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# Technology Licensing between Rival Firms in Presence of Asymmetric Information

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**Abstract:** This paper investigates the possibility of licensing between rival firms in a Cournot duopoly market. Unlike Heywood, Li, and Ye (2014. "Per Unit vs. Ad Valorem Royalties under Asymmetric Information." *International Journal of Industrial Organization* 37:38–46), the cost information of the licensee is private in the pre-licensing stage. If inspection of the licensee's technology is not possible by the licensor i) technology is never transferred from the low-cost firm (licensor) to the high-cost firm (licensee) via fixed-fee and ii) in the case of royalty licensing technology will be transferred only if the cost difference between the firms is sufficiently high. Moreover, under fixed-fee and royalty licensing, the licensee will always allow the licensor to inspect its technology, if inspection is possible. If inspection is undertaken by the licensor, technology will be transferred i) if the cost difference is low via fixed fee and ii) always via royalty.

**Keywords:** technology licensing, cournot competition, asymmetry information
**JEL Classification:** L24, L13, D82

## 1 Introduction

The issue of technology transfer between firms has become a dominant theme in the literature of industrial organization. Broadly, two possible types of channels have been identified via which an inefficient firm can acquire a superior technology and thereby reduce its cost of production. It can buy the technology directly from the research laboratories, or may buy it from the more efficient firm (see Shapiro (1985), Kamien and Tauman (1986) etc.). According to Shapiro (1985), a firm may license its technology to another firm, rather than retain the ownership of the technology, for possible gains from trade. The most common

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forms of licensing are by fixed-fee, royalty and two-part tariff.[1] Marjit (1990) discusses in a Cournot duopoly set-up the possibilities of licensing by fixed-fee and shows that technology is licensed only if the initial cost difference is low. Wang (1998) and Fauli-Oller and Sandonis (2002) however, show that via royalty, technology is always licensed. This is possible as the licensor can control the effective cost of the licensee, thereby the degree of competition, with varying the royalty rates.

Informational asymmetry also plays an important role in framing the licensing agreement and may sometimes eliminate the possibility of licensing completely. This informational asymmetry may be regarding the market demand, available technology of the licensee, quality of the proposed technology to be licensed etc. Literature on licensing that takes into account incomplete information has mainly considered innovators (licensor) who are outsiders to the industry. In Gallini and Wright (1990) the outside innovator (licensor), who has private information on the value of the innovation, signals its technology type with an output-based payment and may leave some of the rents with the licensee. On the other hand Macho-Stadler and Perez-Castrillo (1991) considers a situation where an outside innovator interacts with a monopolist having private information regarding the value of the patent. Sen (2005) develops a model where an outside innovator interacts with a monopolist who is privately informed about its cost. It shows that the low-cost monopolist is always offered a pure fixed-fee contract, while the high-cost monopolist is always offered a positive per-unit royalty. In Beggs (1992) the outside innovator is uninformed about the true value of the patent, which is private information to the buyer who makes the offer. Beggs (1992) shows that royalty licensing is possible in cases where fixed-fee licensing fails. However, in Poddar and Sinha (2002) the licensee possesses private information about the market demand which is unknown to the patentee, who wishes to sell a patent of cost reducing technology to the licensee. It shows that a low demand type is either offered only royalty or a two-part tariff and the high demand type is offered with a contract with only fixed fee.[2]

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**1** Rostoker (1984) for example, shows that royalty alone is used for 39 % of time, fixed-fee alone for 13 % and both instruments together for 46 %.

**2** Bessen (2004) and Schmitz (2002) also discuss the implications of asymmetric information for technology licensing. In Bessen (2004) innovations are cumulative and development costs of second round innovators are private knowledge. In such a set-up it is shown that patent-holders do not necessarily offer ex ante licenses. Schmitz (2002) builds a model where a research lab (outside innovator) owns a patent, but cannot develop a final product using it, and interacts with two down-stream firms that may successfully develop the new product. The benefits of the down-stream firms from being the sole supplier of the new product are private information. In

In contrast to these models the present paper discusses for the first time the issue of technology licensing between the rival firms in a Cournot duopoly market. Licensing can occur via fixed fees or royalties and it is assumed that only the licensee (high-cost firm) has private information about its costs. In Sen (2005) the licensor is an outside-innovator, while in the present model the licensor (low-cost firm) is a rival firm. In our model the duopolists produce output at a constant per-unit cost and the low-cost firm's cost is commonly known. After the licensing of technology the high-cost firm produces its output at a lower unit cost (by using the technology of the licensor). A much related work of the present model is Heywood, Li, and Ye (2014). It studies an inside patent holder's optimal licensing policy where the information about the value of the patent is private to its rival. However, in Heywood, Li, and Ye (2014) prior to licensing the licensor produces at zero unit cost, whereas the licensee produces at a constant unit cost and these costs are commonly known. The incompleteness of information arises in Heywood, Li, and Ye (2014) as the licensor is uncertain about how the licensee will exploit the licensed technology.[3] In the literature on licensing (see Shapiro (1985), Marjit (1990), Wang (1998) etc.) it is generally argued that after the technology is licensed, the licensor and the licensee produce output with the same technology. As uncertainties about the licensee's capabilities in using the licensed technology are not generally discussed in the literature, the present model also assumes that the licensee has the skill to use the technology of the licensor. Heywood, Li, and Ye (2014) reports that "Such incomplete information may be especially likely when the patent holder is entering a new market against a largely unknown rival. For example, Fiat began selling and eventually producing tractors in China in the 1980s and also decided to license its technology to the previous near monopoly of China First Tractor." Based on this fact, *first it seems to be more meaningful to assume that the cost information is private for the licensee as assumed in our work*, which is not the case in Heywood, Li, and Ye (2014). Secondly, Heywood, Li, and Ye (2014) is much skeptic in considering that "the realized value of a patent may, indeed, be unknown to the holder when licensing occurs. This value likely depends on intrinsic features of the rival licensee that are not easily observed such as how a rival's management and workforce implement a technological innovation designed elsewhere for a

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such a situation "the research lab will sometimes sell two licenses, even though under complete information it would have sold one exclusive license".

