Innovation, Diffusion and Shelving

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Abstract

In an oligopoly model with an outside innovator and two asymmetric licensees, we consider a story of technology transfer of a cost reducing innovation where the licensees have asymmetric absorptive capacities of the new innovation. In particular, we assume the innovation only reduces the cost of the inefficient firm, but not the efficient firm. In that context, we explore the strategic incentives of the efficient firm to acquire the technology. We find situations where the efficient firm acquires the technology, however shelves it and situations where it does not shelve it and further licenses it to the inefficient firm. We also see the impact of technological diffusion (or no diffusion) from innovation on consumer welfare and industry profits; and find the optimal mode of technology transfer of the innovator. We extend the analysis where the innovation affects the production cost of both firms, but in a non-uniform way, and find the optimal mode of licensing and technology transfer.

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1. Introduction

In many oligopoly markets, we observe scenarios where a firm sometimes pay to acquire new technologies, however, does not use them for its use i.e. shelves them. The question is, why a firm would do that when acquiring new technology is costly. The reason could be by acquiring the new technology exclusively, the firm prevents its competitor from using it, thus maintaining its strategic advantage in the market. In this backdrop, Stamatopoulos and Tauman (2009), while addressing a story of licensing of a new innovation came across a situation where shelving of new technology indeed happens by one of the licensees. In their story, there is an outside innovator and two asymmetric firms (licensees) with different marginal costs. The innovator offers a technology that reduces the marginal cost of the less efficient firm only. They show that even though innovation cannot improve the technology of the efficient firm, but there might be situations where the efficient firm will pay and acquire the technology and then shelve it to prevent the inefficient firm acquiring it. Although this interesting outcome happens in that story, however, the main objective of their paper was to show the superiority of fixed fee licensing over auction in asymmetric markets with an outside innovator under Cournot competition. We found the feature of shelving and asymmetric absorptive capacity of the new innovation are interesting aspects to look on more closely and pursue our study here in that direction. In our analysis of new technology transfer from an outside innovator with two asymmetric licensees, we elaborate on the scenarios where shelving will always happen, and hence there will be no diffusion of the cost-reducing new technology. We also explore situations where shelving will never happen and the technology diffusion will indeed take place, but may not benefit the consumers in terms of having a lower price of the product.

In order to address the above problem in greater depth, we consider a model with two asymmetric firms (efficient and inefficient), i.e. the potential licensees producing a good which is horizontally differentiated and an outside innovator (e.g. independent research lab). The cost-reducing technology from the innovator reduces the marginal costs of the two firms in a non-uniform manner. In particular, we assume the innovation reduces the marginal cost of the inefficient firm only, and the efficient firm does not get any benefit from it at all.[1] The new

[1] Later we relax this assumption and assume that innovation reduces the cost of both firms non-uniformly and study further.

technology can be transferred to the potential licensees by means of various licensing contracts or transferring the patent right i.e. selling. In the analysis, we first consider a licensing game where the innovator specifically opts for a fixed fee or an exclusive auction to license the technology. We look into the possibility of shelving. Then we explore other possible licensing contracts, namely royalty, two-part tariff licensing (combination of fixed fee and royalty) and auctioning exclusive royalty rights before offering royalty contract (royalty-auction henceforth). We also consider the option for selling the right, and find the most profitable way for the innovator to transfer the new technology. While exploring all these mechanisms of technology transfer, we identify situations when shelving always happens, thus limits the diffusion of new technology; and where shelving never happens and the technology will be successfully put to use and consumers benefit from it. We also find situations where despite successful transfer and diffusion of technology, consumers may not benefit.

We capture the horizontal product differentiation through the well-known spatial framework of linear city model (*a la* Hotelling, 1929) where firms/licensees are located at the end points of a unit interval and consumers are uniformly distributed over the interval. Each consumer buys exactly one unit the product and we assume the market is fully covered.

The game structure is as follows. For the licensing game, in the first stage, we allow the outside innovator to decide on the licensing schemes. Licensees (firms) decide whether to accept or reject the offer. In the second stage, firms produce and compete in prices in the product market. Similar game structure is assumed in the selling game. We first analyze the licensing game followed by the selling game.

In the licensing game, first we look between two schemes, fixed fee licensing and auction, find the optimal licensing contract and address the issue of technology shelving. It is well known, in many situations these two licensing schemes could only be feasible to the innovator when monitoring the output of the licensees are not possible. However, to find the overall optimal licensing contract and to re-address the shelving issue, we also consider other licensing schemes as mentioned before. Finally, we will introduce the selling game and find the most profitable mode of technology transfer of the innovator in this environment and address the issue of technology diffusion and benefit to the consumers from the innovation.

Our main results are as follows. In the case of fixed fee licensing, since the inefficient firm benefits from it only, the innovator will always license technology to the inefficient firm and technology diffusion takes place. Interesting outcome occurs, when the innovator auction-off an exclusive license, we show that the efficient firm wins the auction, however, shelves the innovation. In other words, under auction, the technology is successfully transferred but it is never used for cost reduction purpose, the diffusion of technology does not happen and consumers do not get any benefit from the innovation. Moreover for the innovator, auctioning-off the license is more profitable than fixed fee licensing, hence the outcome under auction will always prevail in this environment. Given this negative outcome, where a new technology is shelved prohibiting any further benefit in terms of diffusion of new knowledge, we look into other possibilities of licensing schemes which is also profitable to innovator (in particular more profitable than auction) and the innovation is actually put to use to reduce cost i.e. not shelved.

We explore royalty, two-part tariff licensing and royalty-auction schemes and find the overall optimal licensing contract of the innovator. We find optimal licensing policy essentially is either pure royalty or two-part tariff and the inefficient firm will acquire it. In particular, for relatively small innovation royalty licensing is optimal, otherwise the optimal licensing scheme is two-part tariff. The technology is always transferred to the inefficient firm as the efficient firm has no incentive to acquire the technology, and also under this situation, it cannot stop the inefficient firm from acquiring it. In this case, knowledge transfer happens and the new technology is put to use. However, the benefit of the new innovation goes on to the consumers in terms of lower price of the good (i.e. higher consumer surplus) occurs only under the optimal two-part tariff licensing. Consumer surplus remains unchanged to the pre-innovation level under the optimal pure royalty licensing, thus consumers do not get any additional benefit after innovation.

Then we move to analyze the selling game in order to find, given a choice between selling the right and licensing, what the innovator would optimally choose. We find it is always optimal for the innovator to sell the new technology, and interestingly, it will always sell it to the efficient firm, unlike the case of licensing where it licenses to the inefficient firm. The efficient firm buys the right of the new technology, and in this case does not shelve it, but further licenses it to the inefficient firm. The inefficient uses the technology, so technology diffusion happens. However, we also note under this situation, the consumers do not get any additional benefit as the prices of the goods do not fall compared to the pre-innovation stage. More specifically, under selling, consumer surplus and profit of the inefficient firm remain unchanged, while the profit of the efficient firm declines significantly. All the gain from the technology transfer is appropriated by the outside innovator.

In the final part of our analysis, we relax the assumption that cost reduction happens to the inefficient firm only, by considering a generic version of the model where the cost reductions happen to both firms but in a non-uniform way. Inefficient firm gets a higher cost reduction than the efficient firm using the new innovation. We also discuss various licensing policies in that environment and find the optimal mode of technology transfer of the innovator.

