Innovation, Diffusion and Shelving

Sougata Poddar♣
Argyros School of Business and Economics
Chapman University, Orange CA 92866, USA

Swapnendu Banerjee
Department of Economics
Jadavpur University, Kolkata 700032, India

Monalisa Ghosh
Department of Economics
Jadavpur University, Kolkata 700032, India

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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. While the innovation reduces the cost of the inefficient firm only, 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 see the impact of technological diffusion (or no diffusion) from innovation on consumer welfare and industry profits. We also find the optimal mode of technology transfer of the innovator in this environment.

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♣ Corresponding author: Chapman University, Orange, CA, USA, Email: poddar@chapman.edu

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. shelve 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 is an interesting aspect 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 cost of the inefficient firm only. The new 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 auction to license the technology. We look into the possibility of shelving. Then we explore other possible licensing contracts, namely royalty and two-part tariff. 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 has her preferred brand, namely, the firm they would like to visit and buy the product net of transportation cost. 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 royalty and two-part tariff licensing schemes later. 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 profitable than auction) and the innovation is actually put to use to reduce cost i.e. not shelved.

We explore royalty and two-part tariff licensing schemes and find the overall optimal licensing contract of the innovator. We find optimal licensing policy consists of pure royalty and 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 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 addition 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.

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 is generally less compared to a firm which is relatively inefficient. To that extent, in this paper 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, 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. Sections 4 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 $F_{\text{B}} = \left[\frac{1}{18t}(3t - \delta + \epsilon)^2 - \frac{1}{18t}(3t - \delta)^2\right] = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t}$.

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=$\left[\frac{1}{18t}(3t - \delta + \epsilon)^2 - \frac{1}{18t}(3t - \delta)^2\right] = \frac{\epsilon(6t - 2\delta + \epsilon)}{18t}$. Now $g_A > g_B$, holds if $\epsilon < 2\delta$ holds. Since we assume $\epsilon \le (c_B - c_A)$ i.e. $\epsilon \le \delta$, 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 be shelved always.

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 either 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. The innovator only 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 will 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 equilibrium 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 $\pi_B^R = \frac{1}{18t}(3t-\delta)^2$.[1]

If $\epsilon > (3t-\delta)$, then the innovator will charge $r^* = \frac{3t-\delta+\epsilon}{2}$ and earns a revenue of $Rev_B^r = \frac{(3t-\delta+\epsilon)^2}{24t}$.[2] But since we assume $\delta \geq \epsilon$, the optimal royalty contract will be 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 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 equilibrium prices, demands and profits can be given as:

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

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

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

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

[1]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.

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

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

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

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 $\frac{3t-\delta}{3} < \epsilon < \delta$.

2.3 Optimal Licensing Contract

We already know that 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 the payoffs of innovator for 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 innovator for 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. Thus $Rev_B^{TPT} > Rev_B^r$ for $\frac{(3t-\delta)}{3} < \epsilon \leq (3t - \delta)$ and therefore, two-part tariff is optimal for $\frac{(3t-\delta)}{3} < \epsilon \leq (3t - \delta)$.

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

Payoffs of innovator for royalty, two-part tariff and Auction:

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

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

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

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 of 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 fetches 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. To analyze the optimal licensing strategy of firm A let us 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, it will choose r optimally by maximizing $Q_B^R=\frac{r}{6t}(3t-\delta+\epsilon-r)+\left[\frac{1}{18t}(3t-\delta+\epsilon-r)^2-\frac{1}{18t}(3t-\delta)^2\right]+\frac{1}{18t}(3t+\delta-\epsilon+r)^2$ where $F=\left[\frac{1}{18t}(3t-\delta+\epsilon-r)^2-\frac{1}{18t}(3t-\delta)^2\right]$. 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 $\pi^A = \frac{\epsilon(3t-\delta)}{6} + \frac{1}{18t}(3t+\delta)^2$.

The innovator will optimally extract the net gain $P_A = \frac{\epsilon(3t-\delta)}{6} + \frac{1}{18t}(3t+\delta)^2 - \frac{1}{18t}(3t+\delta-\epsilon)^2$ 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 $Rev_A^{SELL} = P_A = \frac{\epsilon(3t-\delta)}{6} + \frac{\epsilon(6t+2\delta-\epsilon)}{18t}$. 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 form 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 is 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 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 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 innovator's payoff from Selling and two-part 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 optimum for 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 license 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 of 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 is the licensing game is there in the selling game as well. Thus under selling the innovator cannot be worse-off compared to licensing.

Note that under selling, the price of the goods remain same as the pre-technology transfer stage. The profit of the inefficient firm remain 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 form B remain at the pre-technology transfer level and therefore the prices also remain at the pre-technology transfer level and this happens under $0 < \epsilon \leq \boldsymbol{\frac{(3t-\delta)}{3}}$. 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.

Overall the consumers strictly better-off under when $\frac{(3t-\delta)}{3} < \epsilon \leq \delta$ holds and the consumers are not better-off nor worse-off when $0 < \epsilon \leq \frac{(3t-\delta)}{3}$ holds. Thus the consumers are weakly better-off under licensing compared to selling.

4. 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 only happens to the inefficient firm but 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 remain 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.

In this analysis, we addressed an extreme situation where the cost reduction only happens to the inefficient firm but has no impact on the cost of the efficient firm. In our future research, we relax this and move to a more generic situation where the innovations affects the production costs of both firms, but in a non-uniform way, namely, the cost reduction on the inefficient firm is more than that of the efficient firm. We believe how the magnitude of the innovation will impact the respective production costs of the firms depends on the firms' technology as well as on existing cost conditions. We want to do a general analysis of optimal licensing mechanism or transferring the right to one of the licensees by selling in that new environment and explore the impact of innovation on the consumers.

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