**3** Heywood, Li, and Ye (2014) also assumes that final output and market price are verifiable to a neutral third party.

different production facility." This skepticism, though may be felt from a specific example, but it does not justify the reality where the firms are running after innovation and implementations.[4] *Therefore, it is much more plausible to consider as in the present model that the licensee is much efficient in implementing the techniques of the licensor, as they compete in a same market*. Fan Jun, and Wolfstetter (2015) also studies, licensing in the presence of private information. In Fan Jun, and Wolfstetter (2015) licensing reduces the unit cost of the licensee, which is the licensee's private information. They show that if the licensee is able to make better use of a non-drastic innovation than the inside innovator, then the optimal mechanism may prescribe fixed fees, royalty rates lower than the cost reduction, and even negative royalty rates.

In the present model both the firms can begin the game by offering a fixed-fee or a per-unit royalty, which is to be paid by the licensee after licensing to the licensor. It is shown that technology is never transferred via fixed-fee if the licensor could not inspect the licensee's technology. This is in contrast to Beggs (1992), Poddar and Sinha (2002) and Sen (2005) where fixed-fee licensing is possible. Heywood, Li, and Ye (2014) shows that optimal contract is either a separating contract with both types of rivals being licensed but at different royalty rates, or an excluding contract with only the low cost rival being licensed by royalty. On the other hand, in the present model, if the licensor could not inspect the licensee's technology, separating contract or excluding contract is not possible. Technology is transferred via royalty only if the cost difference between the firms is sufficiently high. The licensor will charge the per-unit royalty such that it separates the licensee into lower cost type and higher cost type. The former rejects the offer, while the latter accepts the offer. However, the licensor could not fully separates each type of the second group, i. e. the higher cost types who accept the offer. Hence, one of the important reasons for observing relatively lower share of fixed-fee licensing in comparison to royalty licensing in the real world (See Rostocker (1984) and Vishwasrao (2007)) can be informational asymmetry about cost. Moreover, Anton and Yao (2004) considers a Cournot market, where an innovating firm has private information about an invention and decides whether to patent and how much knowledge to disclose. In Anton and Yao (2004) larger innovations are protected both through patents and secrecy, and imitation occurs, leading to an implicit licensing relationship between competitors mediated by expected damage payments.

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**4** Nokia has extended a patent licensing agreement with Samsung by five years (Published November 4, 2013 by Nokia – Press Release). It is not justifiable to consider Nokia as incompetent to exploit the technology of Samsung to its full extent.

It is true that through repeated market interaction, the low-cost firm would have learned quite a lot about its rival's business and thereby may know or update its belief about the high-cost firm's technology. However, we consider a situation in which a firm with an advanced technology enters a new market, without any history of interaction with its potential rivals. This situation may arise when a reputed foreign firm (low-cost firm) enters the market of a developing country in which home firm(s) (high-cost firm(s)) already operate(s). The entrant with the advanced technology then faces a dilemma. It can delay the licensing process so that market interaction with the rival reveals some information. However, the delay is costly as it reduces the aggregate market profit[5] in the interim periods (at least part of which the low cost firm can extract), even if the high-cost firm reveals its existing technology by producing according to its best response. Moreover, the high cost firm, anticipating the imminent transfer of technology, may have an incentive to dump the market for a better deal at the time of transfer of technology. This is once again, costly for the low-cost firm. All these are interesting issues and studying these incentives is very important, but is beyond the scope of this particular paper.

The present paper also discusses the possibilities of licensing if the licensor could inspect the licensee's technology. The licensee may allow the licensor to inspect its technology before any offer is made. It is observed in such an extension, that the licensee will always allow the licensor to inspect its technology irrespective of its cost. By allowing inspection the licensee tries to pass a signal that it has a lower unit cost. As the licensee never restricts inspection, if the licensor inspects technology is transferred if the cost difference is low via fixed-fee. However, in the case of royalty licensing, after inspection technology is always transferred. Moreover, if anyone of the firms offers first for the transfer of technology, the expected welfare is always more than the pre-licensing stage. This is not only true when the inspection cost is too high such that the licensor does not inspect, but also when the inspection cost is low for which the licensor inspects the technology of the licensee.

The scheme of the paper is as follows. In Section 2 we model the basic Cournot game in the presence of asymmetric information. Section 3 discusses where the low-cost firm (licensor) offers first to license its technology, while in Section 4 we model the offer by the high-cost firm (licensee). Section 5 extends the model by incorporating inspection and finally we conclude.

5 Profit from selling goods + Revenue from licensing.

## 2 Quantity Competition

In case of transfer of technology a complete information Cournot game is played. In absence of transfer an asymmetric information Cournot game would be played. Let us first discuss what happens when licensing is not possible, i. e. *pre-licensing stage* (firms do not interact for licensing).

