Research Article

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Profit Improving via Strategic Technology Sharing

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Abstract: This paper investigates whether a downstream monopolist has an incentive to freely share its technology to potential entrants. With a linear demand, it is more profitable for the downstream monopolist to share its obsolete technology with the potential entrants even with no returns. In this context, technology sharing is a Pareto improvement. Moreover, the profit of the downstream monopolist via technology sharing increases with the number of new entrants, but the nexus between social welfare and the number of new entrants is non-monotonic.

Keywords: strategic technology sharing, successive monopoly, vertically-related markets, welfare
JEL Classification: L12, L24

1 Introduction

In 2014, Elon Musk, CEO of Tesla Motors, announced that his company would open its patents to those with good faith.[1] This strategy runs counter to the conventional wisdom that the monopolist has an incentive to protect its innovations so as to maintain its market profits. The aim of this paper is to provide an economic rationale to explain why a monopolist with superior technology has an incentive to share its patents with its potential rivals.

The issue on the incentives of a monopolist to transfer its technology to its rivals has been investigated extensively in the literature. For example, Gallini

1 Elon Musk mentioned that the main goals of opening up patents were to accelerate the advent of no emission cars and to address the carbon crisis. Please refer to http://www.teslamotors.com/blog/all-our-patent-are-belong-you for more details.

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(1984) show that an incumbent may strategic licenses its technology to potential entrant in order to prevent this potential entrant to develop a better technology. Shepard (1987) shows that a monopolist can commit to a higher product quality by licensing its technology to its competitors, which in turn raises the industry demand and the industry profit. Wang (2002) and Fauli-Oller and Sandonis (2002) show that an inside patent holder would license its drastic cost-reducing technology to its rival if the products are differentiated enough. The licensing revenue from another brand may outweigh the loss from a more competitive market.

Arya and Mittendorf (2006) discuss licensing behaviors in vertically related markets in which the upstream firm can engage in price discrimination against the downstream firms. They show that a final good monopolist has an incentive to license its technology by means of royalty to a potential rival. By issuing a license, the licensor uses royalty to weaken the competition from the rival, which in turn lowers the input price of the weak rival. Then, the licensor benefits by siphoning some of the gains of the weak rival from the lowered input price via licensing fee. Mukherjee, Broll, and Mukherjee (2008) show that a downstream monopolist has an incentive to create competition in the final good market by using a two-part tariff licensing contract (a positive royalty plus a positive up-front fee) to license its technology if the input market is imperfectly competitive. They find that the positive royalty rate not only weakens the production efficiency of the licensee and mitigates the competition in final good market but also reduces the input price as the derived demand for input facing the upstream firm is lower as well. These two effects benefit the licensor and makes technology licensing happens. Our paper is closely related to Arya and Mittendorf (2006) and Mukherjee, Broll, and Mukherjee (2008) because we all focus on how technology transfer affects the upstream firm's pricing strategies. However, our paper is different form Arya and Mittendorf (2006) and Mukherjee, Broll, and Mukherjee (2008) in some aspects. In their models, the best technology is always licensed to the rivals. However, we show that a final good monopolist has an incentive to share its obsolete technology to potential rivals even if there's no return. This suggests that when licensing is not easy to take place, sharing obsolete technology to potential rivals is also beneficial for the downstream monopolist. Besides, while they consider only one rival in the downstream market, we consider the case where there are many potential entrants in the final good market and find that with technology sharing, the optimal level of the shared technology is negatively related to the number of new entrants. Furthermore, we investigate how the number of new entrants affects the profit of the downstream monopolist and social welfare.

This paper is also relevant to Farrell and Gallini (1988) and Economides (1996). Farrell and Gallini (1988) show that a new product monopolist has an incentive to invite competitors to the market by means of second-sourcing so as to commit to a low future price when consumers incur a large setup cost. However, this second-sourcing involves a time lag; otherwise, it is not profitable for the monopolist to take such a step. Economides (1996) shows that if the network externality is sufficiently strong, a monopolist has the incentive to invite firms to enter and license its technology without charge.

This paper complements the literature on technology transfer with an input supplier (see, for example, Mukherjee 2010; Mukherjee and Pennings 2011; Ishikawa and Horiuchi 2012; Mukherjee and Wang 2013, among others). They all treat the licensed technology as a binary variable and the best technology is always licensed whereas we endogenously determine the shared technology level and investigate the marginal effect of technology sharing. We show that the downstream monopolist is willing to transfer its obsolete technology even when there is no return.

