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Network Economies for Open Source Technologies* (OST)

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ABSTRACT

We focus on a contestable market with network externalities with an incumbent and an entrant. The incumbent, unlike the entrant, already has an installed base of consumers. We look at decision situations of firms regarding how proprietary they want to make their technology , either through patent protection or through development in open source systems (OSS). We explicitly model the direct and indirect effects of network externalities. For example, more software companies are willing to produce programs for an operating system (OS) if it has a larger consumer base. This increased competition could lead to an improvement of the quality of the OS. The model predicts that using open source technologies is likely to enhance the rate of R&D , and consequently the quality of the product.. An incumbent that would choose this strategy is likely to deter entrance of a newcomer because it can play out its advantage of a larger network.

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INTRODUCTION

Research and Development (R&D) is a crucial phenomenon both from the point of view of the individual firm and the economy as a whole. Since innovation could be regarded as a public good, society as a whole benefits from innovation. However, the private benefits to a firm from innovating are likely to be different from the social benefits. In the absence of any mechanism preventing it, the benefits to an innovating firm are likely to be quickly dissipated by the entry of other imitating firms. In such a scenario, firms are unlikely to innovate. Thus according to conventional thinking, firms need to have some sort of reward for innovating. Intellectual property rights such as patents and copyrights provide this compensation. A big portion of the R&D literature has focused on the optimal patents' duration and breadth and the incentive of firms to innovate.

However, a different trend has emerged these days especially with the increasing proliferation of hi-tech (network) industries. Instead of trying to get exclusive ownership rights, an increasing number of firms are making their technology freely available i.e., their technology is no longer proprietary or 'open source' (Cane, Economist, 2004).

In the so-called browser war, in the 1990s, we have witnessed intense competition in the market for internet browsers between Microsoft and Netscape. Netscape had a major head start on Microsoft, controlling 90% of the browser market by 1996 before Microsoft started aggressively selling in the market. With the entry of Microsoft, both firms engaged in a race to have the best available product.

Given the intense competition between the two firms, by the end of 1997 Microsoft was pricing the Internet Explorer free. In contrast, Netscape was charging corporations licensing fees for using their browser. By the end of 1997, Microsoft had stolen a large chunk of Netscape's market share. Netscape eventually followed suit and started giving away its browser free.

The extended battle between Microsoft and Netscape had its toll on the profits of both companies. In 1998 Netscape came up with a new strategy and decided to release its source code, the actual line of programming language, for the Netscape Communicator. This allowed users and developers to look inside the workings of the browser, to modify the software and even to redistribute the new version under their own brand name, provided that the modified source code was also freely available. The whole idea is to turn the entire internet community into a vast research division for Netscape browser.

The term 'open source software' has been widely used in the popular and professional literature (Varian and Shapiro, 2003; Lerner and Tirole, 2004). Instead of keeping their technology proprietary, the firms will distribute it freely. It is this phenomenon that this chapter attempts to explore. We wish to study the decisions of firms whether to keep their technologies proprietary or not.

Even though the whole unorthodox open approach may seem counterintuitive, Netscape was not the only one who employed it. Apache, a program for serving world wide web sites, and Sendmail, a program that routes and delivers internet electronic mail, are examples of free open source programs that dominate the market. Open source approaches have been expanded to the biotechnology and health care industries, Economist (2004a). Linux, an increasingly popular operating system created in 1991 is another classic example of successful open source software. Many of the programmers and software designers advocating OSS may share a utopian vision of software development, or they may simply want to prove themselves to be better than software giant Microsoft. However, the whole idea of OSS may not be so anti-capitalistic as it seems. It is hard to believe that profit-aiming firms will employ the OSS strategy without considering more pragmatic matters. The emergence of OSS as an observable phenomenon may be because the markets under consideration are no longer conventional markets. These markets exhibit "network externalities"- a market has network externalities when buyers of a good exert positive benefits on the other users of the same good. For instance consumers are likely to value computer hardware more the more users of the hardware there are. This could be because there is likely to be a better support system the larger is the network of consumers buying the product. Similarly, it is more likely for improved software to get written for the computer hardware the bigger is the network of consumers buying it. But network externalities can be working both ways, positive or negative, for example, incompatibility with network systems on a rival operating system (such as MS Office) is a major obstacle in the OSS pursuit of the desktop though low prices for OSS products would be a strong incentive to switch and for new customers to enter.

In such a market time is of utmost importance in the race for product improvement. Firms cannot afford to let their competitors get ahead in the race for technological innovation since that would give them the added advantage of a bigger network. Also, consumers in these markets tend to exhibit a very high level of loyalty. That is because learning to use the product involves a cost. Once a consumer becomes familiar with particular software, she is unlikely to switch to a completely different brand performing the same tasks. Instead, she would rather purchase new releases of the same brand even though there can be various close substitutes with similar qualities available in the market. This enhances the effect of network externalities in the long run. Further, OSS *can* feasibly translate into better quality in markets such as those for computers.

The effect of OSS on product improvement is two-pronged. Making the technology freely available meansthat there can be more people directly working on improving the product. For example, ever since Linux went fully OSS, thousands of programmers have volunteered elaborate improvements of their own design for no more reward than the respect of the geek subculture. It is like expanding the R&D department, so larger improvements in quality can be realized. Secondly, there is likely to be a better supply of complementary goods. For instance giving out the source code for an operating system is likely to lead to more software being developed for it, which is in essence equivalent to having a better quality operating system i.e., consumers now find this OS more attractive.

On the other hand, making technology freely available means a loss in license fees. There is also the fear of technology being stolen. But in a market with network externalities, if the firm giving away its technology already has a sufficiently big network then it is more difficult for other firms just entering the market to steal the technology and get ahead since they would also have to overcome the network advantage of the existing firm (Gottinger, 2003). Besides in this digital era, the relative ease of creating software with similar functionalities using different programming codes has made the whole idea of keeping technology proprietary less relevant. Examples abound and have been described recently by Lerner and Schankerman(2010) and Lerner(2012).