1.1 A Brief Discussion on Literature

The theoretical literature of patent licensing and incentives for innovation in a competitive industry can be traced back to Arrow (1962). There is also a vast literature on technology transfer of cost reducing innovations through patent licensing in various oligopoly models (see Kamien and Tauman (1986), Katz and Shapiro (1986), Kamien (1992), Wang (1998), Fauli-Oller and Sandonis (2002), Poddar and Sinha (2004), Sen and Tauman (2007), Wang et. al (2013) and Sinha (2016) to name a few among many others). The literature has discussed when potential licensees are symmetric and asymmetric (i.e. differ in marginal costs of production). Various frameworks are used to find optimal licensing policies. Selling the patent right to one potential licensees to see the implication is relatively new (see Tauman and Weng (2012), Banerjee and Poddar (2019) on this). However, the common thread in all these studies when it comes to a cost reducing innovation, is the uniform cost reduction to all the licensee firms. We believe this assumption of uniform cost reduction is actually far from reality. It is well possible a new technology or innovation may not reduce the costs of production of all firms uniformly, rather it would actually depend on the respective cost structures and cost conditions of the firms which may or may not be the same i.e. when firms are asymmetric. For example, if the firm is already very efficient, the scope of its cost reduction will be generally less compared to a relatively inefficient firm. To that extent, we address a rather extreme situation, where the cost reducing innovation only impacts the inefficient firm but has no impact to the efficient firm in terms of cost reduction. Except Stamatopoulos and Tauman (2009), no paper to the best of our knowledge has addressed this in the licensing literature. In this backdrop of non-uniform cost reduction, we address various issues, starting from optimal licensing policies, transferring the right of a new innovation by selling, technology diffusion or the possibility of shelving the technology and its impact to the consumers.

The rest of the paper is organized as follows. In the next section, we describe the model followed by a complete analysis of the licensing policies. In section 3, we analyze when the technology is transferred by selling the right to one of the firms, and find out the optimal technology transfer policy of the innovator. The impact of the innovation on the consumers are also discussed. Non-uniform cost reductions to the firms from innovation is discussed in section 4. Sections 5 concludes.

2. The Model

Consider two firms, firm A and firm B located in a linear city represented by an unit interval $[0,1]$. Firm A is located at 0 whereas firm B is located at 1 that is at the two extremes of the linear city. Both firms produce homogenous goods with constant but different marginal costs of production and compete in prices. We assume that consumers are uniformly distributed over the interval $[0,1]$. Each consumer purchases exactly one unit of the good either from firm A $(price\ p_A)$ or firm B $(price\ p_B)$. $v > 0$ denotes gross utility of the consumer derived from the good. The transportation cost per unit of distance is t and it is borne by the consumers.

The utility function of a consumer located at x is given by:

$$U = v - p_A - tx \qquad \text{if buys from firm A}$$

$$= v - p_B - (1 - x)t \qquad \text{if buys from firm B}$$

We assume that the market is fully covered and the total demand is normalized to 1. The demand functions for firm A and firm B can be calculated as:

$$Q_A = \frac{1}{2} + \frac{p_B - p_A}{2t} \qquad \text{if } p_B - p_A \in (-t, t)$$

$$= 0 \qquad \text{if } p_B - p_A \leq -t$$

$$= 1 \qquad \text{if } p_B - p_A \geq t$$

and $Q_B = 1 - Q_A$

We assume that firm A is more efficient than firm B, so the marginal cost of firm A (c_A) is less than marginal cost of firm B (c_B).There is an outside innovator (an independent research lab) which has a cost reducing innovation. The innovation helps reduce the per-unit marginal costs of the inefficient firm (i.e. firm B only) by ϵ but not below c_A i.e. we assume $(c_B - \epsilon) \geq c_A$ or $\epsilon \leq (c_B - c_A)$.

The timing of the game is given as follows:

Stage 1: The outside innovator decides on the licensing schemes. The firm accepts or rejects the offer.

Stage 2: The firms compete in prices and products are sold to consumers.

2.1. The Pre-Licensing Game

First we examine the case where the outside innovator is not there and the two asymmetric firms A and B are competing in the market. Let us define $\delta = c_B - c_A \geq 0$ to capture the cost difference. We also assume that $\delta \leq 3t$ so that the less efficient firm's equilibrium quantity is positive. The pre-licensing equilibrium prices, demands and profits can be given as:

$$p_A = \frac{1}{3}(3t + 2c_A + c_B) = c_A + \frac{1}{3}(3t + \delta)$$

$$p_B = \frac{1}{3}(3t + c_A + 2c_B) = c_B + \frac{1}{3}(3t - \delta)$$

$$Q_A = \frac{1}{6t}(3t - c_A + c_B) = \frac{1}{6t}(3t + \delta)$$

$$Q_B = \frac{1}{6t}(3t + c_A - c_B) = \frac{1}{6t}(3t - \delta)$$

$$\pi_A = \frac{1}{18t}(3t - c_A + c_B)^2 = \frac{1}{18t}(3t + \delta)^2$$

$$\pi_B = \frac{1}{18t}(3t + c_A - c_B)^2 = \frac{1}{18t}(3t - \delta)^2$$

2.2 The Licensing Game

Fixed Fee

Let us first consider the game of fixed fee licensing. Under the fixed fee policy, the innovator announces a fee at which it licenses the new technology. Any firm that is willing to pay the fee becomes a licensee. Note that firm A has no incentive to have the license since it will gain nothing from this license. Firm B accepts the license, and the equilibrium prices, demands and profits can be given as:

$$P_A^F = c_A + \frac{1}{3}(3t + \delta - \epsilon)$$

$$P_B^F = c_B - \epsilon + \frac{1}{3}(3t - \delta + \epsilon)$$

$$Q_A^F = \frac{1}{6t}(3t + \delta - \epsilon)$$

$$Q_B^F = \frac{1}{6t}(3t - \delta + \epsilon)$$

$$\pi_A^F = \frac{1}{18t}(3t + \delta - \epsilon)^2$$

$$\pi_B^F = \frac{1}{18t}(3t - \delta + \epsilon)^2 - F_B$$

Since only the inefficient firm B will be willing to get the license, the innovator optimally sets the fee at $F_{\mathrm{B}} = \left[\frac{1}{18t}(3t - \delta + \epsilon)^2 - \frac{1}{18t}(3t - \delta)^2\right] = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t}$.

Auction

Assume the innovator auctions-off one exclusive license. The maximum amount a firm is willing to pay for the license is the difference between its profit if it acquires the license and its profit if its opponent acquires it. Note that if firm A wins, it will shelve the technology as it gets no benefit from it, hence we will be back to the pre-licensing game. But by doing this it can prevent firm B from getting the license. If firm A gets the license and firm B loses, firm A's maximum possible gain will be g_A= $\left[\frac{1}{18t}(3t + \delta)^2 - \frac{1}{18t}(3t + \delta - \epsilon)^2\right] = \frac{\epsilon(6t + 2\delta - \epsilon)}{18t}$ and this gain (which is basically loss avoided) comes from being able to prevent firm B from getting the license. Similarly if firm B gets the license and firm A loses, then firm B's maximum possible gain will be g_B=$\left[\frac{1}{18t}(3t - \delta + \epsilon)^2 - \frac{1}{18t}(3t - \delta)^2\right] = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t}$. Since we assume $\epsilon \leq (c_B - c_A)$ i.e. $\epsilon \leq \delta$, it must be the case that $g_A > g_B$, Therefore firm A can always ensure that it wins the auction by bidding an amount slightly higher than g_B. The equilibrium bid for firm A will therefore be $(g_B + k)$ where $k \approx 0$. Thus firm A will always win the auction, the innovator will extract revenue of

$R_A = g_B + k$ from firm A and the technology will be shelved. Thus firm A will optimally prevent firm B from acquiring the license.

Now looking at the payoffs of the innovator under fixed fee and auction we have the following result.