This paper employs a parsimonious successive monopoly model with potential downstream entrants to show that under a linear demand, it is more profitable for the downstream monopolist to share its technology with its potential rivals. In addition, technology sharing leads to a Pareto improvement. This result is largely different from Lahiri and Ono (1988) where an entry of a less efficient firm reduces the social welfare. It is also found that the profit of the downstream monopolist via technology sharing increases with the number of new entrants. However, there is a non-monotonic relationship between social welfare and the number of new entrants.

The reminder of the paper is organized as follows. Section 2 introduces the model setup and derives the equilibrium under successive monopoly. Section 3 investigates the equilibrium under technology sharing. Section 4 provides a linear example. Section 5 concludes this paper.

2 The Benchmark Model

Assume that there are two incumbent firms, namely, an upstream monopolist (firm U) and a downstream monopolist (firm D) in an industry. There are also N potential entrants in the downstream market. Firm U sells inputs to Firm D by charging the input price w, and one unit of input is required to produce one unit of final product. Without loss of generality, the marginal production cost of firm U is assumed to be zero. Other than paying w to buy the input, the marginal production cost of firm D is $c-\varepsilon$, and that of the potential entrants is c. We assume ε is large enough such that the potential entrants cannot enter into the final good market. This cost structure implies that the potential entrants are too inefficient to enter the downstream market if there is no technology sharing. The inverse market demand function for the final product is $P(Q)$, where Q is the total output of the final product and $P'(Q) < 0$.

We proceed to investigate the equilibrium with no technology sharing. In this case, $Q = x$ as firm D is the only downstream firm, where x is the output of firm D. The game in question comprises two stages. In the first stage, firm U determines the input price, w. In the second stage, firm D determines its output, x, to maximize its profits. The sub-game perfect equilibrium is solved via backward induction.

Given the above setup, the profit functions of firm D and firm U are expressed respectively as follows:

$$\Pi = [P(x) - w - c + \varepsilon]x. \quad [1]$$

$$\Omega = wx. \quad [2]$$

Differentiating eq. [1] with respect to x yields:

$$\frac{\partial \Pi}{\partial x} = P(x) - w - c + \varepsilon + P'x = 0, \quad [3]$$

From eq. [3], we can derive the equilibrium output of firm D in the final stage as $x = x(w)$. Totally differentiating eq. [3] with respect to x and w yields:

$$\frac{\partial x}{\partial w} = \frac{1}{2P' + P''x} < 0. \quad [4]$$

It is intuitive that the output of firm D decreases in w.

In the first stage, firm U determines its profit-maximizing input price. By differentiating eq. [2] with respect to w, we can have the first-order condition as follows:

$$\frac{d\Omega}{dw} = x + w\frac{\partial x}{\partial w} = 0. \quad [5]$$

From eq. [5], we can solve firm U's profit-maximizing input price as w^M, where the variables with a superscript "M" denote that they are associated with the case where firm D monopolizes the final good market.

The social welfare includes the consumer surplus and the firms' profits, and is specified as follows:

$$SW^M = \int_0^{x^M} [P(x) - c + \varepsilon]dx. \quad [6]$$

3 Technology Sharing

Now we are in a position to investigate whether or not firm D has an incentive to share its technology with the potential entrants. With technology sharing, firm D shares its technology to n out of N potential entrants. The marginal production cost of the n new entrants becomes $c - k\varepsilon$, where $k \in [0,1]$ is the level of technology shared by firm D. Note that a higher k implies a higher level of technology sharing. The game in question now comprises four stages. In the first stage, firm D determines the level of technology shared with potential entrants. In the second stage, firm U determines the optimal input price. In the third stage, the potential entrants which own the shared technology decide whether to enter the final good market. Note that if all of the potential entrants with the shared technology decide not to enter the final good market, then the equilibrium restores to that under successive monopoly. We shall center our focus on the case in which entry occurs. In the final stage, once the potential entrants have entered the final good market, firm D and the new entrants compete in quantities in the final good market. Therefore, we have $Q = x + \sum_{i=1}^{n} y_i$, where y_i is the output of new entrant firm i. Again, backward induction is employed to derive the sub-game perfect equilibrium.

In the last stage, if entry occurs, the profit functions of firm D and the new entrant(s) are, respectively, as follows:

$$\Pi = [P(Q) - w - c + \varepsilon]x, \quad [7]$$

$$\pi_i = [P(Q) - w - c + k\varepsilon]y_i \quad \text{for} \quad i = \{1, 2, \ldots, n\}. \quad [8]$$

By differentiating eq. [7] with x and eq. [8] with y_i, we can derive the first-order condition of firm D and the new entrants as follows:

$$\frac{\partial \Pi}{\partial x} = P(Q) - w - c + \varepsilon + P'x = 0, \quad [9]$$

$$\frac{\partial \pi_i}{\partial y_i} = P(Q) - w - c + k\varepsilon + P'y_i = 0 \quad \text{for} \quad i = \{1, 2, \ldots, n\}. \quad [10]$$

Since the new entrants are homogeneous, by symmetry, we can derive the output in the final stage as $x = x(w, k, n)$ and $y_i = y = y(w, k, n)$ for $i = \{1, 2, \ldots, n\}$, and $Q = x + ny$. Moreover, the profit of a representative new entrant is π and $\pi = \pi_i$ for $i = \{1, 2, \ldots, n\}$. Subtracting eqs [10] from [9] yields:

$$-P'(x - y) = \varepsilon(1 - k), \quad [11]$$

which implies the outputs of firm D is higher than the new entrants.