We can thus think of OSS as increasing the rate of product improvement or increasing the success rate of R&D. We model OSS via license fees and assume that OSS increases product development deterministically.

A lower license fee represents a less proprietary technology. A zero or negative license fee means that the technology is totally non-proprietary. Positive license fees represent a proprietary technology - the firm is not willing to freely distribute its technology. The more ‘open’ a firm is the higher is its rate of R&D - in our model R&D translates directly into the quality of the product. The greater the R&D, the higher is the quality of the product. OSS improves the quality of the product in our model by increasing the supply of people or firms working on improving the product.

We look at a market with network externalities with an incumbent and an entrant. The incumbent, unlike the entrant, already has an installed base of consumers. Our objective is to explore the decisions of the firms regarding how proprietary they want to make their technology, i.e., how copyright or ‘open’ to make their product. The decision of copyright or open mentioned above, is modelled via license fees. We wish to see whether the incumbent could use ‘open’ as an entry deterring strategy. We also compare the incumbent's decision with that of a monopoly's.

We explicitly model the direct and indirect effects of network externalities. As in most models, we have the network term showing up in the consumers' utility; the bigger the network, the better off the consumers are. Consumers prefer to use a popular word processor because they know the format of their work can be easily transported to other users' computers. This is the direct effect of network on consumers' utilities. In our model there is also an indirect effect of network externalities - a bigger network translates into better quality. For example, more software companies are willing to produce programs for an operating system if it has a larger consumer base. That is because the downstream software companies thus can tap into this larger network of customers. This improves the quality of the OS. This is the indirect effect of network on consumers' utilities.

Open source system approaches entail some transitional practicable disadvantages against the prevailing standard.

Because of building up a network there will be fewer applications which arise as roadblocks towards further dissemination, for example, as in the case of Linux, only a single digit percentage works for computer games (Economist, 2004b). Incompatibility issues with the dominant operating system are also one of the biggest obstacles for further dissemination, in particular, for large corporations who would face significant switching costs with possible operational disruptions. On the benefit side, however, open source systems may induce R&D in complementary products and sectors because of lower license fees, thus lower costs of R&D, thee are more incentives to enlarge and expand product development and applications beyond core innovations. Because of its continuously ongoing character it is more likely to be incremental than seminal which poses questions of their own as to whether open source systems can genuinely foster innovation. For dedicated applications as initially built up from scratch such as search through Google it may yield some big advantages , not the least because of comparatively low implementation and operational costs.

This paper is organized as follows: The next section looks at the literature related to this work. In Section 3. we present the model. In Section 4, we look at the equilibrium results and give interpretations. Section 5 indicates extensions to our model and draws conclusions on further use.

Patenting, Licensing and Open Source Technologies

The issues covered in this paper relate to work on network externalities, R&D, entry deterrence and licensing.

R&D is an extensively researched area in industrial organization starting with Arrow's pioneering article where he asked: “What is the gain from innovation to a firm that is the only one to undertake R&D, given that its innovation is protected by a patent of unlimited duration?" (Arrow, 1962). Since then there has been a spate of research on R&D covering issues such as the incentives to innovate, patent races, welfare implications of R&D, choice and adoption of technologies. However, most of this work has focused on conventional markets rather than on markets with network externalities in which dynamic or ‘Schumpeterian’ competition evolves (Evans and Schmalensee, 2001). We explicitly look at the effect of network externalities on R&D competition and introduce the possibility of firms not wanting their technology to be proprietary which is not recognized by the traditional R&D literature.

Within the topic of R&D, there has been some work devoted to licensing. This literature takes as the starting point one or more firms having a patent. Licensing is then a means of disseminating an innovation. Among the incentives for licensing are product market competition which creates incentives for managers who would otherwise exploit their monopoly positions, cost savings to the licensees which could be appropriated by the licensing firm, and lowering rivals' incentives to invent around the innovation. Katz and Shapiro (1985) look at the incentives to engage in licensing once an innovation is developed in a world of perfect patents.

They also look at the incentives to innovate, given the feasibility of licensing. Katz and Shapiro (1986) examine the optimal licensing strategy of a research lab selling to firms who are product market competitors. They show that the seller's incentives to develop an innovation may be excessive and the incentives to disseminate information may be too low. Kende (1998) explores the conditions under which a monopolist selling a system consisting of a main component and differentiated secondary components can increase profits by allowing competition in the market for the secondary components. Opening the system in this fashion can increase profits by giving consumers an added *incentive* to incur the setup cost of purchasing the main component.
The results show that an open system is likely to be more profitable than a closed one when it is more elastic, when secondary-component variety is more valued, and when the share of the main component in the total system budget of the consumer is high.

Licensing plays an important role in our model. However the relation between licensing and innovation has been reversed compared to the traditional licensing literature described above. Instead of licensing being used as a means of diffusing an innovation *after* it has occurred, in our model licensing actually leads to continuously higher innovation.

Farrell and Saloner (1985, 1986) and Katz and Shapiro (1985,1986) are the pioneering works exploring the implications of network externalities in industrial organization. Farrell and Saloner concentrate on the demand side and show that the existence of network externalities leads to coordination problems and thus to a multiplicity of equilibria. In a model where two conflicting technologies compete, they show that "excess inertia" might exist in equilibrium, i.e., the adoption of a new standard might be too slow compared to the social optimum.

Katz and Shapiro extend the scope of Farrell and Saloner's works by including the supply side. They look at the issues of compatibility and pricing in the presence of network externalities. The model of Katz and Shapiro (1985) will serve as a building block for our model. The issues we address, however, are different. They use their model to reinforce the importance of consumer expectations in markets with network externalities. They also show that the private decisions of firms regarding compatibility is greatly affected by whether firms can act unilaterally (or if a consensus is required) and whether side payments are feasible. Katz and Shapiro (1986) show that in the presence of network externalities the private and social incentives to achieve compatibility may diverge.