Consider a Cournot duopoly producing a homogeneous product. The market demand is given by: $P = a - q$, where $q$ is industry output. The two firms, firm 1 and firm 2 produce output ($q_1$ and $q_2$) at a constant unit cost $c_1$ and $c_2$ respectively. In the following sections of the paper we refer "firm 1" as the "licensee" and "firm 2" as the "licensor", where we discuss the issue of licensing. $P$ is the market price and $a > 0$, $c_1$ is privately known to firm 1 only, while $c_2$ is commonly known. It is also commonly known that $c_2$ is less than the unit cost of firm 1.[6] Firm 2 believes that $c_1$ is distributed uniformly in $(c_2, \bar{c}_1)$,[7] with density $f(c_1) = \frac{1}{\bar{c}_1 - c_2}$. The belief of firm 2 is defined by $\mu$. Without any loss of generality, assume $c_2 = 0$ and $c_1 < \bar{c}_1 = \frac{a}{2}$.

Let firm i's profit be: $\Pi_i = (a - q_i - q_j - c_i)q_i$, where $q_i$ is the quantity chosen by firm i, $i, j = 1, 2$ and $i \neq j$. The two firms choose their outputs simultaneously. We first proceed to identify pure-strategy equilibrium of this game. Firm 1's equilibrium choice $q_1^\star(c_1)$ must satisfy

$$q_1^\star(c_1) \in arg \max_{q_1}[(a - q_1 - q_2 - c_1)q_1] \Rightarrow q_1^\star(c_1) = \frac{a - c_1 - q_2}{2}. \qquad [1]$$

Firm 2 does not know which type of firm 1 it faces, so its pay-off is the expected profit over the types of firm 1:

$$q_2^\star \in arg \max_{q_2} \int_0^{\bar{c}_1} (a - q_1(c_1) - q_2)q_2 f(c_1)dc_1 \Rightarrow q_2^\star = \frac{a + Ec_1|_\mu}{3} \qquad [2]$$

($q_2^\star$ is derived using eq. [1]) where $Ec_1|_\mu$ is the expected cost of firm 1 that firm 2 believes. Plugging in for $q_1^\star(c_1)$, we obtain $q_1^\star(c_1) = \frac{2a - 3c_1 - Ec_1|_\mu}{6}$. Therefore the profits of the firms in this Cournot game are

$$\Pi_1(c_1) = \left(\frac{2a - 3c_1 - Ec_1|_\mu}{6}\right)^2, E\Pi_2 = \left(\frac{a + Ec_1|_\mu}{3}\right)^2 \qquad [3]$$

**6** As discussed in the introduction firm 1, the licensee, is the high-cost firm and firm 2, the licensor, is the low-cost firm.

**7** When $c_1 \geq \bar{c}_1$, then in a situation with complete information, firm 2 becomes the monopolist. We assume to keep matters interesting, that firm 2 knows that this can never happen in this situation. Moreover, this belief is a correct belief in this model.

where $\Pi_1(c_1)$ is the actual profit of firm 1, while $E\Pi_2$ is the expected profit[8] of firm 2.[9] Moreover, the industry output is

$$q = q_1^\star(c_1) + q_2^\star = \frac{4a - 3c_1 + Ec_1|_\mu}{6} = \frac{17a - 12c_1}{24} \qquad [4]$$

where $Ec_1|_\mu = \frac{\bar{c}_1}{2} = \frac{a}{4}$. However, the Consumer surplus is $CS = \frac{q^2}{2}$ and the industry profit is $IP = \Pi_1(c_1) + E\Pi_2$. Therefore, the actual Social Welfare in the pre-licensing situation is $W_{PL} = IP + CS$. The Expected CS is

$$ECS = \int_0^{\bar{c}_1} CSf(c_1)dc_1 = \frac{1}{2\bar{c}_1}\int_0^{\bar{c}_1}\left[\frac{17a - 12c_1}{24}\right]^2 dc_1 = 0.17274a^2 \qquad [5]$$

and the Expected IP is

$$EIP = \int_0^{\bar{c}_1} IPf(c_1)dc_1 = \frac{1}{576\bar{c}_1}\int_0^{\bar{c}_1}\left[149a^2 - 168ac_1 + 144{c_1}^2\right]dc_1 = 0.2066a^2. \qquad [6]$$

Therefore, the Expected Welfare is

$$EW_{PL} = ECS + EIP = 0.37934a^2. \qquad [7]$$

# 3 Offer by the Licensor

The Licensor, i. e. low-cost firm (firm 2) in this context may be willing to license its technology to the licensee, i. e. high-cost firm (firm 1) before they take their production decision. Until Section 5, we assume that the licensor cannot inspect the licensee's technology before deciding whether to license its technology.[10] The transfer of technology will allow the licensee to produce with the superior

**8** The findings of this paper (discussed later) have wider applicability beyond a highly stylized model with constant costs and linear demand. In the present set-up of constant costs and linear demand, we observe that the output and the profit (expected) of the low-cost firm is directly related to the expected cost ($Ec_1|_\mu$) of the high-cost firm. On the other hand, the output and the profit of the high-cost firm is inversely related to its actual cost, as well as to the expected cost ($Ec_1|_\mu$) of the high-cost firm as believed by the low-cost firm. These relations also hold in a more general set-up about demand and cost, which are the major driving forces of the results that we derive in the following sections. Please see Sen (2015) for an analysis of technology licensing in a general demand structure, where the cost information about the firms is complete. It shows that the results of the linear demand set-up, also holds in a more general set-up.