Proposition 1

Between fixed fee and auction policy, it is always weakly optimal for the innovator, to auction off an exclusive license and the efficient firm will get it; however, the technology will always be shelved.

For any positive k (even if $k \approx 0$) the revenue of the innovator is higher in case of an exclusive auction. This result comes from the nature of the licensing environments, i.e. in case of fixed fee both firms can get the license in lieu of a fixed payment but in case of auction only the highest bidder gets it. The competitive environment of the auction setting leads to such outcome. As we see, under this environment, there will be no real diffusion of the new technology. Since the technology is shelved, cost conditions of both firms do not change and the good will be sold at the same price as the pre-licensing stage. Consumers do not get better off. The profit of the inefficient firm remains same whereas the profit of the efficient firm decreases from the pre-licensing stage by the amount of the revenue extracted by the innovator. Only the innovator benefits from the transaction.

Given this negative and less desirable outcome under these two licensing policies, we now consider other licensing possibilities to see if a different and possibly better outcome can be achieved. First we consider a royalty licensing policy followed by a two-part tariff licensing scheme.

Royalty

First note that like the fixed fee licensing, only the inefficient firm B will be interested to get the license. Let the per-unit royalty fee charged by the innovator to firm B be r. Firm B's profit function will be $\pi_B = p_B Q_B - (c_B - \epsilon + r)Q_B$. Firm A's profit function is $\pi_A = p_A Q_A - c_A Q_A$. When firm B accepts the license, the expressions for prices, demands and profits are as follows:

$$P_A^R = c_A + \frac{1}{3}(3t + \delta - \epsilon + r)$$

$P_B^R = c_B - \epsilon + r + \frac{1}{3}(3t - \delta + \epsilon - r)$

$Q_A^R = \frac{1}{6t}(3t + \delta - \epsilon + r)$

$Q_B^R = \frac{1}{6t}(3t - \delta + \epsilon - r)$

$\pi_A^R = \frac{1}{18t}(3t + \delta - \epsilon + r)^2$

$\pi_B^R = \frac{1}{18t}(3t - \delta + \epsilon - r)^2$

The outside innovator will maximize rQ_B and the optimum royalty rate should have been $r^* = \frac{3t-\delta+\epsilon}{2} > 0$. Now $\frac{3t-\delta+\epsilon}{2} > \epsilon \;\forall\; \epsilon \leq (3t - \delta)$. In this case innovator sets $r^* = \epsilon$ and gets revenue $Rev_B^r = \frac{\epsilon}{6t}(3t - \delta)$. Firm B's payoff accepting the royalty licensing will be $\pi_B^R = \frac{1}{18t}(3t - \delta)^2$.[2] If $\epsilon > (3t - \delta)$, then the innovator will charge $r^* = \frac{3t-\delta+\epsilon}{2}$ and earns a revenue of $Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{24t}$.[3] But since we assume $\delta \geq \epsilon$, the optimal royalty contract will depend on the magnitude of δ. Now $\delta > (3t - \delta)$ if and only if $\delta > \frac{3t}{2}$. In this case the innovator charges $r^* = \epsilon$ for $0 < \epsilon \leq (3t - \delta)$ and $r^* = \frac{3t-\delta+\epsilon}{2}$ for $(3t - \delta) < \epsilon \leq \delta$. If $\delta \leq \frac{3t}{2}$, then innovator can only charge $r^* = \epsilon$. To keep things rather general we consider $\delta > \frac{3t}{2}$ since we will have all possibilities open with this assumption and therefore this case is less restrictive to $\delta \leq \frac{3t}{2}$. Therefore given $\delta > \frac{3t}{2}$, the optimum royalty contract will be: $r^* = \epsilon \;\forall\; 0 < \epsilon \leq (3t - \delta)$ and $r^* = \frac{3t-\delta+\epsilon}{2} \;\forall\; (3t - \delta) < \epsilon \leq \delta$. The revenue of the innovator will be $Rev_B^r = \frac{\epsilon}{6t}(3t - \delta) \forall\; (3t - \delta) < \epsilon \leq \delta$ and $Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{24t} \forall\; (3t - \delta) < \epsilon \leq \delta$.

Two-Part Tariff

Suppose the outside innovator license the innovation to firm B by charging a two-part tariff i.e. a

[2]If firm B rejects, it gets pre-licensing payoff $\frac{1}{18t}(3t - \delta)^2$ as firm A has no incentive to acquire the technology.

[3]Once again Firm B will be strictly better off accepting the contract with payoff $\frac{(3t-\delta+\epsilon)^2}{72t}$.

combination of fixed fee F_B and a per unit royalty r. This situation is similar to the royalty licensing except that a fixed fee is charged in addition to the per-unit royalty. In this situation the expressions for prices, demands and profits can be given as:

$$P_A^{TPT} = c_A + \frac{1}{3}(3t + \delta - \epsilon + r)$$

$$P_B^{TPT} = c_B - \epsilon + r + \frac{1}{3}(3t - \delta + \epsilon - r)$$

$$Q_A^{TPT} = \frac{1}{6t}(3t + \delta - \epsilon + r)$$

$$Q_B^{TPT} = \frac{1}{6t}(3t - \delta + \epsilon - r)$$

$$\pi_A^{TPT} = \frac{1}{18t}(3t + \delta - \epsilon + r)^2$$

$$\pi_B^{TPT} = \frac{1}{18t}(3t - \delta + \epsilon - r)^2 - F_B$$

The innovator will offer the two-part tariff licensing contract to firm B by maximizing $Rev_{TPT} = rQ_B^{TPT} + F_B = \frac{r}{6t}(3t - \delta + \epsilon - r) + \frac{1}{18t}(3t - \delta + \epsilon - r)^2 - \frac{1}{18t}(3t - \delta)^2$.

The optimal two-part tariff royalty rate can be calculated as $r_B^{TPT} = \frac{\epsilon - \delta + 3t}{4}$. Now $\frac{\epsilon - \delta + 3t}{4} \geq \epsilon$ if $\epsilon \leq \frac{3t-\delta}{3}$. So $r_A^{TPT} = \epsilon$ if $\epsilon \leq \frac{3t-\delta}{3}$ and $r_A^{TPT} = \frac{\epsilon + \delta + 3t}{4}$ if $\epsilon > \frac{3t-\delta}{3}$.

Now once again since the maximum value of ϵ can be δ we need to check whether $\frac{3t-\delta}{3}$ is greater than δ or not. We get that $\frac{3t-\delta}{3} > \delta$ iff $\delta < \frac{3t}{4}$, therefore $\frac{3t-\delta}{3} \leq \delta$ iff $\delta \geq \frac{3t}{4}$. Once again for the sake of generality we assumed in the last section that $\delta > \frac{3t}{2}$ holds implying that $\delta \geq \frac{3t}{4}$ holds. This will keep all possibilities open and we proceed with that.

If the innovator offers the two-part tariff contract to firm B then the optimum two part tariff contracts offered will be $\{r_B^{TPT} = \epsilon;\ F_B^{TPT} = 0\}$ if $\epsilon \leq \frac{3t-\delta}{3}$; $\{r_B^{TPT} = \frac{\epsilon - \delta + 3t}{4};\ F_B^{TPT} = \frac{(\epsilon - \delta + 3t)^2}{32t} - \frac{(3t-\delta)^2}{18t}\}$ if $\frac{3t-\delta}{3} < \epsilon < \delta$.

The optimal profit of the innovator, therefore, will be $R^{*}_{TPTfirmB} = \frac{\epsilon}{6t}(3t-\delta)$ if $\epsilon \leq \frac{3t-\delta}{3}$; $R^{*}_{TPTfirmB} = \frac{(\epsilon-\delta+3t)^2}{16t} - \frac{(3t-\delta)^2}{18t}$ if $\frac{3t-\delta}{3} < \epsilon < \delta$.