They show the conditions under which firms may use compatibility as a medium for reducing competition.

While a lot of work has been done in the area of network externalities, little of it specifically addresses R&D. Katz and Shapiro(1992) look at whether there is too much or too little technological innovation in a market with network externalities compared to the social optimum. In particular they look at whether a new product which embodies technological progress is introduced too early or too late compared to the social optimum. Their conclusion is that contrary to what was earlier believed to be true, there is *excess momentum* in equilibrium, i.e., a new product is introduced too soon compared to the social optimum. That happens because the sooner the product is introduced, the sooner the firm can start building up a network and reaping its benefits. Choi (1994) looks at a two-period model of a monopoly in a market with networkexternalities.

He studies the incentive of the monopolist to introduce an incompatible improved product in the presence of network externalities. Kristiansen (1996) studies the consequences of network externalities on the riskiness of R&D projects chosen by an entrant and an incumbent. He shows that the incumbent chooses a too risky project that too often lets a new firm with an incompatible technology enter as compared to the social optimum. In addition, the entrant has an incentive to choose more certain projects than are socially optimal and these strengthen the possibility of adoption of an incompatible technology. Regibeau and Rockett (1998) analyze compatibility choices of two firms which must also decide when to introduce their goods in a market characterized by network externalities. They show that the firms' incentives to achieve compatibility depend crucially on the time at which the degree of compatibility must be chosen. The current paper is also related to the literature on investment as a means of entry deterrence. Firms compete not only with existing firms, as is transparent, but also with potential entrants. In an extension of the Spence model Dixit (1980) shows that an incumbent firm may make irrevocable commitment of investment in order to alter the initial conditions of the post-entry game to its own advantage. One of the questions we are interested in is whether the incumbent chooses its license fees so as to discourage entry. That is, the incumbent could be thought of as choosing investment in *quality* as a means of deterring entry.

Network Competition under OS Licensing

There are two firms, an incumbent, I. and an entrant, E. The incumbent has an installed base of consumers of $x_I > 0$ unlike the entrant ($x_E = 0$). We consider a two stage game in a market with network externalities. The products of the firms are incompatible (i.e., they have separate networks).

In the first stage, firms charge a license fee (f) to other downstream firms for use of their product (for example, Microsoft licenses their Windows operating system to other companies to develop applications software). The number of downstream firms willing to work on a firm's product (m_i) depends on the license fee charged and also the initial network of the firm (the consumer base x_i for firm i).

$$m_i = k + x_i - f_i,\ k > 0 \quad (1)$$

k is a measure of the potential market size of downstream firms independent of the license fee and initial network.

The smaller the license fee charged, the more freely the firm distributes its technology and in our terminology, the more 'open' the firm is. We assume no competition in getting downstream firms to buy the firms' licenses. m_i decreases as f_i increases because as the licenses become more expensive fewer downstream firms buy them. This is just the standard argument for a downward sloping demand in price. As for the relationship between m_i and x_i, since the downstream firms are developing products that could be used in conjunction with the firm's product (like complements), the larger the installed base of customers that the firm has, the larger is the potential demand for the downstream firms' product. Thus, the more the downstream firms are willing to pay for the license.

Let us define: If $f_i < f_j$ then firm i chooses to be more open than firm j. (Alternatively firm j chooses to be less open than firm i).

In the second stage firms engage in Cournot competition to sell their products directly to the consumers. The inverse demands for the products of the two firms are given by

$$p_i = A + q_i + \gamma x_i - (x_I + x_E) \qquad (2)$$

where $i \in \{I.E\}$. p_i is the price charged by firm i. $x_i \geq 0$ is the amount of output firm i sells, x_i is the initial network of firm i. q_i is the quality of firm i's product.

Note that ideally we would want to include the *expected* network size in the demand functions instead of just the initial network size. . However, the implications of forming expectations for equilibria in games similar to ours have been extensively studied (see Katz & Shapiro, Farrell & Saloner). Since we are not interested in analyzing the role of expectations and would like to keep our model simple we just include the initial network size in the consumer's utility function.

The more downstream firms (m_i) a firm licenses out to, the better the quality q_i of its product will be. We assume the following functional form for q_i:

$$q_i = m_i \ , i \in \{I,E\} \qquad (3)$$

Firm *i's* profit is:

$$\Pi_i = x_i p_i + f_i m_i , i \in \{I,E\}$$

The first term represents the profits from direct sales and the second term represents the revenues from licensing. Both firms are assumed to have identical costs which we have normalized to zero. By staying out of the market the entrant makes zero profit.

As the profit function above shows, the license fees (and hence the decision about how closed or open a firm wants to be) affects a firm's profits through two avenues. The first is the direct effect on profits through the licensing revenues. Then there is also an indirect effect through the quality of the firm's product which affects the profits made from direct sales.
The timing of the game is as follows

1. Incumbent I sets its license fee f_I . This determines quality q_I .
2. Entrant E decides whether to enter.
3. If E enters, it chooses a license fee f_E from its set of acceptable license fees. This determines quality q_E .
4. Firm(s) play an output game (Cournot).

Firms choose their license fees and output levels to maximize their profits. However we do restrict the strategy set of the entrant. We do this in order to rule out situations where the entrant enters in order to make money solely out of licensing knowing that at the fee it charges or close to it, it could not sell any output in the second stage. Since the downstream firms could be thought of as producing complementary goods, it would be unreasonable to expect them to buy licenses knowing that the entrant has no *potential* to sell output. Hence we restrict the entrant to choosing a license fee from its set of "acceptable license fees". An acceptable license fee for the entrant, given that the incumbent charges a license fee f_I , is f_E such that for every $\varepsilon > 0$, $x_E(f_I, f_E - \varepsilon) > 0$ where $x_E(f_I, f_E)$ is the optimal output for the entrant in the ensuing Cournot game. Thus, the "downstream firms" are not willing to buy licenses unless the entrant has the potential to sell output by making an arbitrarily small reduction in its license fees.