Totally differentiating eqs [9] and [10] with respect to x, y, w, k and n yields:

$$\begin{aligned}
&\frac{\partial x}{\partial w}=\frac{P'-nP''(x-y)}{P'[(n+2)P'+P''Q]}, &&\frac{\partial y}{\partial w}=\frac{P'+P''(x-y)}{P'[(n+2)P'+P''Q]}<0,\\
&\frac{\partial x}{\partial k}=\frac{n\varepsilon(P'+P''x)}{P'[(n+2)P'+P''Q]}<0, &&\frac{\partial y}{\partial k}=\frac{-\varepsilon(2P'+P''x)}{P'[(n+2)P'+P''Q]}>0,\\
&\frac{\partial x}{\partial n}=\frac{-(P'+P''x)y}{(n+2)P'+P''Q}<0, &&\frac{\partial y}{\partial n}=\frac{-(P'+P''y)y}{(n+2)P'+P''Q}<0.
\end{aligned} \qquad [12]$$

We assume the demand function is not too convex, that is, $(n+2)P'+P''Q<0$ to ensure the second-order conditions and the stability condition are hold. Since $Q=x+ny$, from eq. [12], it is straightforward to show that:

$$\frac{\partial Q}{\partial w}=\frac{n+1}{(n+2)P'+P''Q}<0,\quad \frac{\partial Q}{\partial k}=\frac{-n\varepsilon}{(n+2)P'+P''Q}>0,\quad \frac{\partial Q}{\partial n}=\frac{P'y}{(n+2)P'+P''Q}>0. \qquad [13]$$

The aggregate final output decreases with w but increases with k and n. That is to say the aggregate final output decreases as the input price increases; however, if the level of technology shared by firm D or the number of new entrants is higher, then the aggregate final output increases.

In the third stage, the potential entrants with the technology shared by firm D determine whether to enter into the final good market or not. These potential entrants will enter the market if $\pi_i \geq 0$. Note that a lower input price and/or a higher level of technology shared by firm D will encourage the potential entrants to enter into the final good market.

Since we assume that one unit of input is required to produce one unit of final output, from eqs [9] and [10], we can have the derived demand for inputs of firm D and a representative new entrant respectively as follows:

$$w=P(Q)-c+\varepsilon+P'x,$$
$$w=P(Q)-c+k\varepsilon+P'y.$$

From the above, it shows that the derived demand for inputs of firm D and the representative new entrant are of the same shape except firm D has a higher willingness to pay than the new entrant for every unit of inputs. Horizontally summing over the derived demand for inputs yields the derived demand for inputs facing firm U as follows:

$$Q(w)=\begin{cases} x(w) & \text{if } w\geq \hat{w},\\ x(w)+ny(w) & \text{if } w<\hat{w}, \end{cases} \qquad [14]$$

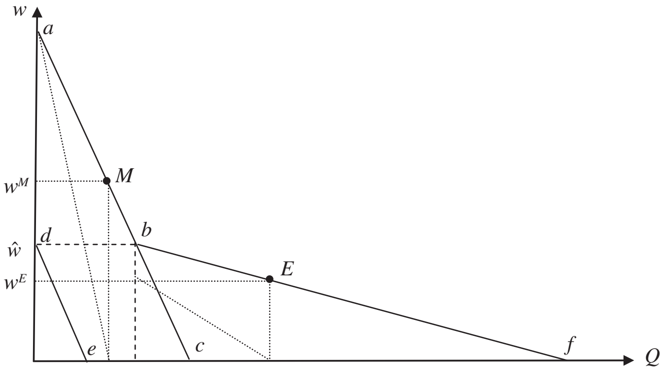

Figure 1: The derived demand for inputs facing firm U.