Royalty-Auction

In this case, the innovator first calls an exclusive auction to offer a royalty contract, then whoever wins the auction, the royalty contract is offered to the winner. Note here in this case, firm A will be interested to participate because if wins it can shelve the technology, thereby stopping firm B to acquire it.

From the previous royalty analysis we know the optimal royalty contract to firm B is: $r^* = \epsilon \; \forall \; 0 < \epsilon \leq (3t-\delta)$ and $r^* = \frac{3t-\delta+\epsilon}{2} \; \forall \; (3t-\delta) < \epsilon \leq \delta$ and optimal two-part tariff contract is: $\{r_B^{TPT} = \epsilon;\; F_B^{TPT} = 0\}$ if $\epsilon \leq \frac{3t-\delta}{3}$; $\{r_B^{TPT} = \frac{\epsilon-\delta+3t}{4};\; F_B^{TPT} = \frac{(\epsilon-\delta+3t)^2}{32t} - \frac{(3t-\delta)^2}{18t}\}$ if $\frac{3t-\delta}{3} < \epsilon < \delta$.

Suppose B wins the auction for royalty:

Case (i): $r^* = \epsilon$. Then after making the royalty payment, firm B will be left with no surplus, therefore zero willingness to pay to win the auction. Hence the innovator will not be able to extract anything more from B in the auction, therefore not an attractive option for the innovator to hold auction.

Case (ii): $r^* = \frac{3t-\delta+\epsilon}{4} < \epsilon$. Here the innovator can extract at most F_B^{TPT} in the auction itself (apart from royalty payment) which is also equivalent to its optimal two-part tariff contract payoff. Thus holding an auction, the innovator cannot do any better than two-part tariff.

Suppose A wins the auction for royalty. Note that in this case, there will be no royalty payment as firm A is not going to use it (note the technology is not useful to firm A). It will be shelved only and we are back to the pre-licensing scenario. Recall, the maximum willingness to pay by firm A to win the auction is: $g_A = \left[\frac{1}{18t}(3t+\delta)^2 - \frac{1}{18t}(3t+\delta-\epsilon)^2\right] = \frac{\epsilon(6t+2\delta-\epsilon)}{18t}$ which will be the revenue to the innovator coming from auction.

Now if we compare between g_A (A wins) and F_B^{TPT} (B wins), A wins if $g_A > F_B^{TPT}$ and makes a payment of F_B^{TPT} (and no further payment) which is strictly less than the two-part tariff payment $R^{*}_{TPTfirmB}$ from B. Hence holding auction is not an attractive option for the innovator here. If $g_A < F_B^{TPT}$, B wins but then we are exactly at the two-part tariff situation payoff wise to the innovator.

So holding an auction and then offering royalty contract does not do any better than a two-part tariff contract to the innovator.

2.3 Optimal Licensing Contract

We already know that the innovator will prefer auction over fixed fee licensing. Now, we compare payoffs of the innovator from auction, royalty and two-part tariff licensing to find out the optimal contract of the innovator.

Case (i) $\boldsymbol{0 < \epsilon \leq \frac{(3t-\delta)}{3}}$

Under this range of innovation payoffs of the innovator from royalty, two-part tariff and auction are as follows:

$$Rev_B^r = \frac{\epsilon}{6t}(3t - \delta)$$

$$Rev_B^{TPT} = \frac{\epsilon}{6t}(3t - \delta)$$

$$Rev_A^{Auc} = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t} + k$$

It is evident that two-part tariff payoff is same as royalty. So, we need to compare between royalty and auction. We get $Rev_B^r > Rev_A^{Auc}$if $\epsilon < (3t - \delta)$. Therefore, for $\epsilon \leq \frac{(3t-\delta)}{3}$ revenue from royalty will be higher than auction. Therefore, it is optimal for the innovator to charge $r^* = \epsilon$ and royalty licensing will be optimal.

Case (ii) $\boldsymbol{\frac{(3t-\delta)}{3} < \epsilon \leq (3t - \delta)}$

Payoffs of the innovator from royalty, two-part tariff and auction are:

$$Rev_B^r = \frac{\epsilon}{6t}(3t - \delta)$$

$$Rev_B^{TPT} = \frac{(3t - \delta + \epsilon)^2}{16t} - \frac{(3t - \delta)^2}{18t}$$

$$Rev_A^{Auc} = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t} + k$$

We know that for $\epsilon < (3t-\delta)$, $Rev_B^r > Rev_A^{Auc}$ and therefore the innovator will always earn a higher profit under royalty than auction. Therefore, we need to check between two-part tariff and royalty. Now $Rev_B^{TPT} - Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{16t} - \frac{(3t-\delta)^2}{18t} - \frac{\epsilon}{6t}(3t-\delta) = (3t-\delta-3\epsilon)^2 > 0$ always holds. Therefore, two-part tariff is optimal for $\frac{(3t-\delta)}{3} < \epsilon \leq (3t-\delta)$.

Case (iii) $(\boldsymbol{3t-\delta}) < \boldsymbol{\epsilon} \leq \boldsymbol{\delta}$

Payoffs of the innovator from royalty, two-part tariff and auction are:

$$Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{24t}$$

$$Rev_B^{TPT} = \frac{(3t-\delta+\epsilon)^2}{16t} - \frac{(3t-\delta)^2}{18t}$$

$$Rev_A^{Auc} = \frac{\epsilon(6t-2\delta+\epsilon)}{18t} + k$$

First we compare royalty and auction policy in this range and we get that $Rev_A^{Auc} = \frac{\epsilon(6t-2\delta+\epsilon)}{18t} > Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{24t}$ iff $(3t-\delta-\epsilon)[3(3t-\delta)+\epsilon] < 0$ holds. Since $[3(3t-\delta)+\epsilon] > 0$ we need $(3t-\delta-\epsilon) < 0$ to hold implying $\epsilon > (3t-\delta)$ holds. Thus $Rev_A^{Auc} > Rev_B^r$ for $(3t-\delta) < \epsilon \leq \delta$. Finally in this range we need to compare auction policy and two part tariff and we go by the following way. At $\epsilon = (3t-\delta)$, $Rev_A^{Auc} = 0.166\frac{(3t-\delta)^2}{t}$ and $Rev_B^{TPT} = 0.194\frac{(3t-\delta)^2}{t}$. Define $G = Rev_B^{TPT} - Rev_A^{Auc} = \frac{(3t-\delta+\epsilon)^2}{16t} - \frac{(3t-\delta)^2}{18t} - \frac{\epsilon(6t-2\delta+\epsilon)}{18t}$. We get that $\frac{dG}{d\epsilon} = \frac{(3t-\delta)+\epsilon}{72t} > 0$. This shows that $Rev_B^{TPT} > Rev_A^{Auc}$ for all $(3t-\delta) < \epsilon \leq \delta$. Therefore, the innovator will license the technology through two-part tariff by charging $r_B^{TPT} = \frac{3t-\delta+\epsilon}{4}$ and $F_B^{TPT} = \frac{(3t-\delta+\epsilon)^2}{32t} - \frac{(3t-\delta)^2}{18t}$.