As in other two-stage games, we will now proceed to solve the second stage output game first in order to determine the Subgame Perfect Equilibria.

Equilibrium Licensing
Given the results from the second stage output game, we will move on to solving the first stage. Note that if q_i were independent of m_i , then the only component of the firm's profit that depends on f_i is the revenue from licensing which is maximized when firm i charges a license fee of $[k + x_i]/2$. This is our full 'closed' benchmark.

Before we go on to see how the two firms strategically choose their license fees we look at the decision of the incumbent if it were a monopolist in this market.

CASE 1: MONOPOLY: NO POTENTIAL ENTRANT

Theorem 1 The monopolist charges a license fee $f_I^M = [k + (1 - \gamma)\, x_I - A]/3$.
The proof follows the structure of a Stackelberg game, a complete proof is given in the Appendix.

We see in Theorem 1 that if $\gamma < 1$, the optimal license fee is *increasing* in x_I; if $\gamma > 1$. the optimal license fee is *decreasing* in x_I. To see why, note that the firm's profit has two components - the revenue from selling licenses and that from direct sales. As we saw above, the revenue from licenses is maximized when the license fee is $[k + x_I]/2$. However, by lowering its license fee the firm can improve its product's quality and thus make more profits from its direct sales. So the optimal license fee is less than $[k + x_I]/2$. Thus increasing the license fee by a small amount beyond the optimal one increases the revenue from licenses and decreases that from direct sales, and the two exactly balance at the optimal license fee. When $\gamma < 1$, the contribution of network size to consumer utility is small compared to its contribution to m. The result is that starting from an optimal f for a given x_I, a higher x_I means that increasing f_I will increase the revenues from licenses by dx_I but decrease the revenue from direct sales only by $(1 + \gamma)dx_I/2 < dx_I$. Therefore at the higher x_I profits have to be increasing in f at the previously optimal f. Thus, given the concavity of the profit function in f, the optimal license fee must be *increasing* in x_I. Exactly the opposite argument holds when $\gamma > 1$. Thus the optimal license fee is *decreasing* in x_I when $\gamma > 1$.

CASE 2. DUOPOLY: WITH INCUMBENT AND POTENTIAL ENTRANT

We now look at a market that has an incumbent firm (I) with an installed consumer base of x_I and a potential entrant (E).

Once the firms have decided their license fees, they play a Cournot output game (Shapiro, 1989).

The result of the Cournot game is described by the intersection of the two reaction functions that gives the unique interior Cournot outputs, i.e.:

$$x_I = (A + 2q_I + 2\gamma x_I - q_E)/3\ ,\ x_E = (A + 2q_E - \gamma x_I - q_I)/3$$

. Call these optimal output levels $x_i(f_I, f_E)$, $i \in \{I, E\}$.
First we make the following definitions.

If the incumbent charges its monopoly license fee f_I^M, and the entrant stays out of the market, then we say that entry is blocked.

If the incumbent charges a fee different from f_I^M in equilibrium, and the entrant stays out of the market, then we say that entry is deterred.

If the entrant enters but sells nothing in equilibrium then we say that entry is restricted.

If the entrant sells a positive amount in equilibrium, we say that entry is unrestricted.

We can now go on and characterize the entry decision of firm E and the equilibrium license fees for the two firms. But before we do that we briefly state the optimal response of the entrant, assuming that the firms produce optimally in the Cournot subgame, to the different license fees that the incumbent can charge. For proofs please refer to the appendix. We can show that there exists a license fee f_I^D for the incumbent such that for all $f_I < f_I^D$ the optimal response of the entrant is to stay out of the market and for $f_I > f_I^D$ it is to enter. There exists $f_I^R > f_I^D$ such that in the interval $[f_I^D, f_I^R]$ the best response of the entrant is to charge the largest acceptable license fee that makes optimal x_E exactly 0, and for $f_I > f_I^R$ it is optimal for the entrant to enter and charge its unconstrained optimal license fee resulting in a positive x_E

Theorem 2 The levels of x_I^o, A and k determine the entry decision and license fees in equilibrium as follows:

1. Entry is blocked if $(1 + 2\gamma)\, x_I^o \geq A + 2k$.
2. For $A + 2k \geq (1 + 2\gamma)\, x_I^o \geq A + k/2$, entry is restricted with the incumbent charging f_I^M and earning its monopoly profits.)
3. For $A + k/2 > (1 + 2\gamma)\, x_I^o > 2A/5 + k/5$. Entry is restricted with the incumbent charging f_I^R and earning less than its monopoly profits.
4. For $2A/5 + k/5 > (1 + 2\gamma)\, x_I^o$, entry is unrestricted and the firms just charge the unconstrained Stackelberg license fees.

Proof. See Appendix

When the network advantage of the incumbent is not big enough to block entry. the entrant enters the market. However if the advantage is still sufficiently large then the incumbent is able to charge its monopoly fees and make its monopoly profits while restricting the entrant to zero output in the Cournot output game.

Given that the network advantage of the incumbent is not big enough to block entry, we saw in Statement 2 of Proposition 2 that if it is still sufficiently high then the incumbent can restrict entry and make monopoly profits. If its advantage is however not big enough to do that, even then a sufficiently high network advantage allows it to restrict entry. It then charges f_I^R which is different from its monopoly license fee and earns less than its monopoly profits. Thus in this case the incumbent is able to act as a monopolist in the output market but not in license fees.

If the initial network advantage of the incumbent is not very big compared to A and k then not only is it unable to keep the entrant out of the market but it is unprofitable to restrict its entry too. In that case the entrant enters the market and both firms sell positive amounts of output.