**9** In fact, this is the unique equilibrium. See Fudenberg and Tirole (2010).

**10** It may be due to the nature of technology or the cost of inspection may be very high.

technology of the licensor (zero unit cost).[11] Let us assume, that the licensor offers a fixed-fee or a per-unit royalty, to be paid by the licensee for licensing-in the licensor's technology.[12] Observing the offer of the licensor, the licensee either accepts or rejects it. If the offer is accepted, in the final stage of the game output is produced by the firms in a set-up of complete information (both firms produce output with zero unit cost). On the other hand, if the offer is rejected, the licensor may get some additional information regarding the actual cost of the licensee. This may help the licensor to reap some additional profit, while the output will still be produced in a sphere of incomplete information. This is because, from eq. [3], the profits of the firms depend on the expected cost ($Ec_1$) of the licensee. The following two subsections solve for the *Perfect Bayesian Equilibrium* in case of fixed-fee licensing and royalty licensing respectively.

## 3.1 Fixed-Fee Licensing

In the first stage of the game, the licensor offers a fixed-fee ($F$) to license its technology to the licensee. The licensee after observing $F$, either accepts or rejects the offer. Licensee will accept the offer (reject otherwise) if the profit after licensing is greater than the profit in absence of licensing, i. e.

$$\Pi_1^F - F \geq \Pi_1(c_1) = \left(\frac{2a - 3c_1 - Ec_1|_{\mu(F)}}{6}\right)^2, \qquad [8]$$

where $Ec_1|_{\mu(F)}$ is the expected cost of licensee given belief $\mu(F)$ and $\Pi_1^F$ $(= \Pi_2^F = \frac{a^2}{9})$ is the profit of each firm after the transfer of technology.[13] If licensee rejects the offer, licensor believes $(\mu(F))$ that $c_1 \in (0, \tilde{c}_1(F)]$ and uniformly distributed. We shall check the consistency of this belief later on. For sequential rationality of licensee's strategy, $\tilde{c}_1(F)$ type must be indifferent between acceptance and rejection. Licensee is indifferent when the ineq. [8] holds with strict equality. Since $\Pi_1(c_1)$ is a decreasing function of $c_1$, $\tilde{c}_1(F)$ can be solved uniquely from this equality. Thus,

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11 However, in Heywood, Li, and Ye (2014), realization of actual cost to the licensee is the rival's private information and is distributed such that it takes the value 0 with probability $\beta$ and the value $c(<c_1)$ with probability $1-\beta$, where $c_1$ the unit cost of licensee is commonly know prior licensing.

12 In the present paper fixed-fee and per-unit royalty cannot be negative as otherwise technology will never be transferred.

13 Firm i's profit under complete information is $\pi_i(c_i, c_j) = \frac{(a-2c_i+c_j)^2}{9}$, $i = 1, 2$ and $i \neq j$, where $c_i$ $(c_j)$ is the unit cost of production of firm i (firm j). Here $c_2 = 0$, $\frac{a}{2} > c_1 > 0$. It is also assumed that $\frac{a^2}{9} - F > 0$.

$$\begin{aligned} \frac{a^2}{9} - F &= \left(\frac{2a - 3\tilde{c}_1(F) - Ec_1|_{\mu(F)}}{6}\right)^2 \\ or, \tilde{c}_1(F) &= \frac{4\left(a - \sqrt{a^2 - 9F}\right)}{7}, \end{aligned} \qquad [9]$$

and $\tilde{c}_1(F) \le \bar{c}_1 = \frac{a}{2}$ if $F \le \frac{7a^2}{64}$. Since $\tilde{c}_1(F)$ is indifferent between acceptance and rejection, every $c_1 < \tilde{c}_1(F)$ is better off by rejecting the offer and every $c_1 > \tilde{c}_1(F)$ is better off by accepting the offer. The following lemma summarizes this observation.

**Lemma 1:** *For any $F \le \frac{7a^2}{64}$, the offer $F$ is accepted if and only if $c_1 \ge \tilde{c}_1(F)$.*

Licensor hence tries to maximize its expected profit by choosing $F$ consistent with the belief given in Lemma 1.[14] Licensor's equilibrium choice must satisfy

$$\max_{\tilde{c}_1} L = \int_0^{\tilde{c}_1} E\Pi_2 f(c_1) dc_1 + \int_{\tilde{c}_1}^{\bar{c}_1} (\Pi_2^F + F) f(c_1) dc_1, \qquad [10]$$

where $L$ is the expected profit of licensor from offering $F$. $\Pi_2^F + F$ is its profit when the offer is accepted. $E\Pi_2 = \frac{(a + Ec_1|_{\mu(F)})^2}{9}$ is the expected profit of licensor if the offer gets rejected, where $Ec_1|_{\mu(F)}$ is the (updated) expected cost of licensee as believed by licensor, contingent on the updated belief that $c_1$ is distributed uniformly in $(0, \tilde{c}_1)$. Substituting $F$ from eq. [9], eq. [10] reduces to (subject to $0 < \tilde{c}_1 < \bar{c}_1$)

$$\begin{aligned} \max_{\tilde{c}_1} L &= \frac{1}{9\bar{c}_1} \int_0^{\tilde{c}_1} \left(a + \frac{\tilde{c}_1}{2}\right)^2 dc_1 + \frac{1}{\bar{c}_1} \int_{\tilde{c}_1}^{\bar{c}_1} \left[\frac{2a^2}{9} - \frac{(4a - 7\tilde{c}_1)^2}{144}\right] dc_1 \\ &= \frac{\tilde{c}_1 (2a + \tilde{c}_1)^2}{36\bar{c}_1} + \frac{(16a^2 + 56a\tilde{c}_1 - 49\tilde{c}_1^{\,2})(\bar{c}_1 - \tilde{c}_1)}{144\bar{c}_1}. \end{aligned} \qquad [11]$$