Therefore we have the following result which characterizes the overall licensing policy:

Proposition 2

The optimal licensing contract of the innovator is given as follows. Royalty to firm B, i.e. $r_B^* = \epsilon$ *for all* $0 < \epsilon \leq \frac{(3t-\delta)}{3}$ *and* $Rev^* = \frac{\epsilon}{6t}(3t-\delta)$. *Two part tariff to firm B, i.e.* $\left\{r_B^{TPT} = \frac{\epsilon-\delta+3t}{4};\ F_B^{TPT} = \frac{(\epsilon-\delta+3t)^2}{32t} - \frac{(3t-\delta)^2}{18t}\right\}$ *for all* $\frac{3t-\delta}{3} < \epsilon \leq \delta$ *and* $Rev^* = \frac{(3t-\delta+\epsilon)^2}{16t} - \frac{(3t-\delta)^2}{18t}$.

The intuition for the above result is that for relatively higher magnitude of cost reduction the innovator leaves some surplus per-unit output for the licensee firm B as this will increase the operative profit of firm B through relatively greater output and increased market coverage in the subsequent market competition. The innovator then finds it optimal to extract the remaining surplus through an up-front fee. But for lower degree of cost reduction, output and market coverage effect for firm B is not that much and therefore it is optimal for the innovator to extract the entire cost reducing benefit per-unit from the licensee firm B. Thus a pure royalty will maximize the extraction for the innovator for lower degree of cost reduction. Also note that auction of an exclusive license is never optimal since the auction effectively plays out like a second price auction where firm B's maximum bidding potential is also lower. This makes auction a relatively low-revenue potential technology transfer mechanism for the innovator whereas non-exclusive royalty and two-part tariff fetch better revenue for the innovator.

3. The Selling Game

We now consider the possibility of selling the technology by the outside innovator. The innovator sells it by charging a fixed fee. The innovator can sell the technology to either the efficient firm A or the inefficient firm B. Now, it is straightforward that if the innovator sells it to firm B, then no further licensing happens as firm A has no incentive to acquire the license whereas if the innovator sells it to firm A, then further licensing happens as we will see below.

When the innovator sells the technology to firm B then only firm B's cost is reduced. The gain for firm B from this purchase will be $\frac{1}{18t}(3t-\delta+\epsilon)^2 - \frac{1}{18t}(3t-\delta)^2 = \frac{\epsilon}{18t}(6t-2\delta+\epsilon)$. This will be charged by the outside innovator as the fixed fee for the sale and therefore the revenue of the innovator, if it sells to firm B, will be $Rev_B^{SELL} = \frac{\epsilon(6t-2\delta+\epsilon)}{18t}$. Note that it is same as the fee under fixed fee licensing.

However, if the innovator sells it to the efficient firm A, then firm A has the option of further licensing it to firm B as firm B gains from the transferred technology. To get the entire picture of this subgame we need to analyze the optimal licensing strategy of firm A. For this purpose, we start with the generalized two-part tariff licensing scheme. If firm A offers a two-part tariff licensing to firm B with royalty rate r and the fixed fee component $F = \left[\frac{1}{18t}(3t - \delta + \epsilon - r)^2 - \frac{1}{18t}(3t - \delta)^2\right]$, it will choose r optimally by maximizing $\pi_A = \frac{r}{6t}(3t - \delta + \epsilon - r) + \left[\frac{1}{18t}(3t - \delta + \epsilon - r)^2 - \frac{1}{18t}(3t - \delta)^2\right] + \frac{1}{18t}(3t + \delta - \epsilon + r)^2$. Maximization yields $r^* = \frac{9t+\delta-\epsilon}{2} > \epsilon$. Therefore $r^* = \epsilon$ and $F^* = 0$ and the optimal licensing scheme turns out to be pure royalty. Therefore, firm A's gross payoff from this licensing, post technology sale is, $\pi_A = \frac{\epsilon(3t-\delta)}{6t} + \frac{1}{18t}(3t + \delta)^2$.

The innovator will optimally extract the net gain $P_A = \frac{\epsilon(3t-\delta)}{6t} + \frac{1}{18t}(3t + \delta)^2 - \frac{1}{18t}(3t + \delta - \epsilon)^2$ since the no-acceptance payoff for firm A is $\frac{1}{18t}(3t + \delta - \epsilon)^2$ (since in that case firm B would get the technology) and P_A also denotes the price of sale to firm A. Thus the revenue of the innovator if it decides to sell the technology to firm A is $Rev_A^{SELL} = P_A = \frac{\epsilon(3t-\delta)}{6t} + \frac{\epsilon(6t+2\delta-\epsilon)}{18t}$. One can easily check that $Rev_A^{SELL} > Rev_B^{SELL}$ since $\epsilon \leq \delta$. Thus the innovator will optimally sell the license to the efficient firm A.

Proposition 3

If the innovator chooses to sell the technology to one of the competing firms, it will choose the efficient firm. The efficient firm further licenses the technology to the inefficient firm.

If the innovation is sold to the inefficient firm B then no further licensing happens. In other words, there is no scope for additional gain. Therefore if the innovation is sold to firm B the innovator's revenue potential is lower. On the contrary if the innovation is sold to firm A then firm A further licenses it to firm B using royalty licensing which the innovator can potentially extract from firm A. Here the revenue potential is higher and therefore the innovator will optimally sell the technology to the efficient firm A.

Summary

When the outside innovator auctions off an exclusive license or exclusively sell the right of the new technology, it will always choose the efficient firm. Under auction licensing policy, innovation is shelved, no technological diffusion happens whereas under selling, innovation is not shelved, it is further licensed and technological diffusion happens. For any other form of licensing it chooses the inefficient firm since the efficient firm will not accept as the licensing environment is not exclusive. Here technology diffusion takes place but the gains from diffusion is extracted by the innovator.

Now we look into the optimal method of technology transfer from the innovator's point of view. For that purpose we need to compare the payoffs of the innovator from selling and optimal licensing.

3.1 Comparison between Selling and Licensing

Case 1: $\mathbf{0 < \epsilon \leq \frac{(3t-\delta)}{3}}$

In this range the optimal licensing policy was pure royalty and therefore we need to compare the payoffs of the innovator from selling and royalty licensing. The payoff from selling is $Rev_A^{SELL} = \frac{\epsilon}{6t}(3t-\delta) + \frac{\epsilon(6t+2\delta-\epsilon)}{18t}$ and the payoff from royalty licensing is $Rev_B^r = \frac{\epsilon}{6t}(3t-\delta)$. It is straightforward that the innovator can generate a higher payoff from selling the patent rather than licensing it.

Case 2: $\mathbf{\frac{(3t-\delta)}{3} < \epsilon \leq \delta}$

In this range the we need to compare the innovator's payoff from selling and two-part tariff licensing which are respectively $Rev_A^{SELL} = \frac{\epsilon}{6t}(3t-\delta) + \frac{\epsilon(6t+2\delta-\epsilon)}{18t}$ and $Rev_B^{TPT} = \frac{(3t-\delta+\epsilon)^2}{16t} - \frac{(3t-\delta)^2}{18t}$.

To achieve the task, let us define $G = Rev_A^{SELL} - Rev_B^{TPT} = \frac{\epsilon}{6t}(3t-\delta) + \frac{\epsilon(6t+2\delta-\epsilon)}{18t} - \frac{(3t-\delta+\epsilon)^2}{16t} + \frac{(3t-\delta)^2}{18t}$. Now at $\epsilon = \frac{(3t-\delta)}{3}$, $G = \frac{(3t-\delta)(15t+7\delta)}{162t} > 0$ and at $\epsilon = \delta$, $G = \frac{(3t-\delta)(3t+2\delta)}{18t} +$

$\frac{\delta(6t+\delta)}{18t} - \frac{9t}{16} > 0$ since we focus on $\frac{3t}{2} < \delta < 3t$. Also we get that $\frac{dG}{d\epsilon} = \frac{33t+5\boldsymbol{\delta}}{72t} - \frac{\epsilon}{8t}$ and therefore $\frac{d^2G}{d\epsilon^2} = -\frac{1}{8t} < 0$. Therefore G is concave with positive values at both $\epsilon = \frac{(3t-\delta)}{3}$ and $\epsilon = \delta$ which means that $G > 0\ \forall\epsilon \in \left[\frac{(3t-\delta)}{3}, \delta\right]$. This shows that $Rev_A^{SELL} > Rev_B^{TPT}$.