where $\hat{w}$ is the critical input price beyond which the new entrants are unprofitable to enter into the final good market.[2] We use Figure 1 to demonstrate the derived demand for inputs facing firm U. The derived demand for inputs of firm D and a representative new entrant are $\overline{ac}$ and $\overline{de}$, respectively. Note that the derived demand for inputs of new entrant is positive only if $w < \hat{w}$. Horizontally summing over the derived demand for inputs of firm D and all the n new entrants, we can have the derived demand for inputs facing firm U as $\overline{abf}$. Note that the slope of $\overline{ab}$ can be referred to the case of monopoly where only firm D serves the final good market, which is $1/(\partial x/\partial w) = 2P' + P''x$ (where $\partial x/\partial w$ is derived in eq. [4]), and the slope of $\overline{bf}$ can be derived by utilizing eq. [13] and is $1/(\partial Q/\partial w) = [(n+2)P' + P''Q]/(n+1)$. Moreover, if k is higher, then the kinked point of the derived demand is also higher as the willingness to pay for the inputs of the new entrants is higher, which shifts $\overline{bf}$ outward. Furthermore, if n is larger, there will be more new entrants and more demands for inputs, making the slope of $\overline{bf}$ flatter.

In the second stage, firm U determines the optimal input price to maximize its own profit. The profit function of firm U is as follows:

$$\Omega = \begin{cases} wx(w) & \text{if } w \geq \hat{w}, \\ w[x(w) + ny(w)] & \phantom{\text{if }} w < \hat{w}. \end{cases} \quad [15]$$

If $w \geq \hat{w}$, there will be no new entrants and the equilibrium restores to that under successive monopoly (i. e., eq. [5]), which is point M in Figure 1 and w^M is firm U's optimal input price.

2 Given the input price and assuming $y = 0$, from eq. [11], it is derivable that the output of firm D is $x = -\varepsilon(1-k)/P'$. Substituting these into eq. [10] yields $\hat{w} = P(x = -\varepsilon(1-k)/P') - c + k\varepsilon$.

We then focus on the case where $w < \hat{w}$. Differentiating eq. [15] with respect to w yields:

$$\frac{d\Omega}{dw} = (x + ny) + w\left[\frac{\partial x}{\partial w} + n\frac{\partial y}{\partial w}\right] = 0 \qquad [16]$$

By solving the first-order condition in eq. [16], we derive firm U's optimal input price with new entrants, w^E, where the variables with a superscript "E" denote that they are associated with the case with new entrants. Note that $\hat{w} \le w^M$ because the new entrants are less efficient than firm D. The corresponding equilibrium is denoted at point E in Figure 1.

Totally differentiating eq. [16] with respect to w and k yields:

$$\frac{\partial^2\Omega}{\partial w^2}dw + \frac{\partial^2\Omega}{\partial w \partial k}dk = 0,$$

It is assumed that $\partial^2\Omega/\partial w^2 < 0$ in order to satisfy the second-order condition. Moreover, $\partial^2\Omega/\partial w\partial k > 0$. This is because, given other things being equal, an increase in k increases the new entrants' willingness to pay for the input (i. e., the $\overline{bf}$ in Figure 1 shifts outward), inducing a higher marginal profit for firm U. Therefore, we derive that:

$$\frac{\partial w^E}{\partial k} = -\frac{\partial^2\Omega/\partial w\partial k}{\partial^2\Omega/\partial w^2} > 0.$$

This result follows that if there are new entrants (i. e., $w < \hat{w}$), an increase in k will raise the input price under technology sharing (i. e., w^E).

We then investigate whether the input supplier, firm U, has an incentive to determine its input price as w^E and serves the new entrants. Note that firm U has an incentive to serve the new entrants if $\Omega^E(k) \ge \Omega^M$.

Totally differentiating Ω^E with respect to k yields:

$$\frac{d\Omega^E}{dk} = \frac{\partial\Omega}{\partial w}\frac{\partial w^E}{\partial k} + \frac{\partial\Omega}{\partial x}\frac{\partial x}{\partial k} + \frac{\partial\Omega}{\partial y}\frac{\partial y}{\partial k} = w^E\frac{\partial Q}{\partial k} > 0, \qquad [17]$$

where $\partial\Omega/\partial w = 0$ by envelope theorem, $\partial\Omega/\partial x = w^E$, and $\partial\Omega/\partial y = nw^E$. Equation [17] indicates that an increase in k will raise the profit of firm U. If $k = 0$, the cost structure is the same as that in Section 2. In this context, firm U choose to serve firm D only by setting $w = w^M$, implying that $\Omega^M > \Omega^E(k = 0)$. By contrast, if $k = 1$, firm D and the new entrants have the same production efficiency. In such a circumstance, given $w = w^M$, the aggregate input demanded is higher than that under successive monopoly, resulting a higher profit level for firm U, i. e., $\Omega^E(k = 1) > \Omega^M$. From eq. [17] and the above discussion, it is obvious that there exists a critical level of technology sharing, $\hat{k} \in (0, 1)$, such that $\Omega^E = \Omega^M$ and above which firm U will set its input price at w^E. Therefore, the optimal input price schedule of firm U is as follows:

$$w = \begin{cases} w^M & \text{if} \quad 0 \le k < \hat{k}, \\ w^E & \quad\quad \hat{k} \le k \le 1. \end{cases}$$