As corollaries to Proposition 2 we get the result that there is no entry deterrence and we also get a comparison between the monopoly license fees of the incumbent and its license fees when a potential entrant exists.

Corollary 1 There is no entry deterrence.

At f_I^D the entrant produces nothing and the incumbent just makes the profits it would as a monopolist in the second stage output game. Since f_I^D is the largest license fee for the incumbent that deters entry, if $f_I^M \leq f_I^D$ then there is blocked entry. If $f_I^M > f_I^D$ however, then entry is not blocked. But it also means that the incumbent's profits must be increasing at f_I^D (since the monopoly profits are concave in f_I and from Lemma A.2 we know that in the interval $[f_I^D, f_I^R]$, the incumbent makes monopoly profits). Hence the incumbent will not find it profitable to charge f_I^D or less. Thus entry is not deterred.

As a corollary to Theorem 2 we get a comparison between the monopoly license fees of the incumbent and its license fees when a potential entrant exists.

Corollary 2 At the equilibrium duopoly license fee f_I^*, $f_I^* \leq f_I^M$ always and sometimes $f_I^* < f_I^M$

Proof. See Appendix

Thus we see that the presence of another firm makes the incumbent choose at most the license fee it would if it were a monopolist. In other words the incumbent chooses its technology to be at most as closed as that of the monopolist.

If its initial network is not very big then the presence of the other firm makes it want to be more open . The firm is then willing to give up more of the licensing revenue in order to improve quality since that will help it in the second stage output competition. If its network advantage is already very big then it does not need to raise quality to give it a competitive edge in the second stage and it continues charging its monopoly license fees.

Theorem 3 For $(1 + 2\gamma)\, x_I^o < A + 2k$ (i.e., when the entrant enters). there exists x_I^{o*}, such that for $x_I^o > x_I^{o*}$,, $f_I^* > f_E^*$ and for $x_I^o < x_I^{o*}$, , $f_I^* < f_E^*$, i.e., if the incumbent' s network is smaller than x_I^{o*}, then the incumbent chooses to be more open and if the network is bigger than x_I^{o*},, then the entrant chooses to be more open.

Proof. See Appendix

Consider first the scenario where the incumbent has a small network advantage, namely the case of unrestricted entry and restricted entry without monopoly profits. Because of the installed base of consumers that firm I has, firm E is at a disadvantage in the output market so cannot expect to make as large a profit from direct sales as can firm I. Firm I on the other hand, when it has a small network advantage, would want to compound its advantage in the output market by increasing its quality more that firm E. Given this initial imbalance in network advantage, firm E is less willing to afford a loss in revenue licenses in order to improve quality. Thus the incumbent charges a lower license fees than the entrant, in other words, the incumbent is more open than the entrant.

To examine this phenomenon in more detail, consider first the case of unrestricted entry. In this case we can isolate two effects that make the incumbent choose to be more open than the entrant, namely the "Stackelberg" effect and the "network" effect. The "Stackelberg" effect can be discerned by comparing the Cournot license fee (when the two firms choose their license fees simultaneously) with the Stackelberg license fee in the absence of network externalities. In the Cournot case with x_I^o = 0, both firms charge exactly the same fees whereas in the Stackelberg case the incumbent charges a lower fee. Thus part of the reason that the incumbent chooses to be more open is just the "first mover" or Stackelberg effect. Now if we reintroduce the network term, we see that the incumbent chooses to be even more open while the entrant chooses to be less open.

From the Appendix (A .10) we see that starting from an optimal f_I increasing x_I^o r by a small amount increases the marginal effect of f_I on license revenues by less than it decreases the marginal effect of f_I on direct sales. Thus the introduction of x_I^o requires a reduction in f_I in order to bring the marginal effects of f_I on direct sales revenues and licensing revenues into balance again. For the entrant, we see from the reaction function (equation 15) that both a larger x_I^o and a smaller f_I , lead E to charge a higher f_E. In the case where there is restricted entry without monopoly profits, the entrant is held down to zero output but the incumbent has to lower its license fee below its monopoly level to do so. The entrant on the other hand is able to charge its full copyright license fee. Thus again, the incumbent chooses to be more open than the entrant.

If, however, the incumbent has a large network advantage so that it can still charge its monopoly license fee and make its optimal monopoly profits, then the entrant has to fight to even stay alive in the market. The bigger the incumbent's network is the more difficult it is for the entrant to stay alive i.e.. the smaller is the license fee it charges . Thus there exists a sufficiently large network advantage x_I^{o*} for the incumbent beyond which the entrant charges a lower license fee i.e., chooses to be more open.

CONCLUSIONS AND EXTENSIONS

This paper has shown that being "open" could be a very sensible, in fact, optimal equilibrium strategy for profit-maximizing firms in a market with network externalities, for example, the internet and computer related markets. As in most other theoretical models, we could not possibly include all the factors relevant to this recently observed phenomenon. Instead, we construct one way of modelling "open", trying to capture the central idea of why "open" makes sense. We devote this section to discussing what can be done or added on to our model in future research efforts on this topic.

In our model we have excluded the traditional "technology stealing" effect. One might argue that that is precisely why we need copyrights and patents - to prevent the influx of copycats into the market driving profits to zero. However, as we mentioned in the introduction, in a market with network externalities, there is a natural barrier against imitators getting ahead of an innovator with an installed base of consumers, namely that consumers will perceive their product to be not as attractive as the incumbent's, even if they are of the same quality. It would still be interesting to see the result of this business stealing" effect being put back into the model. We would expect it there to still be "open" in equilibrium, though to a lesser extent. The equilibrium now needs to strike a balance between the two opposing effects of going "open", namely, the indirect network effect of quality improvement, and the "technology stealing" effect. We could also make the probability of technology being stolen vary inversely with network size, in which case we would expect the result that the incumbent goes more open to be reinforced.