Therefore, it is optimal for the innovator to sell the patent instead of licensing and this holds for all $0 < \epsilon \leq \delta$. From the above analysis we can state the following.

Proposition 4

It is optimal for the innovator to sell the patent to the efficient firm, which will further license it to the inefficient firm. Technology diffusion takes place but all the gain from the technology transfer is appropriated by the innovator.

The intuition for the above result is that under selling the efficient firm can further license the technology to the inefficient firm. Thus the efficient firm can extract the surplus from the inefficient firm B which in turn is extracted by the innovator. Therefore the selling game has the licensing game embedded in it and all possibilities that are there in the licensing game are there in the selling game as well. Thus under selling the innovator cannot be worse-off compared to licensing.

Note that under selling, the prices of the goods remain same as the pre-technology transfer stage. The profit of the inefficient firm remains unchanged, while the profit of the efficient firm declines significantly compared to pre-technology transfer stage. The outside innovator benefits exclusively from the transaction.

3.2 Consumer Welfare

Now let us look into the aspect of benefit to the consumers from the innovation under licensing and selling. More precisely, we will look into the consumer surplus under both environments.

The prices charged under selling by both the firms will be $P_A^{SELL} = c_A + \frac{1}{3}(3t + \delta)$ and $P_B^{SELL} = c_B + \frac{1}{3}(3t - \delta)$. When $\epsilon < \frac{(3t-\delta)}{3}$ holds, then optimal two-part tariff is in fact pure royalty licensing and therefore when $r_B^{TPT} = \epsilon$ holds, the prices are $P_A^{TPT} = c_A + \frac{1}{3}(3t + \delta)$ and $P_B^{TPT} = c_B + \frac{1}{3}(3t - \delta)$. Therefore the consumer surplus will be the same. But if $\epsilon > \frac{(3t-\delta)}{3}$ holds, then under optimal two-part tariff $r_B^{TPT} = \frac{3t-\delta+\epsilon}{4} < \epsilon$ and the prices are $P_A^{TPT} = c_A + \frac{5t+\delta-\epsilon}{4}$, $P_B^{TPT} = c_B + \frac{6t-2\delta-\epsilon}{3}$. Now, both $P_A^{TPT} < P_A^{SELL}$ and $P_B^{TPT} < P_B^{SELL}$ holds as $r_B^{TPT} < \epsilon$ under this case. Therefore consumer surplus is higher under the two-part tariff case of licensing compared to selling. The intuition is that in case of selling, firm A purchases the right and subsequently offers a royalty licensing contract to firm B by charging $r^* = \epsilon$. Therefore both the marginal costs of firm A and firm B remain at the pre-technology transfer level and therefore the prices also remain at the pre-technology transfer level and this happens under $0 < \epsilon \leq \frac{(3t-\delta)}{3}$. But for $\frac{(3t-\delta)}{3} < \epsilon \leq \delta$ the optimal licensing to the inefficient firm B is two-part tariff with a royalty rate of less than ϵ. Thus in this range, the marginal cost of firm B falls and therefore the price charged by firm B also falls. Since the firms are assumed to compete in prices and prices are strategic compliments, firm A also optimally reduces its price. Thus the consumers are better off in this range and therefore overall consumers' surplus is greater under two-part tariff licensing than selling. Hence, we summarize the above discussion below.

Proposition 5:

Consumers are better-off (at least weakly) under licensing than selling.

4. Extension: Asymmetric Absorptive Capacity

We now extend the analysis in the following natural direction. The cost reducing innovation affects both firms but in a non-uniform manner. It reduces the marginal cost of the inefficient firm more than the efficient firm to stay in line of the previous analysis. This can be due to asymmetric absorptive capacities of the new technology to the licensees. It also could be that the scope of cost reduction for the efficient firm is less than the inefficient firm, simply because the efficient is already very efficient. Under this, like before we first consider a licensing game where the innovator specifically opts for a fixed fee or an auction to license the new technology. Then we explore other possible licensing contracts, namely royalty and two-part tariff followed by selling the right of to one of the licensees. The analysis concludes with a brief discussion on consumer welfare. One difference between this analysis and the previous analysis is, here since the efficient firm also gets some cost reduction, shelving will never happen.

4.1 The licensing Game

Let's assume the total size of cost reduction under new technology licensing from the innovator is ϵ. However, due to asymmetric absorptive capacities, cost reduction for the inefficient firm is ϵ and for the efficient firm is $\lambda\epsilon$, where $0 < \lambda < 1$.

The innovator has two options, either he would offer non-exclusive licenses through a fixed fee licensing contract or offer an exclusive license through auction. Like before, exclusivity means that only one licensee gets the technology.

Assumption: $\epsilon < \delta < 3t$

Fixed fee

In case of fixed fee any firm can get the license by paying the fee set by the innovator. The equilibrium prices, demands, profits and fees can be given as:

$$P_A^F = c_A - \lambda\epsilon + \frac{1}{3}(3t + \delta - \epsilon(1-\lambda))$$

$$P_B^F = c_B - \epsilon + \frac{1}{3}(3t - \delta + \epsilon(1-\lambda))$$

$$Q_A^F = \frac{1}{6t}(3t + \delta - \epsilon(1-\lambda))$$

$$Q_B^F = \frac{1}{6t}(3t - \delta + \epsilon(1-\lambda))$$

$$\pi_A^F = \frac{1}{18t}(3t + \delta - \epsilon(1-\lambda))^2 - F_A$$

$$\pi_B^F = \frac{1}{18t}(3t - \delta + \epsilon(1-\lambda))^2 - F_B$$

$$F_A = \frac{1}{18t}(3t + \delta - \epsilon(1-\lambda))^2 - \frac{1}{18t}(3t + \delta - \epsilon)^2$$

$$F_B = \frac{1}{18t}(3t - \delta + \epsilon(1-\lambda))^2 - \frac{1}{18t}(3t - \delta - \lambda\epsilon)^2$$

Note that when $\lambda = 0$, $F_A = 0$, i.e. we are back to our previous analysis where the innovation only reduces the cost of the inefficient firm.

Thus the total fixed fee licensing revenue of the innovator is:

$$F_A + F_B = \frac{\lambda\epsilon}{18t}\{6t + 2\delta - 2\epsilon + \lambda\epsilon\} + \frac{\epsilon}{18t}\{6t - 2\delta + \epsilon - 2\lambda\epsilon\}$$

Auction

Under auction the innovator offers one exclusive license for the innovation. Both firms can bid for the new innovation and the highest bidder wins it. We work out the maximum bids of A and B.

$$b_A = \frac{\epsilon(1+\lambda)}{18t}\{6t + 2\delta - \epsilon(1-\lambda)\}$$

$$b_B = \frac{\epsilon(1+\lambda)}{18t}\{6t - 2\delta + \epsilon(1-\lambda)\}$$

Note that $b_A > b_B \forall\lambda \in [0,1]$ and $\epsilon < \delta$. Thus firm A will always win the auction by bidding

$b^* = \frac{\epsilon(1+\lambda)}{18t}\{6t - 2\delta + \epsilon(1-\lambda)\} + k$ where $k \approx 0$ which is also the innovator's revenue from holding auction.

Comparing $(F_A + F_B)$ and b^* we get the following.