Given the above result, we establish the lemma as follows:

Lemma 1: *The input supplier has an incentive to suppress its input price from w^M to w^E and serve the new entrants only if the shared technology level is large enough (i. e., $\hat{k} \le k \le 1.$).*

In the first stage, firm D determines the optimal technology-sharing level. The objective function for firm D is expressed as follows:

$$\max_k \Pi^E(x(k), y(k), w^E(k)) = \left[P(x + ny) - w^E - c + \varepsilon\right] x$$

By totally differentiating Π with respect to k, we derive the following first-order derivative:

$$\begin{aligned} \frac{d\Pi^E}{dk} &= \frac{\partial \Pi}{\partial x}\left(\frac{\partial x}{\partial w}\frac{\partial w^E}{\partial k} + \frac{\partial x}{\partial k}\right) + \frac{\partial \Pi}{\partial y}\left(\frac{\partial y}{\partial w}\frac{\partial w^E}{\partial k} + \frac{\partial y}{\partial k}\right) + \frac{\partial \Pi}{\partial w}\frac{\partial w^E}{\partial k} \\ &= x\left[nP'\left(\frac{\partial y}{\partial w}\frac{\partial w^E}{\partial k} + \frac{\partial y}{\partial k}\right) - \frac{\partial w^E}{\partial k}\right] < 0, \end{aligned} \quad [18]$$

where $dy/dk = (\partial y/\partial w)(\partial w^E/\partial k) + (\partial y/\partial k) > 0$ and $(\partial w^E/\partial k) > 0$. The above equation is negative, implying that a higher k decreases firm D's profit under technology sharing. The economic explanation is as follows. When $k \ge \hat{k}$, an increase in k increases both the outputs of the new entrants and the input price under technology sharing. In this context, firm D not only faces a more intensive competition from the new entrants but also a higher w^E charged by firm U, resulting in a lower profit level. Therefore, by eq. [18], it is optimal for firm D to set $k = \hat{k}$. If the profit gain from the lowered input price is larger than the profit loss from the new entrants, firm D is willing to share its technology to its potential rivals.

We then examine how the number of new entrants affects $\hat{k}$. Note that $\hat{k}$ is the critical technology sharing level such that $\Omega^E(k = \hat{k}) = \Omega^M$ and is the profit-maximizing technology sharing level of firm D. By setting $\Omega^E(n, k) = \Omega^M$ and using implicit function theorem, we have:

$$\frac{\partial \hat{k}}{\partial n} = -\frac{d\Omega^E/dn}{d\Omega^E/dk} = -\frac{\partial Q/\partial n}{\partial Q/\partial k} = \frac{P'y}{n\varepsilon} < 0,$$

where $d\Omega^E/dk > 0$ (according to eq. [17]) and

$$\frac{d\Omega^E}{dn} = \frac{\partial\Omega}{\partial w}\frac{\partial w}{\partial n} + \frac{\partial\Omega}{\partial x}\frac{\partial x}{\partial n} + \frac{\partial\Omega}{\partial y}\frac{\partial y}{\partial n} + \frac{\partial\Omega}{\partial n} = w^E\frac{\partial Q}{\partial n} > 0$$

as $\partial\Omega/\partial w = 0$ (by envelope theorem), $\partial\Omega/\partial x = w^E$, $\partial\Omega/\partial y = nw^E$, and $\partial\Omega/\partial n = w^E y$. This result implies that this critical level of technology sharing decreases with n. The intuition is as follows. If the number of new entrants is large, the aggregate derived demand for inputs from the new entrants (high cost firms) will be large. Firm U will make more profits from serving all the firms, which in turn implies firm U has more incentive to suppress its input price and the critical level of technology sharing could be lower. Specifically, for each n, there is a corresponding $\hat{k}$ to induce firm U to serves all firms by charging the optimal input price, w^E. We present this result as the following proposition:

Proposition 1: *For each number of new entrants, there exists a corresponding technology sharing level, $\hat{k}$, which induces the upstream firm to serve all the downstream firms by charging the optimal input price, w^E. Moreover, $\hat{k}$ is negatively related to the number of new entrants.*