Another possibility is to introduce competition in the first stage of the game. As of now, the incumbent and the entrant do not compete for downstream firms, each of them faces an identical and independent demand for its licenses. This could be justified if there are numerous downstream firms looking for prospective technologies to develop. A more realistic setting may be one where both the incumbent and the entrant are competing in license fees for downstream firms to buy their licenses. Each downstream firm buys at most one unit of the license.

However, this should not change our results drastically and we should still see "open" as an equilibrium strategy.

In fact, with competition, both the incumbent and the entrant are likely to go more open because now they need to compete to sell their licenses.

We could introduce costs into the technology of the firms. In our current model, we have normalized both firms' costs to zero. Differences in the technologies of the firms may sway our results either way depending on who has the better (less costly) technology. It would also be interesting to see how the coupling of the "technology stealing" effect and positive costs may work. For example, if the incumbent freely distributes its technology then the costs for the entrant may fall because it can now "steal' the technology of the incumbent.

In our model, we don't have entry deterrence but we have restricted entry in which the entrant sells licenses in the first stage, but produces nothing in the second stage. This may seem a bit unrealistic. With positive fixed costs, we should be able to have the standard entry deterrence result. We would still expect restricted entry but one where the entrant is 'restricted" to some positive output level.

Another possible extension is making innovation stochastic, i.e. replacing the link *of* $q_i = q\ (m_i)$ with $q_i = q(m_i,\varepsilon_i)$, where ε_i is stochastic. We argue that this again should not change our results qualitatively so long as the resulting distributions for qualities exhibit second order stochastic dominance - the larger the m, the more likely it is for firm i to have a bigger innovation.

Making the game more dynamic is also another interesting extension. As *of* now, we have two stages in the game. *If* we add in more stages in the game, the network effect may get compounded since it now lasts longer, a big early network carries all the way into later stages too. It is even more essential for firms to build up a network fast to lure in more customers, the "open" result thus may be even more pronounced.

We can bring back expectations in consumers utility. Instead *of only* caring about the initial size of the network, consumers now form expectations on how big the future network size for a firm will be before they make their purchase decisions. We then need to deal with much more complicated algebra and to adopt a more refined equilibrium concept in the second stage to handle this problem. For example, we can use the Fulfilled Expectations Cournot Equilibrium (FECE) as in Katz and Shapiro(1986). We suspect that doing so will not buy us anything new in our results.

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APPENDIX

Proof of Theorem 1

When the monopolist has a product of quality q_I and charges a price of p_I the only consumers who buy from it are the ones for whom $r + q_I + \gamma x_I^o - p_I \geq 0$. Therefore demand for the monopolist's product equals $A + q_I + \gamma x_I^o - p_I$. It's revenue(R) equals $p_I (A + q_I + \gamma x_I^o - p_I)$.. The optimal price for selling its output is thus given by:

$$\partial R / \partial p_I = A + q_I + \gamma x_I^o - 2 p_I = 0$$

$$\text{or} \qquad p_I^M = x_I^M = (A + q_I + \gamma x_I^o)/ 2 \qquad \text{(A1)}$$

The monopolist's profit is therefore

$$\prod_I^M = [(A + q_I + \gamma x_I^o)/ 2]^2 + f_I (k_I + x_I^o - f_I)$$

$\prod_I^M$ *is* concave in f_I.

Therefore,

$$\partial \prod_I^M / \partial f_I = (A + (1 + \gamma) x_I^o + k - f_I)/2 + k + x_I^o - 2 f_I = 0$$

gives us the optimal f_I:

$$f_I^M =(k + (1 - \gamma) x_I^o - A) /3 \qquad \text{(A2)}$$

If $\gamma > 1$ we see that f_I^M is decreasing in x_I^o whereas $\gamma < 1$, f_I^M is increasing in x_I^o.

Duopoly: With Incumbent and Potential Entrant

We saw in Section 3 that when the firms sell positive amounts of output, the equilibrium price equals the equilibrium output for each firm. Thus the first component of a firm's profit $p_i x_i$ just equals $(x_i)^2$ in equilibrium. The same is true if a firm sells zero output (since then $p_i x_i = (x_i)^2 = 0$) or if a firm sells its monopoly output (as previously analyzed). Thus a firm's equilibrium profits can be written as:

$$\Pi_i = [x_i(f_i,f_j)]^2 + f_i m(f_i,x_i^o) \ , i \in \{I,E\} \qquad \text{(A3)}$$

Assuming no constraints on the *x's* and the *f's.,* making use of(A1)-(A3) and substituting , the profits can be written as:

$$\Pi_i = [(A + k+2 (1 + \gamma) x_i^o - (1 + \gamma) x_j^o + f_j - 2f_i/3)]^2 + f_i (k + x_i^o - f_i) , \quad i\in\{I,E\} \qquad \text{(A4)}$$

It can be checked that Π_i in the above equation is concave in f_i. *Setting* $\partial \Pi_i / \partial f_i = 0$ *gives us the Cournot reaction function in license fees for firm i,* $j \in\{I,E\}$:

$$f_i = k/2 +(2 (1 + \gamma) x_j^o/5 + (1 -8 \gamma)x_i^o/10 - 2A/5 - 2f_j/5 \qquad \text{(A5)}$$

We note from equation (A5) that the reaction functions in license fees are downward sloping. The reason behind this is as follows: From equation (A3) we see that a firm's equilibrium profit has two components , $[x_i(f_i,f_j)]^2$,which represents the revenues from direct sales and $f_i m(f_i,x_i^o)$ which is the revenue from licensing. Firm i's reaction function gives us the optimal f_i for every f_j that the other firm might charge.

