovation by the other firm.

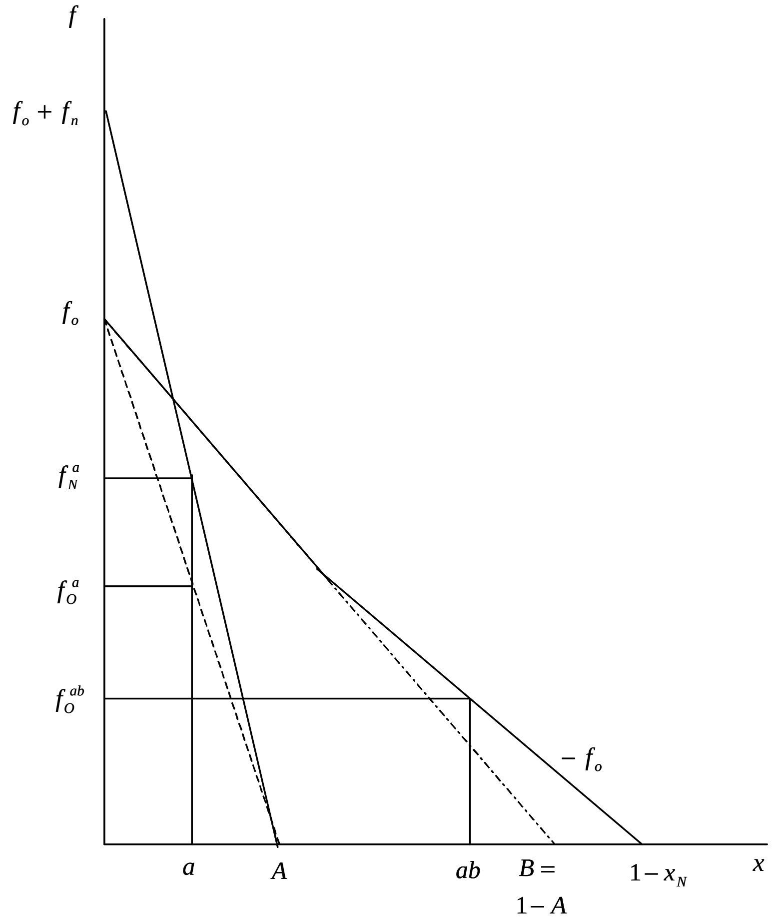

Figure 1: Demand of new and old product when one …rm innovates

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