From eq. [11] and substituting $\bar{c}_1 = \frac{a}{2}$, given $\tilde{c}_1 \in (0, \bar{c}_1)$,

$$\frac{dL}{d\tilde{c}_1} = \frac{28a^2 - 129a\tilde{c}_1 + 159\tilde{c}_1^{\,2}}{144\bar{c}_1} > 0. \qquad [12]$$

The expected profit of licensor if the offer is rejected is always less than its expected profit in the pre-licensing stage. Moreover, the profit of licensor if the offer is accepted by licensee is more than the expected profit in the pre-licensing stage if $\tilde{c}_1$ (or $F$) is much higher than zero. This is because the licensor loses,

**14** As from eq. [9], we observe a one to one relation between $\tilde{c}_1$ and $F$, we carry out the exercise by choosing $\tilde{c}_1$ instead of $F$.

if $\tilde{c}_1$ (or $F$) is low (assume $\tilde{c}_1 < Ec_1|_\mu$), for which such $F$ is not offered. However, if $\tilde{c}_1$ is high or licensor charges higher $F$ (assume $\tilde{c}_1 > Ec_1|_\mu$), then licensor gains, but the probability of rejection also increases. Now, depending on the belief, licensor's expected profit from charging any $F$, such that offer is accepted by the higher-cost type (licensee), is always less than the profit of licensor in the pre-licensing stage. This happens in case of fixed-fee licensing as after the transfer of technology the firms produce at zero cost, which increases the competition in the market and drives down the profit of licensor. Hence, licensor will set $F$ such that $\tilde{c}_1(F) = \bar{c}_1$, and as $c_1 < \bar{c}_1$ the licensee will reject the offer. Using Lemma 1, we can find a pooling equilibrium where technology will never be transferred if the licensor initiates the game by offering a fixed-fee to license the technology. It is optimal for licensor to offer a higher $F$ ($\tilde{c}_1(F) = \bar{c}_1$) such that the offer is always rejected. This is equivalent to not offer any fixed-fee as licensor does not want to license its technology. Hence, the technology will not be transferred via a fixed-fee to the licensee, as the licensor believes that if the licensee accepts the offer, then its unit cost must be too high.

**Proposition 1:** *No equilibrium exists such that technology is transferred by fixed-fee. The licensor offers a high enough fixed-fee that every high cost-type rejects.*

Wang (1998) as well as Marjit (1990) shows that when the costs are common knowledge, under fixed-fee licensing, licensor will license its technology to licensee if and only if the cost difference is low. However, the technology is never transferred, when the cost of licensee is its private knowledge, if the licensor offers a fixed-fee to license its technology. This is because in the present model the licensee's gain is necessarily lower than the licensor's loss, and so no mutually agreeable lump-sum transfer can exist if the actual cost of licensee is low. This is an inherent feature of Cournot market, as in the pre-licensing stage the profit of licensor is much higher if the cost information about the licensee is private ($\frac{(a + Ec_1|_\mu)^2}{9}$), than when it is not ($\frac{(a + c_1)^2}{9}$) for $c_1$ much lower, i. e. the cost difference is low.

## 3.2 Royalty Licensing

In this section, consider that the licensor transfers its technology to the licensee through royalty licensing. Licensor begins the game by offering a per-unit royalty ($r$), to license its technology, to be paid by licensee. Licensee after observing $r$ either accepts or rejects the offer. It accepts the offer (reject otherwise) if (as in eq. [8])

$$\Pi_1^R(r) \geq \Pi_1(c_1) = \left(\frac{2a - 3c_1 - Ec_1|_{\mu(r)}}{6}\right)^2, \tag{13}$$

where $\Pi_1^R(r) = \frac{(a-2r)^2}{9}$ is the profit of licensee after the technology is transferred and $\Pi_1(c_1)$ is its profit if the offer $(r)$ is rejected. After the transfer of technology the unit cost of both the firms are zero, but licensee pays a per-unit royalty to licensor. Thus, the effective unit cost of licensee after the transfer of technology is $r$. While the profit of licensor after the transfer of technology is $\Pi_2^R(r) = \frac{(a+r)^2}{9} + \frac{r(a-2r)}{3}$. $Ec_1|_{\mu(r)}$ is the expected cost of licensee given belief $\mu(r)$. If licensee rejects $r$, licensor believes $(\mu(r))$ that $c_1 \in (0, \hat{c}_1(r)]$ and uniformly distributed (later the consistency of this belief is checked). Comparing relation [13] with eq. [3], it can be argued that licensee is better-off than under the pre-licensing stage, not only when it accepts the offer, but also when it rejects the offer (as then licensor believes that $c_1 < \hat{c}_1$ and thereby $Ec_1|_{\mu(r)} < Ec_1|_{\mu} = \frac{\bar{c}_1}{2}$). For sequential rationality of licensee's strategy, $\hat{c}_1(r)$ type must be indifferent between acceptance and rejection. Licensee is indifferent when the ineq. [13] holds with strict equality. Since $\Pi_1(c_1)$ is a decreasing function of $c_1$, $\hat{c}_1(r)$ can be solved uniquely from this equality. Thus,

$$\begin{aligned} \frac{(a-2r)^2}{9} &= \left(\frac{2a - 3\hat{c}_1(r) - Ec_1|_{\mu(r)}}{6}\right)^2 \\ or,\ \frac{(a-2r)^2}{9} &= \frac{(4a - 6\hat{c}_1 - \hat{c}_1)^2}{144} \\ or,\ \hat{c}_1(r) &= \frac{8r}{7}, \end{aligned} \tag{14}$$

where $\hat{c}_1(r) \leq \bar{c}_1 = \frac{a}{2}$, if $r \leq \frac{7a}{16}$. Since $\hat{c}_1(r)$ is indifferent between acceptance and rejection, every $c_1 < \hat{c}_1(r)$ is better off by rejecting the offer and every $c_1 > \hat{c}_1(r)$ is better off by accepting the offer.