Assuming that both firms sell positive amounts, increasing f_i by a small amount decreases the profit from the first term (since from the Cournot game, x_i is decreasing in f_i). At the optimal f_i this must be exactly offset by the increase in revenue from licensing. Again, given that both firms sell positive amounts, the equilibrium x_i is increasing in f_j whereas the firm i's revenue from licensing is unaffected by it. Thus if we now increase f_j, then a small increase in f_i from its previous optimal level increases the revenue from the license fees by the same amount as before. However, the decrease in revenue from direct sales is larger since x_i is larger. Thus with the larger f_j profits are decreasing in i's license fees at the previously optimal f_i. Given the concavity of the profit function in a firm's own license fee this requires a lowering of f_i in order to reach equilibrium again. Hence the reaction function is downward sloping.

Lemma A1. There exists f_I^D for the incumbent such that for all $f_I < f_I^D$ the optimal response of the entrant is to stay out of the market and for $f_I > f_I^D$ it is to enter. f_I^D is thus the largest license fee for the incumbent that deters entry.

Proof. Let f_I^D be the license fee for which $f_E = 0$ is the smallest license fee that makes $x_E (f_E, f_I^D) = 0$. When $f_E = 0$. $x_E = 0$, and $f_I = f_I^D$ then $\Pi_E = 0$ and $\partial \Pi_E / \partial f_E = 0 + k > 0$. Thus reducing f_E will only make Π_E negative while a bigger f_E is not an acceptable license fee. So entry is deterred at f_I^D.

To calculate f_I^D we set x_E equal to zero and $f_E = 0$ with it.
We then get

$$A+2(k - f_E) - (k + x_I{}^o - f_I^D) - \gamma x_I{}^o = 0 \qquad (A6)$$

$$\text{Therefore, } f_I^D = (1 + \gamma)\, x_I{}^o - A - k \qquad (A7)$$

Entry is deterred at any $f_I < f_I^D$ too, since then the smallest f_E that makes $x_E (f_E, f_I) = 0$. must be negative ,see (A6). For $f_I > f_I^D$ the smallest f_E that makes $x_E (f_E, f_I) = 0$. is positive, thus there do exist acceptable license fees that give the entrant positive profits. Hence the entrant will enter and so there is no entry deterrence. Thus f_I^D *is* indeed the largest license fee that the incumbent can charge and still deter entry.

Lemma A2. There exists $f_I^R > f_I^D$,such that in the interval $[f_I^D, f_I^R]$ it is optimal for firm E to charge the largest acceptable license fee f_E that makes $x_E = 0$ and for $f_I > f_I^R$ the optimal response for firm E induces it to produce a positive amount.

Proof. From equation (A5) we know that the best response for the entrant to f_I^R is given by

$$2 f_E = k + (4 (1 + \gamma)\, x_I{}^o/5 - 4A/5 - 4 f_I^R /5 \qquad (A8)$$

For x_E to equal zero when $f_I = f_I^R$, f_E must be as given by (A6) with f_I^R replacing f_I^D, i.e. $2 f_E = A + k - (1 + \gamma)\, x_I{}^o + f_I^R$ (A9)

If there were no restrictions on the x's. then when firm I chose f_I^R and firm E chose its license fee optimally, by definition of f_I^R in the subsequent output game firm E would end up selling nothing. If firm I chose $f_I > f_I^R$ and firm E chose its license fee optimally, then in the subsequent output game firm E would end up selling a positive amount. If however firm I chose $f_I < f_I^R$ and firm E chose its license fee according to its reaction function, then in the subsequent output game firm E would be required to sell a negative amount. Since that is not possible E just sets its license fee at the level that just makes its output in the next stage zero. Hence when there is no entry block, in the interval $[f_I^D, f_I^R]$ firm E charges the largest acceptable license fee f_E that makes $x_E = 0$. Firm I makes profits according to the monopolist's profit function. This is where the inequality $x_i \geq 0$ for the entrant is binding.

For $f_I > f_I^R$ the entrant just plays its unconstrained best response in the Stackelberg game. f_I^R is the smallest license fee for the incumbent above which the entrant plays its unconstrained optimal fees and output in equilibrium.

Proof of Theorem 2

We prove the theorem in a few steps.

Lemma A3. Entry is blocked if $(1 + 2\gamma)\, x_I^o \geq A + 2k$.

We find the smallest f_E that gives us $x_E\,(f_E, f_I^M) = 0$

From (A6) we get:

$$A + 2(k - f_E) - (k + x_I^0 - f_I^M) - \gamma x_I^o = 0$$

Substituting the expression for f_I^M from equation (A2) into the above gives us:

$$f_{E^*} = A + 2k - (1 + 2\gamma)x_I^o/3$$

f_{E^*} *is* the largest acceptable license fee for the entrant when the incumbent charges f_I^M

When $f_{E^*} \leq 0$, Π_E at f_{E^*} is non-positive (when $f_{E^*} \geq 0$, Π_E at f_{E^*} is non-negative).

Further, $\partial \Pi_E / \partial f_E = k - 2f_{E^*} > 0$.

Given the concavity of Π_E in f_E means that if $f_{E^*} \leq 0$,

there is no acceptable license fee for the entrant that gives it a positive profit. Hence entry is blocked if $f_{E^*} \leq 0$, i.e. if

$$A + 2k < (1 + 2\gamma)x_I^o$$

$f_{E^*} = 0$ is the largest f_{E^*} for which entry is blocked since if $f_{E^*} > 0$ then there does exist an acceptable license fee for the entrant that gives it positive profit.

Lemma A4: For $A + 2k \geq (1 + 2\gamma)\, x_I^o \geq A + k/2$, *entry is restricted with the incumbent charging* f_I^M *and earning its monopoly profits.*

We saw earlier that in the interval $[f_I^D, f_I^R]$ firm E charges the smallest f_E that makes $x_E = 0$, firm *I* makes profits according to the monopolist's profit function.

We know that the incumbent makes the largest possible profits when it is a monopolist charging f_I^M.