We then investigate the effect of technology sharing on social welfare. The social welfare with technology sharing is defined as the aggregation of consumer surplus and the profits of the firms, which can be expressed as follows:

$$SW^E = CS^E + \Omega^E + \Pi^E + n\pi^E,$$

where $CS^E = \int_0^{Q^E} \left[P(t) - P(Q^E)\right] dt$, increasing with the final outputs. Note that if it is profitable for firm D to share its technology to potential entrants, i. e., $\Pi^E > \Pi^M$, then technology sharing leads to a Pareto improvement. The intuition is as follows. Note that the profit-maximizing technology sharing level of firm D is $\hat{k}$, at which $\Omega^E = \Omega^M$. In addition, as the input price with technology sharing, w^E, is lower than that with no technology sharing, w^M. Given $\Omega^E = w^E Q^E = w^M Q^M = \Omega^M$, we have $Q^E > Q^M$. As the consumer surplus is positively related to the final outputs, we have $CS^E > CS^M$. Furthermore, the potential entrants enter into the final good market if and only if they have positive profits, which implies $\pi^E \geq \pi^M = 0$. Therefore, if it is profitable for firm D to share its technology to potential entrants, then technology sharing in the downstream market is a Pareto improvement.

4 A Linear Demand Example

In this section, we provide a linear example to illustrate our results. The inverse market demand is given as $P = a - bQ$. Proceeding as that in Section 2, the equilibrium total outputs and input price under successive monopoly are derived as follows:

$$w^M = \frac{a-c+\varepsilon}{2} \quad \text{and} \quad Q^M = x^M = \frac{a-c+\varepsilon}{4b}. \qquad [19]$$

By utilizing eqs [1], [2] and [6], the profits of the downstream and the upstream firms and the resulting social welfare are derived as follows:

$$\Omega^M = \frac{(a-c+\varepsilon)^2}{8b}, \quad \Pi^M = \frac{(a-c+\varepsilon)^2}{16b}, \text{ and } \quad SW^M = \frac{7}{32b}(a-c+\varepsilon)^2. \qquad [20]$$

We then derive the equilibrium with technology sharing. Proceeding as that in Section 3, we can derive the equilibrium under technology sharing. By utilizing eqs [9] and [10], the equilibrium outputs of firm D and a representative new entrant in the final stage are as follows:

$$x = \frac{a-w-c+\varepsilon(1-kn+n)}{(2+n)b} \quad \text{and} \quad y = \frac{a-w-c-\varepsilon(1-2k)}{(2+n)b}. \qquad [21]$$

Note that $y > 0$ if $w < a - c + \varepsilon(2k-1)$. In such a circumstance, from eq. [21], the total output in final good market is as follows:

$$Q = x + ny = \frac{(1+n)(a-c-w) + \varepsilon(1+kn)}{(2+n)b}.$$

By contrast, if $w \geq a - c + \varepsilon(2k-1)$, entry does not occur and the total output of the final product is $x = (a-w-c+\varepsilon)/2b$. Since we assume that one unit of input is required to produce one unit of final output, the derived demand for the input is as follows:

$$Q = \begin{cases} \dfrac{a-c+\varepsilon}{2b} - \dfrac{w}{2b} & \text{if} \quad w \geq a-c+\varepsilon(2k-1), \\ \dfrac{(1+n)(a-c)+\varepsilon(1+kn)}{(2+n)b} - \dfrac{1+n}{(2+n)b}w & \quad\;\; w < a-c+\varepsilon(2k-1). \end{cases} \qquad [22]$$

In the third stage, the potential entrants enter into the final good market if $\pi_i \geq 0$. By eq. [21], it is apparent that the potential entrants will enter the market and produce positive outputs if their marginal cost (i. e., $w + c - k\varepsilon$) is not too high.

In the second stage, firm U determines the optimal input price. By substituting eq. [22] into eq. [2], the profit function of firm U is:

$$\Omega = \begin{cases} w\left(\frac{a-c+\varepsilon}{2b} - \frac{w}{2b}\right) & \text{if} \quad w \geq a-c+\varepsilon(2k-1), \\ w\left[\frac{(1+n)(a-c)+\varepsilon(1+kn)}{(2+n)b} - \frac{1+n}{(2+n)b}w\right] & \quad\quad w < a-c+\varepsilon(2k-1). \end{cases} \quad [23]$$

By routine calculations, we derive the optimal input price schedule as follows:

$$w = \begin{cases} \frac{a-c+\varepsilon}{2} = w^M & \text{if} \quad 0 \leq k < \hat{k}, \\ \frac{a-c}{2} + \frac{\varepsilon(1+kn)}{2(1+n)} = w^E & \quad\quad \hat{k} \leq k \leq 1. \end{cases} \quad [24]$$

where $\hat{k} \equiv \left[\sqrt{2(1+n)(2+n)}(a-c+\varepsilon) - 2(1+n)(a-c) - 2\varepsilon\right] \Big/ 2n\varepsilon$ is the critical level of the shared technology such that firm U is indifferent from serving firm D only or all the downstream firms, that is, $\Omega^E = \Omega^M$. If $0 \leq k < \hat{k}$, there will be no entrants in the downstream market. The equilibrium outcome is restored to that under successive monopoly. If $\hat{k} \leq k \leq 1$, firm U will set a lower price, w^E, to serve firm U and all the new entrants. It is obvious that $\partial\hat{k} \big/ \partial n < 0$. This result echoes the finding in Proposition 1.