**Lemma 2:** *For any $r \leq \frac{7a}{16}$, the offer $r$ is accepted if and only if $c_1 \geq \hat{c}_1(r)$.*

Hence licensor's choice of $r$, consistent with belief (Lemma 2), must maximize its expected profit given by

$$\max_r J = \int_0^{\hat{c}_1} E\Pi_2 f(c_1) dc_1 + \int_{\hat{c}_1}^{\bar{c}_1} \Pi_2^R(r) f(c_1) dc_1 \tag{15}$$

subject to $0 \leq r \leq \bar{r}$, where $\bar{r} = \frac{7a}{16}$ and $\hat{c}_1(\bar{r}) = \bar{c}_1$. $E\Pi_2 = \frac{(a + Ec_1|_{\mu(r)})^2}{9}$ is the expected profit of licensor when the offer is rejected, where $Ec_1|_{\mu(r)}$ is the expected cost of licensee when the offer $r$ is rejected and licensor believes that $c_1$ is distributed uniformly in $(0, \hat{c}_1)$. $\Pi_2^R(r)$ is the profit of licensor after the technology is transferred, and is equal to $\frac{(a+r)^2}{9} + \frac{r(a-2r)}{3}$. Substituting these into eq. [15] the objective function of licensor reduces to

$$\begin{aligned}\max_r J &= \frac{1}{9\bar{c}_1}\left[\int_0^{\hat{c}_1}\left(a+\frac{\hat{c}_1}{2}\right)^2 dc_1 + \int_{\hat{c}_1}^{\bar{c}_1}\left(a^2+5ar-5r^2\right)dc_1\right] \\ &= \frac{1}{9\bar{c}_1}\left[\left(a+\frac{\hat{c}_1}{2}\right)^2\hat{c}_1 + \left(a^2+5ar-5r^2\right)\left(\bar{c}_1-\hat{c}_1\right)\right] \\ &= \frac{1}{9\bar{c}_1}\left[\frac{2r}{7}\left(2a+\frac{8r}{7}\right)^2 + \left(\frac{a}{2}-\frac{8r}{7}\right)\left(a^2+5ar-5r^2\right)\right]\end{aligned} \qquad [16]$$

subject to $0 \le r \le \bar{r}$. From eq. [16],

$$\frac{dJ}{dr} = \frac{1}{9\bar{c}_1}\left[\frac{5a^2}{2} - \frac{677ar}{49} + \frac{6264r^2}{343}\right] \textit{ and } \frac{d^2J}{dr^2} = \frac{1}{9\bar{c}_1}\left[-\frac{677a}{49} + \frac{12528r}{343}\right]. \qquad [17]$$

From eq. [17] $\frac{dJ}{dr} = 0$ and $\frac{d^2J}{dr^2} < 0$, if $r = r_2 = 0.2995a$.[15] Therefore $J$ is maximized at $r = r_2$ and $\hat{c}_1(r_2) = 0.34234a < \bar{c}_1$. This ensures, from Lemma 2 that if $c_1 < \hat{c}_1(r_2)$ the offer will be rejected and for $\hat{c}_1(r_2) \le c_1 < \bar{c}_1$ the offer will be accepted and thereby the technology will be transferred. *Will licensor actually offer* $r_2$? If licensor offers this, then its expected profit is $J(r_2)$. However, if it offers $r \ge \bar{c}_1 = \frac{a}{2}$, then the offer will be rejected by every cost-type. Then its prior and posterior beliefs would be same and the expected profit of licensor will be $E\Pi_2 = \left(\frac{a + Ec_1|_\mu}{3}\right)^2$, where $Ec_1|_\mu = \frac{\bar{c}_1}{2} = \frac{a}{4}$ is the expected cost as in the pre-licensing stage. However, as $J(r_2) > E\Pi_2$, therefore licensor will offer $r_2$ and the technology will be transferred if $\hat{c}_1(r_2) \le c_1 < \bar{c}_1$ and rejected if $c_1 < \hat{c}_1(r_2)$.

**Proposition 2:** *The licensor will charge a per unit royalty* $r_2$ *(*$< \frac{a}{2}$*) to license its technology and technology will be transferred if and only if* $c_1 \in [\hat{c}_1(r_2), \bar{c}_1)$.

As in case of fixed-fee licensing, the expected profit of licensor if the offer is rejected is always less than its expected profit in the pre-licensing stage. The rejection of offer is likely to happen if the actual cost of licensee is low. Moreover, the profit of licensor if the offer is accepted by licensee is more than its expected profit in the pre-licensing stage, if $\hat{c}_1$ (or $r$) is much higher than zero. This therefore demands charging higher per-unit royalty (payment) such that licensor is better-off than in the pre-licensing stage. However, if $\hat{c}_1$ is high (or licensor charges higher $r$), then the probability of rejection also increases. These phenomena are true even in case of