Thus if, when there is no blocked entry, $f_I^M \leq f_I^R$ then the optimal license fee for the incumbent is just f_I^M

$$f_I^{\,M} \le f_I^{\,R} \iff k + (1-\gamma)x_I^o - A/3 \le (1+\gamma)\,x_I^{\,o} - A$$

which gives us the condition

$$k+2A < 2(1+\text{-}\gamma)\,x_I^{\,o}$$

Putting together this condition with that for no blocked entry $f_I^{\,D} > f_I^M$ *(Lemma A3)* gives us the required result:

$$A+k/2 \le (1+2\gamma)\,x_I^{\,o} \le A+2k$$

Lemma A5. For $A + k/2 > (1+2\gamma)\,x_I^{\,o} \ge 2A/5 + k/5$. entry is restricted with the incumbent charging f_I^R and earning less than its monopoly profits.

When $k+2A > 2\,(1+\gamma)x_I^{\,o}$ then the optimal monopoly license fee, f_I^M is bigger than f_I^R (Lemma A4.)

Since the incumbent's profits in the range [f_I^D, f_I^R] coincide with its monopoly profits Π_I^M, its profits must be increasing in [f_I^D, f_I^R].

Call Π_I^S unconstrained Stackelberg profits for firm I. We get Π_I^S by substituting f_E from firm E's reaction function (A5) into firm's I profit function (A4):

$$\Pi_I^S = [\,A/5 + k/2 + 4(1+\gamma)\,x_I^o/5 - 4\,f_I/5\,]^2 + f_I(k + x_I^o - f_I)$$

Then, for $f_I > f_I^R$ the incumbent's profits coincide with Π_I^S, and at $f_I = f_I^R$, $\Pi_I^M = \Pi_I^S$ (since x_E in the output game equals zero when $f_I = f_I^R$ and E chooses its best response to f_I^R, thus making $\Pi_I^M = \Pi_I^S$). It can be checked that Π_I^S is concave in f_I.

If Π_I^S is decreasing in f_I *at* $f_I = f_I^R$ then given the concavity of Π_I^S, the optimal license fee for the incumbent must be f_I^R .

$$\partial\Pi_I^S/\partial f_I = -8/5\,[\,A/5 + k/2 + 4(1+\gamma)\,x_I^o/5 - 4\,f_I/5\,] + k + x_I^o - 2\,f_I \qquad \text{(A10)}$$

When $f_I = f_I^R = (1+\gamma)\,x_I^o - A$,

$$\partial\Pi_I^S/\partial f_I = 1/5\,[k + 2A - 5(1+2\gamma)\,x_I^{\,o}\,]$$

Π_I^S is decreasing in f_I *at* $f_I = f_I^R$ if

$$k+2A \le 5(1+2\gamma)\,x_I^o$$

Thus for $2A/5 + k/5 \le (1+2\gamma)\,x_I^o \le A + k/2$, , the optimal f_I *is* f_I^R and the incumbent earns less than monopoly profits.

Lemma A6. For $2A/5+k/5 > (1+2\gamma)\,x_I^o$, *entry is unrestricted and the firms just charge the unconstrained Stackelberg license fees.*

If $k + 2A > (1+2\gamma)\,x_I^o$ then we infer from Lemmas A2 to A3 that there is no blocked entry, the incumbent's profits are increasing in the range $[f_I^D, f_I^R]$, and are also increasing at $f_I = f_I^R$ .The incumbent's profits are continuous in the relevant range of $f_I \ge f_I^D$ and coincide with Π_I^S for $f_I \ge$

f_I^R. Since Π_I^S is concave, the optimal license fee for the incumbent must be given by the one that maximizes Π_I^S. Call this license f_I^S. Setting $\partial \Pi_I^S / \partial f_I = 0$ from (A10) we get

$$f_I^S = [5k - 8A - (7 + 32\gamma)\, x_I^o] / 18 \qquad \text{(A11)}$$

Given our definition of f_I^R, $f_I \geq f_I^R$ is optimal for $x_E > 0$.

Thus if $k + 2A > 5(1 + 2\gamma)\, x_I^o$, then the incumbent charges f_I^S, the entrant charges f_E given by its reaction function, and both firms produce positive amounts.

Proof of Corollary 2

From Lemmas *A2* and A3 we infer that for $A + k/2 \leq (1 + 2\gamma)\, x_I^o$, the incumbent charges its optimal monopoly license fee, f_I^M. Hence the statement of the corollary is true in this case. From Lemma A4, when $2A/5 + k/5 \leq (1 + 2\gamma)\, x_I \leq A + k/2$. the optimal f_I *is* f_I^R. But in this scenario monopoly profits are increasing in the interval $[f_I^D, f_I^R]$ as we saw in Lemma *A4*. Thus it must be the case that $f_I^M > f_I^R = f_{I^*}$. Finally, when $k + 2A > 5(1 + 2\gamma)\, x_I^o$, the optimal license fee for the incumbent is given by f_I^S in equation (A11).

$$f_I^S - f_I^M = -[2A + k + 13\,(1 + 2\gamma)\, x_I^o] / 18 < 0 .$$

Thus when $k + 2A > 5(1 + 2\gamma)\, x_I^o$, $f_I^M > f_I^S = f_{I^*}$

Proof of Theorem 3

It can be checked that in the cases when there is unrestricted entry and when there is restricted entry without monopoly output, $f_I < f_E$. When there is restricted entry with monopoly profits

$$f_I - f_E = [-k - 2A + (2+\gamma)\, x_I^o] / 3$$

Thus,

$$f_I < f_E \text{ if } k + 2A > (2+\gamma)\, x_I^o ,$$
$$f_I > f_E \text{ if } k + 2A < (2+\gamma)\, x_I$$

Hence,

$$k + 2A = (2+\gamma)\, x_I^o$$