In the following, we focus on the case where $\hat{k} \leq k \leq 1$. In the first stage, firm D determines the optimal shared technology. By substituting eqs [21] and [24] into eqs [7], [8] and [23], the equilibrium profits of firm U, firm D, and the representative new entrant are derivable as follows:

$$\Omega^E = \frac{[(1+n)(a-c)+\varepsilon(1+kn)]^2}{4(1+n)(2+n)b},$$

$$\Pi^E = \frac{[(1+n)(a-c)+\varepsilon(1+4n+2n^2-kn(3+2n))]^2}{4(1+n)^2(2+n)^2b}, \quad \text{and} \quad [25]$$

$$\pi^E = \frac{[(1+n)(a-c)-\varepsilon(3+2n-k(4+3n))]^2}{4(1+n)^2(2+n)^2b},$$

By differentiating eq. [25] with respect to k, we derive that:

$$\frac{d\Pi^E}{dk} = -\frac{\varepsilon n(3+2n)}{(1+n)(2+n)}x < 0.$$

It follows that the optimal technology to be shared is a corner solution and is at $k = \hat{k}$. By substituting $\hat{k}$ into eqs [24] and [25], the equilibrium input price, final outputs and the profits of the firms are as follows:

$$w^E = \frac{\sqrt{(1+n)(2+n)}(a-c+\varepsilon)}{2\sqrt{2}(1+n)}, \quad Q^E = \frac{\sqrt{(1+n)(2+n)}(a-c+\varepsilon)}{2\sqrt{2}(2+n)b}, \quad \Omega^E = \frac{(a-c+\varepsilon)^2}{8b}, \qquad [26]$$

$$\Pi^E = \frac{\left[4(1+n)(2+n)-(3+2n)\sqrt{2(1+n)(2+n)}\right]^2(a-c+\varepsilon)^2}{16(1+n)^2(2+n)^2b}, \quad \text{and}$$
$$\pi^E = \frac{\left[4(1+n)(2+n)-(4+3n)\sqrt{2(1+n)(2+n)}\right]^2(a-c+\varepsilon)^2}{16n^2(1+n)^2(2+n)^2b}. \qquad [27]$$

By comparing Π^E in eq. [27] and Π^M in eq. [20], we have

$$\Pi^E - \Pi^M = \frac{(a-c+\varepsilon)^2\Phi\Psi}{16(1+n)^2(2+n)^2b} > 0,$$

where

$$\begin{aligned}\Phi &= \left[3(1+n)(2+n)-(3+2n)\sqrt{2(1+n)(2+n)}\right]\\ &= \left[\sqrt{(1+n)(2+n)(18+27n+9n^2)}-\sqrt{(1+n)(2+n)(18+24n+8n^2)}\right] > 0, \text{and}\\ \Psi &= \left[5(1+n)(2+n)-(3+2n)\sqrt{2(1+n)(2+n)}\right] > 0\end{aligned}$$

This result follows that under the linear demand, firm D's profit gain from the lowered input price (i. e., w^E) is larger than its profit loss from the competition of new entrants. Therefore, firm D is willing to share its obsolete technology to its potential rivals. Thus, we present this result as the following proposition.

Proposition 2: *It is beneficial for the downstream monopolist to share its obsolete technology to potential entrants in a successive monopoly.*

Moreover, by comparing the above equilibrium (i. e., eqs [26] and [27]) to those under successive monopoly (i. e., eqs [19] and [20]), we find that:

$$w^E < w^M, \quad Q^E > Q^M, \quad \Omega^E = \Omega^M, \text{ and } \quad \pi^E > 0 \geq \pi^M,$$

where $Q^E > Q^M$ implies $CS^E > CS^M$. That is to say, technology sharing increases the profits of the firms and the consumer surplus, leading to a Pareto improvement. This is because technology sharing suppresses the input price, which in turn decreases the distortion of double marginalization. Thus, we construct this result as the following proposition.