15 The decimal figures in this paper are rounded off.

fixed-fee licensing (as discussed in the previous section). Contrary to what happens in fixed-fee licensing, in the present context *licensor's expected profit from charging* $r_2$, *is greater than its profit in the pre-licensing stage*. This happens in the case of royalty licensing as after the transfer of technology licensee produces at $r_2$, which softens the competition in the market and increases the profit of licensor. On the other hand in case of fixed-fee licensing after transfer both the firms produce at zero cost, which increases competition in the market and thereby reduces the licensor's profit in the post-licensing stage.[16] Thus, in the case of royalty licensing licensor will charge the per-unit royalty such that it separates the cost types of the licensee into two groups. The lower cost types rejects the offer, while the higher cost types accept. However, licensor could not fully separates each type of the second group, i. e. the firm who accepts the offer. Wang (1998) builds a duopoly model, where the information is complete, and shows that via royalty the licensor will always license its technology to the licensee (if the innovation is non-drastic or $0 < c_1 < \bar{c}_1$). Incomplete information changes this result. In a situation, when the cost of the licensee is privately known, then if licensor charges a per-unit royalty, technology will be transferred only if the cost difference between the firms is sufficiently high. Secondly, in case of complete information the licensor will charge the royalty rate such that the effective unit cost of the licensee (the unit cost of the licensor plus per-unit royalty) is same under licensing and no-licensing. However, in the present model, the effective unit cost of the licensee (except the limiting case) is less in the case of licensing than under no-licensing. Thus, the presence of private information helps the licensee to be strictly better-off in case of licensing than under no-licensing. The present analysis, also highlights that the licensor will always prefer royalty licensing in comparison to fixed-fee licensing or licensing by a combination of fixed-fee and per-unit royalty (two-part tariff).[17]

## 3.3 Welfare Analysis

If $c_1 \geq \hat{c}_1 = 0.34234a$, then technology will be transferred at per-unit royalty $r_2 = 0.2995a$ and the industry output will be[18]

**16** Ensuring a constant profit to licensee in the post-licensing stage (say $z$), the post-transfer industry profit and licensor's profit are $\frac{2a^2 + ar_2 - r_2^2}{9}$ (say $A$) and $\frac{a^2 + 5ar_2 - 5r_2^2}{9} = A - z$ respectively in case of royalty licensing, while the post-transfer industry profit and licensor's profit are $\frac{2a^2}{9}$ (say $B$) and $\frac{a^2}{9} + F = B - z$ respectively in case of fixed-fee licensing, where $A > B$.

**17** For the analysis of two-part tariff, kindly see Appendix.

**18** We thank an anonymous referee and the editor of this journal for suggesting to incorporate the welfare analysis in the present paper.

$$q_1 + q_2 = \frac{a - 2r_2}{3} + \frac{a + r_2}{3} = \frac{2a - r_2}{3} = 0.56684a. \quad [18]$$

On the other hand in the pre-licensing stage the industry output is

$$q_1^\star(c_1) + q_2^\star = \frac{4a - 3c_1 + Ec_1|_\mu}{6} = \frac{17a - 12c_1}{24} \quad [19]$$

where $Ec_1|_\mu = \frac{\bar{c}_1}{2} = \frac{a}{4}$. Comparing eqs [18] and [19], it can be said that if $c_1 \geq \hat{c}_1 = 0.34234a$, then the realized output in the pre-licensing stage is always less than the output after the transfer of technology. On the other hand, if $c_1 < \hat{c}_1$, technology will not be transferred as licensee will reject the offer, then the industry output will be

$$q_1^\star(c_1) + q_2^\star = \frac{4a - 3c_1 + Ec_1|_{\mu(r_2)}}{6} = \frac{4.17117a - 3c_1}{6} \quad [20]$$

where $Ec_1|_{\mu(r_2)} = \frac{\hat{c}_1}{2} = 0.17117a$. From eqs [19] and [20], it can be shown that if $c_1 < \hat{c}_1$, then the industry output will be less than the output in the pre-licensing stage. However, comparing eqs [18], [19] and [20], it can be said that the realized output in the pre-licensing stage is always less than the expected output (ex-ante) if licensor offers. This implies that the expected industry output as well as the consumer surplus will always be more, if licensor offers any $r$ for transferring the technology, than in the pre-licensing stage.

Moreover, as the expected profit of licensor and the realized profit of licensee increase after licensor offers, this implies that the social welfare (expected) will also increase as the expected industry profit and the expected consumer surplus increase simultaneously.

# 4 Offer by the Licensee

The present section examines what happens when the licensee makes the first offer, either by offering a fixed-fee or per-unit royalty to the licensor to use its technology.

## 4.1 Fixed-Fee Licensing

Licensee initiates the game with an offer of fixed-fee $(F)$. After observing the offer $F$ made by licensee, licensor updates its belief and then decides whether to accept the offer or reject it. We denote the updated belief of licensor about licensee's costs after receiving the offer $F$ as $\mu(F)$. If licensor accepts the offer, the technology is transferred and a complete information Cournot game is played in the final stage. If licensor rejects the offer, then an asymmetric information Cournot game is played in the final stage, with $\mu(F)$ being licensor's belief. We consider equilibrium in (weakly) monotonic strategies, i. e. higher cost types offer weakly higher fixed-fees.

Suppose there exists an equilibrium in which the technology is transferred at $F = F_0$ $(>0)$. Then, the following condition must hold:

$$\Pi_2^F + F_0 \geq E\Pi_2|_{\mu(F_0)}, \ \ or \ \ \frac{a^2}{9} + F_0 \geq \frac{(a + Ec_1|_{\mu(F_0)})^2}{9}, \tag{21}$$

where $\Pi_2^F = \Pi_1^F = \frac{a^2}{9}$ is the profit of each firm after the transfer of technology via fixed-fee. $\Pi_2^F + F_0$ is the net benefit of licensor, if it accepts the offer in the equilibrium. If the offer is rejected licensor gets $E\Pi_2|_{\mu(F_0)}$. The above relation [21] implies that licensor must be better-off after the transfer of technology given belief $\mu(F_0)$.