$(F_A + F_B) - b^* = \frac{\lambda\epsilon}{9t}(2\delta - 2\epsilon + \lambda\epsilon) - k$. Given $\epsilon < \delta$, for $\forall\lambda \in (0,1)$, fixed fee licensing is better for $k \approx 0$.

Proposition 6:

Under asymmetric absorptive capacity of new innovation, between fixed fee and auction policy, it is optimal for the innovator to license the innovation using fixed fee to both firms.

Note that this result is different when we compare it to a similar result (Proposition 1) from the previous analysis where cost reduction happens only to the inefficient firm. There auction turns out to be weakly better than fixed fee to the innovator, here the reverse happens. The reason is that in this situation under fixed fee licensing both firms purchase the license and the innovator therefore can extract fixed fees from both the licensees. Thus the total revenue for the innovator is higher. In the previous case only the inefficient firm purchased the license and therefore the revenue of the innovator was lower. In case of exclusive auction the efficient firm just outbids the inefficient firm and even if $\lambda > 0$ creates a upward pressure on that bid, the total increase in fixed fee licensing revenue exceeds that of the increase in the optimal bid of the inefficient firm (which is the optimal bid of the efficient firm) and therefore the total revenue from fixed fee licensing exceeds the revenue from exclusive auction.

Two-part Tariff

Under two-part tariff licensing both firms can acquire the license by paying a combination of a fixed fee and a royalty to the innovator. Different royalty rates would be charged by the innovator i.e.,$r_A \neq r_B$ due to asymmetric absorptive capacities of the firms. This also results into different willingness to pay for the same technology for the two licensees. Resulting expressions for prices, demands and profits can be given as:

$$P_A^{TPT} = c_A - \lambda\epsilon + r_A + \frac{1}{3}(3t + \delta + r_B - r_A - \epsilon(1-\lambda))$$

$$P_B^{TPT} = c_B - \epsilon + r_B + \frac{1}{3}(3t - \delta - r_B + r_A + \epsilon(1-\lambda))$$

$$Q_A^{TPT} = \frac{1}{6t}(3t + \delta + r_B - r_A - \epsilon(1-\lambda))$$

$$Q_B^{TPT} = \frac{1}{6t}(3t - \delta - r_B + r_A + \epsilon(1-\lambda))$$

$$\pi_A^{TPT} = \frac{1}{18t}(3t + \delta + r_B - r_A - \epsilon(1-\lambda))^2 - F_A$$

$$\pi_B^{TPT} = \frac{1}{18t}(3t - \delta - r_B + r_A + \epsilon(1-\lambda))^2 - F_B$$

Total profit earned by the innovator would be $Rev_{TPT} = Rev_{TPT}^A + Rev_{TPT}^B = (r_A Q_A^{TPT} + F_A) + (r_B Q_B^{TPT} + F_B)$, where

$Rev_{TPT}^{A} = \frac{r_A}{6t}\left(3t + \delta + r_B - r_A - \epsilon(1-\lambda)\right) + \frac{1}{18t}\left(3t + \delta + r_B - r_A - \epsilon(1-\lambda)\right)^2 -$
$\frac{1}{18t}(3t + \delta + r_B - \epsilon)^2$ and

$$Rev_{TPT}^{B} = \frac{r_B}{6t}(3t - \delta - r_B + r_A + \epsilon(1-\lambda)) + \frac{1}{18t}(3t - \delta - r_B + r_A + \epsilon(1-\lambda))^2 - \frac{1}{18t}(3t - \delta + r_A - \lambda\epsilon)^2$$

It is straightforward to find that the derivatives with respect to r_A and r_B are positive:

$\frac{\partial\, Rev_{TPT}}{\partial r_A} = \frac{3t+\delta+2r_B+\epsilon(1+\lambda)-4r_A}{18t} > 0,$

$\frac{\partial\, Rev_{TPT}}{\partial r_B} = \frac{15t+3\delta+2r_A-\epsilon(3-\lambda)}{18t} > 0.$

Thus, $r_A^* = \lambda\epsilon$, $r_B^* = \epsilon$, and $F_A^* = F_B^* = 0$ i.e., the optimal two-part tariff licensing will be reduced to a pure royalty contract for both the firms. Henceforth, we replace the notation Rev_{TPT} by Rev_R .

Revenue of the innovator:

The innovator can earn a revenue of $Rev_R^A = \frac{\lambda\epsilon(3t+\delta)}{6t}$ from the efficient firm and $Rev_R^B = \frac{\epsilon(3t-\delta)}{6t}$ from the inefficient one. Thus the total revenue will be $Rev_R = \frac{\epsilon[3t\lambda+\delta\lambda+3t-\delta]}{6t}$.

4.2 Optimal Licensing

To find optimal licensing, we need to compare, $Rev_F = \frac{\lambda\epsilon}{18t}\{6t + 2\delta - 2\epsilon + \lambda\epsilon\} + \frac{\epsilon}{18t}\{6t - 2\delta + \epsilon - 2\lambda\epsilon\}$ and $Rev_R = \frac{\epsilon[3t\lambda+\delta\lambda+3t-\delta]}{6t}$.

$Rev_F \geq Rev_R \Rightarrow \epsilon\lambda^2 - (3t + \delta + 4\epsilon)\lambda + (\epsilon + \delta - 3t) \geq 0$.

Now solving for the roots of the following equation, $\epsilon\lambda^2 - (3t + \delta + 4\epsilon)\lambda + (\epsilon + \delta - 3t) = 0$ we get the relevant root, $\lambda^* = \frac{(3t+\delta+4\epsilon)-\sqrt{(3t+\delta+4\epsilon)^2-4\epsilon(\epsilon+\delta-3t)}}{2\epsilon}$

$= \frac{(3t+\delta+4\epsilon)-\sqrt{9t^2+\delta^2+12\epsilon^2+6t\delta+4\delta\epsilon+36t\epsilon}}{2\epsilon}$ (The other root is greater than 1)

Therefore, we have the following result.

Proposition 7:

Under asymmetric absorptive capacity of new innovation, comparing between fixed fee and royalty licensing, we find the optimal licensing policy of the innovator is as follows.

If $\epsilon + \delta - 3t < 0$*, then* $\lambda^* < 0$*, and we have* $Rev_F < Rev_R$ *. So royalty is optimal.*
If $\epsilon + \delta - 3t > 0$*, then* $0 < \lambda^* < 1$*, and we have* $Rev_F < Rev_R$ *for* $\lambda^* < \lambda \leq 1$*, hence royalty is optimal; and* $Rev_F > Rev_R$ *for* $0 \leq \lambda < \lambda^*$*, so fixed fee is optimal.*

Note that the optimal licensing policy for the innovator is significantly different from the optimal licensing policy obtained in the previous analysis where cost reduction happens to inefficient firm only (see Proposition 2). When the extent of cost reduction and the cost difference is not that high then the extraction possibility from fixed fee licensing is lower. Thus for $\epsilon + \delta - 3t < 0$, royalty licensing does better for the innovator. When $\epsilon + \delta - 3t > 0$, if λ is sufficiently high then both firms' costs are reduced by almost the same amount. The competitive effect post technology licensing robs-off the innovator sufficient revenue from fixed fee licensing. Thus for $\epsilon + \delta - 3t > 0$ and for sufficiently high λ, once again, royalty licensing does better for the innovator compared to fixed fee. But for sufficiently low λ the competitive effect post licensing is lower and therefore the extraction possibility from fixed fee licensing increases which outweighs the revenue from royalty licensing.