Proposition 3: *Technology sharing in the downstream market is a Pareto improvement under a successive monopoly.*

We can further investigate how the number of new entrants affects the profit of firm D. Differentiating Π^E in eq. [27] with respect to n yields:

$$\frac{d\Pi^E}{dn}=\frac{\left[2\sqrt{2}(1+n)(2+n)-(3+2n)\sqrt{(1+n)(2+n)}\right](a-c+\varepsilon)^2}{8(1+n)^2(2+n)^2\sqrt{(1+n)(2+n)}b}>0.$$

Note that n can be a choice variable of firm D as firm D may be able to determine n out of N potential entrants to share its technology. It follows that the profit of firm D increases with the number of new entrants and firm D would like to share its technology with all N potential entrants. We present this result as the following proposition.

Proposition 4: *The profit that the downstream monopolist can earn via technology sharing increases with the number of new entrants.*

The intuition is as follows. From Proposition 1, when n increases, the derived demand for inputs facing firm U increases as well. This effect raises the incentive of firm U to serve all the downstream firms. Therefore, firm D could share less superior technology with the new entrants (as $\partial\hat{k}/\partial n<0$) which in turn lowers the input price ($\partial w^E/\partial n<0$ by eq. [26]) and thus increases firm D's profit.

We then investigate how the number of new entrants affects the social welfare under technology sharing. The social welfare level under the optimal technology sharing can be derived by utilizing eqs [26] and [27] and is as follows:

$$\begin{aligned}SW^E&=(a-c+\varepsilon-\frac{b}{2}Q)Q-(1-k)\varepsilon ny\\&=\frac{(a-c+\varepsilon)^2}{8n^2(1+n)(2+n)b}\begin{bmatrix}16+28n+55n^2+60n^3+19n^4\\-4\sqrt{2(1+n)(2+n)}(2+2n+5n^2+3n^3)\end{bmatrix},\end{aligned}$$

where $(1-k)\varepsilon ny$ on the RHS of the first equation represents the distortion on production efficiency since these outputs are produced by the less efficient new entrants. It is derivable that SW^E is larger than SW^M in eq. [20], which echoes the finding in Proposition 3.

Differentiating SW^E with respect to n yields:

$$\begin{aligned}\frac{dSW^E}{dn}&=\frac{(a-c+\varepsilon)^2}{8n^3[(1+n)(2+n)]^{5/2}b}\\&\begin{bmatrix}2\sqrt{2}(1+n)(2+n)(16+38n+30n^2+11n^3+n^4)\\-\sqrt{(1+n)(2+n)}(64+200n+232n^2+129n^3+34n^4+3n^5)\end{bmatrix}.\end{aligned}\qquad[28]$$

By setting eq. [28] equals to zero, we derive that $n = 9.2324$.[3] It implies that the relationship between social welfare and the number of new entrants is non-monotonic. We establish the proposition as follows:

Proposition 5: *There exists a non-monotonic relationship between the number of new entrants and social welfare when technology sharing is considered.*

The economic explanation is as follows. Note that the input price is an internal transfer between the upstream and the downstream firms. Therefore, the social welfare level depends on the volume of outputs and by whom (the efficient firm or the inefficient firms) the outputs are produced. Although an increase in the number of new entrants leads to a more intensive competition in final good market, it also reduces the level of shared technology. As a result, when the number of new entrants is very large, most of the outputs are produced by the much less efficient new entrants, which causes a large distortion on production efficiency and is socially undesirable. This result is in line with Lahiri and Ono (1988) who show that the entry of less efficient firms is not innocuous to social welfare.[4]

5 Conclusions

This paper provides a new economic rationale to explain why a downstream monopolist is willing to share its obsolete technology with potential entrants. Although technology sharing intensifies competition in the downstream market, it can suppress the input price charged by the upstream monopolist. Under a linear specification, we show that it is beneficial for the downstream monopolist to share its obsolete technology to its potential rivals as the gain from a lowered input price outweighs the loss due to competition. In addition, technology sharing is a Pareto improvement since it induces competition in final good markets and mitigates the problem of double marginalization. It is also found that the profit gain of the downstream monopolist from technology sharing increases with the number of new entrants. However, the social welfare does not necessarily increase with the number of new entrants because a more obsolete technology will be shared. Finally, if the downstream market is

3 The social welfare function is concave in n for $1 \le n < 14.6241$, and then convex in n for $n > 14.6241$. When $n \to \infty$, the social welfare is approximately $0.25368(a - c + \varepsilon)^2/b$ and is lower than that at $n = 9.2324$ (where $SW = 0.25467(a - c + \varepsilon)^2/b$).

4 We thank an anonymous referee for suggesting this comparison.

characterized by an oligopoly with cost-inefficient potential entrants, the input price suppressing effect still exists and the intuition applies.

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