4.3 Selling the Technology

If the innovator sells it to the efficient firm A then firm A has the option of further licensing it to firm B. Therefore, like before to get the entire picture of this sub-game we need to analyze the optimal licensing strategy of firm A, we start with the generalized two-part tariff licensing scheme. If firm A goes for two-part tariff licensing to firm B with royalty rate r_B to firm B and the fixed fee component $F_B = \left[\frac{1}{18t}(3t - \delta - \lambda\epsilon + \epsilon - r_B)^2 - \frac{1}{18t}(3t - \delta - \lambda\epsilon)^2\right]$, it will choose r_B optimally by maximizing $\pi^A = \frac{r_B}{6t}(3t - \delta - \lambda\epsilon + \epsilon - r_B) + \left[\frac{1}{18t}(3t - \delta - \lambda\epsilon + \epsilon - r_B)^2 - \frac{1}{18t}(3t - \delta - \lambda\epsilon)^2\right] + \frac{1}{18t}(3t + \delta + \lambda\epsilon - \epsilon + r_B)^2$. Maximization yields $r_B^* = \frac{9t + \delta - (1-\lambda)\epsilon}{2} > \epsilon$.

Therefore $r_{\boldsymbol{B}}^* = \epsilon$ and $F_B^* = 0$ and once again the optimal licensing scheme turns out to be pure royalty. Therefore, firm A's gross payoff from this licensing, post technology sale, is $\pi^A = \frac{\epsilon(3t-\delta-\lambda\epsilon)}{6t} + \frac{1}{18t}(3t+\delta+\lambda\epsilon)^2$ which is nothing but the revenue if the license is sold to firm A. The innovator will optimally extract the net gain $P_A = \frac{\epsilon(3t-\delta-\lambda\epsilon)}{6t} + \frac{1}{18t}(3t+\delta+\lambda\epsilon)^2 - \frac{1}{18t}(3t+\delta-\epsilon)^2$ since the no-acceptance payoff for firm A is $\frac{1}{18t}(3t+\delta-\epsilon)^2$. P_A denotes the price of sale to firm A. Thus the revenue of the innovator if it decides to sell the technology to firm A is $Rev_A^{SELL} = P_A = \frac{\epsilon(3t-\delta-\lambda\epsilon)}{6t} + \frac{(1+\lambda)\epsilon(6t+2\delta-(1-\lambda)\epsilon)}{18t}$.

Similarly if the technology is sold to firm B then firm B will license it to firm A and the optimal two-part tariff license will again be a royalty contract with $r_A^* = \lambda\epsilon$ (since $r_A^* = \frac{9t-\delta+(1-\lambda)\epsilon}{2} > \lambda\epsilon$) and therefore the maximum possible price that can be extracted by the innovator from firm B can be $P_B = \frac{\lambda\epsilon(3t+\delta-\epsilon)}{6t} + \frac{1}{18t}(3t-\delta+\epsilon)^2 - \frac{1}{18t}(3t-\delta-\lambda\epsilon)^2$ which implies $P_B = \frac{\lambda\epsilon(3t+\delta-\epsilon)}{6t} + \frac{(1+\lambda)\epsilon(6t-2\delta+(1-\lambda)\epsilon)}{18t} = Rev_B^{SELL}$. It is easy to check that $Rev_A^{SELL} > Rev_B^{SELL}$ and therefore even with asymmetric non-extreme absorptive capacity, the license will be sold to the efficient firm A who will further 'royalty license' it to the inefficient firm B. Interestingly this holds for all values of absorptive capacity λ.

Comparing $Rev_A^{SELL} = P_A = \frac{\epsilon(3t-\delta-\lambda\epsilon)}{6t} + \frac{(1+\lambda)\epsilon(6t+2\delta-(1-\lambda)\epsilon)}{18t}$ with optimal licensing revenues $Rev_R = \frac{\epsilon[3t\lambda+\delta\lambda+3t-\delta]}{6t}$ and $Rev_F = \frac{\lambda\epsilon}{18t}\{6t+2\delta-2\epsilon+\lambda\epsilon\} + \frac{\epsilon}{18t}\{6t-2\delta+\epsilon-2\lambda\epsilon\}$ one can check that Rev_A^{SELL} exceeds Rev_R and Rev_F for relevant parametric ranges of λ and given $\epsilon < \delta$ and $\delta < 3t$. Hence, we have the following result.

Proposition 8:

Under asymmetric absorptive capacity of new innovation, it is optimal for the innovator to sell the license to the efficient firm, which will further license it to the inefficient firm.

Thus for the outside innovator selling does better compared to licensing once again for all values of absorptive capacity. The intuition of the result, once again, is that the selling game has further licensing possibilities and therefore all possibilities that are available to the innovator in the licensing game is there in the selling game as well. Therefore with selling the innovator cannot be worse off compared to only licensing and this holds for the asymmetric absorptive capacity case as well. This result is robust and remains unchanged in all possible asymmetric absorptive capacities scenarios including the extreme case where the cost reduction due to innovation happens only to the inefficient firm.

Looking into the aspect of consumer welfare before and after the new technology transfer, we find when the new technology is transferred under the optimal fixed fee licensing policy there is an increase in surplus to the consumers as the prices drop compared to the pre-licensing scenario. When the new technology is transferred under pure royalty licensing, the prices of the product remain same as pre-licensing scenario, as the marginal costs of the licensees do not change after paying the royalty to the innovator, hence no change in consumer surplus. Finally, when the technology is transferred by selling, there is a drop in the marginal cost of production of the efficient firm (buyer firm), however no drop in marginal cost of the inefficient firm compared to pre-licensing stage as the technology gets licensed by pure royalty from the efficient firm. So overall, there would be some increase in consumer surplus under selling. Note that in all above cases full diffusion of technology happens as there is no shelving possibility here.

5. Conclusion

In this paper, we consider a new technology of a cost-reducing innovation from an outside innovator to two potential asymmetric firms. We address a situation, where the cost reduction to the firms are non-uniform from the same innovation due to asymmetric absorptive capacities of the firms. We consider an extreme situation where cost reduction only happens to the inefficient firm but innovation has no impact on the cost of the efficient firm. In this environment, first we analyze all possible licensing contracts and find out the optimal licensing policy. We show if the technology is licensed using an auction, the efficient firm will always win the auction, but shelve the technology and stop the inefficient firm from acquiring it. Therefore, no real technology diffusion happens, and the pre-licensing outcome prevails in the market. Under fixed fee or any other licensing policy (e.g. royalty or two-part tariff), the efficient firm cannot prevent the inefficient firm from acquiring the technology and moreover since the efficient firm has no benefit from acquiring it, the new technology always goes to the inefficient firm. We show that the optimal licensing policy of the innovator is royalty or two-part tariff depending on the size of the innovation. Also in some sense royalty or two-part tariff is also better than auction as new technological diffusion happens under this. Moreover, under the two-part tariff policy, the consumers get better off compared to the pre-licensing stage in terms of lower price of the good. Thus, under two-part tariff licensing scheme, not only the innovator is better off, the benefit of the new innovation goes to the consumers as well. Instead of licensing if the innovator sells the right of the new innovation to one of the firms, we find that the efficient firm will acquire the right. However, in this case, instead of shelving the technology, it will further license it to the inefficient firm. The inefficient will use the technology, so technological diffusion happens as well. But here the consumers are not better off compared to pre-technology transfer stage as the prices of the goods do not fall. The profit of the inefficient firm remains unchanged, while the profit of the efficient firm declines significantly which implies total industry profit declines. All the surplus coming from the cost reducing innovation is extracted by the innovator.

Later we also extend the analysis where innovation impacts both firms but non-uniformly and find the optimal licensing policy of the outside innovator. Finally we discuss on the optimal mode of technology transfer of the innovator in that environment.

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