If $F_0$ is the equilibrium fixed fee at which technology is transferred by type $c_1$, then

$$\Pi_1^F - F_0 \geq \Pi_1(c_1), \ \ or \ \ \frac{a^2}{9} - F_0 \geq \frac{(2a - 3c_1 - Ec_1|_{\mu(F_0)})^2}{36}, \tag{22}$$

and $F_0$ is also the pay-off maximizing offer of type $c_1$. Here $\Pi_1^F - F_0$ is the net benefit of licensee if the offer is accepted. If the offer is rejected licensee gets $\Pi_1(c_1)$. Relation [22] implies that licensee must also be better-off after the transfer of technology given belief $\mu(F_0)$ of licensor. Notice that if $c_1 = \hat{c}_1$ offers $F_0$ that licensor accepts, then the higher cost-types, $c_1 \in (\hat{c}_1, \bar{c}_1)$, also have an incentive to offer $F_0$, since $\Pi_1(c_1)$ falls as $c_1$ increases given $\mu(F_0)$.

Suppose relation [21] holds with strict inequality, i. e.

$$\frac{a^2}{9} + F_0 > \frac{(a + Ec_1|_{\mu(F_0)})^2}{9}, \tag{23}$$

then there exists $F_1 = F_0 - \varepsilon$, $\varepsilon > 0$, such that

$$\frac{a^2}{9} + F_1 > \frac{(a + Ec_1|_{\mu(F_0)})^2}{9}. \tag{24}$$

Since, the strategies are weakly monotone and $F_1 < F_0$, it must be the case that $Ec_1|_{\mu(F_1)} \leq Ec_1|_{\mu(F_0)}$. The choice of the offer (F) in the contract by licensee reveals that the lower cost type will always choose a lower (weakly) fixed-fee, compared to a higher cost type. Thus,

$$\frac{\left(a+Ec_1|_{\mu(F_0)}\right)^2}{9} \geq \frac{\left(a+Ec_1|_{\mu(F_1)}\right)^2}{9}$$

$$\Leftrightarrow \frac{a^2}{9}+F_1 > \frac{\left(a+Ec_1|_{\mu(F_1)}\right)^2}{9}.$$

The above relation implies that licensor will definitely accept $F_1$ and technology will be transferred if relation [23] holds. Hence, if an equilibrium exists at which technology is transferred at $F_0 > 0$, then it must be the case that

$$\frac{a^2}{9}+F_0 = \frac{\left(a+Ec_1|_{\mu(F_0)}\right)^2}{9}. \qquad [25]$$

Otherwise, licensee will always offer a lower fixed-fee such that the technology is transferred. Notice that if licensor accepts any $F_1(<F_0)$, then every type who offers $F_0$ has the incentive to offer $F_1$. Then, $F_0$ cannot be an equilibrium. Hence, for $F_0$ to be part of an equilibrium at which transfer takes place, licensor must reject any offer below $F_0$. Hence, if $\hat{c}_1$ is the lowest type that offers $F_0$, then $\hat{c}_1$ must be indifferent between acceptance at $F_0$ and rejection of the offer below $F_0$. Therefore,

$$\Pi_1^F - F_0 = \Pi_1(\hat{c}_1), \ or \ \frac{a^2}{9} - F_0 = \frac{\left(2a-3\hat{c}_1-Ec_1|_{\mu(F<F_0)}\right)^2}{36} \qquad [26]$$

where $Ec_1|_{\mu(F<F_0)} < Ec_1|_{\mu(F_0)} = \frac{\hat{c}_1+\bar{c}_1}{2}$, as the strategy is monotonic. Since, every cost-type $c_1 \in [\hat{c}_1, \bar{c}_1)$ also offers $F_0$, the updated belief of licensor ($\mu(F_0)$) is as follows: $c_1$ is uniformly distributed in $[\hat{c}_1, \bar{c}_1)$ and hence $Ec_1|_{\mu(F<F_0)} < \hat{c}_1$. From eq. [26]

$$F_0 = \frac{a^2}{9} - \frac{\left(2a-3\hat{c}_1-Ec_1|_{\mu(F<F_0)}\right)^2}{36} = F_{01}(say), \qquad [27]$$

where $F_{01}$ is the maximum offer by licensee. On the other hand from eq. [25] we have

$$F_0 = \frac{\left(a+\frac{\hat{c}_1+\bar{c}_1}{2}\right)^2}{9} - \frac{a^2}{9} = F_{02}, \qquad [28]$$

where $F_{02}$ is the minimum fixed-fee to be offered to licensor such that it accepts the offer. However, as $F_{01} < \frac{a^2}{9} - \frac{(2a-4\hat{c}_1)^2}{36} < F_{02}$, therefore $F_0\ (>0)$ does not exist such that technology is transferred.

Let us now assume that all the cost-types offer $F=0$. Then the belief ($\mu$) of licensor remains unaffected and assumes that $c_1$ is distributed uniformly in $(0, \bar{c}_1)$. Then

$$\Pi_2^F + F < E\Pi_2, \ or \ \frac{a^2}{9} < \frac{\left(a+Ec_1|_{\mu(F=0)}\right)^2}{9}, \qquad [29]$$

where $\Pi_2^F = \frac{a^2}{9}$ is the net benefit of licensor if it accepts the offer as $F = 0$. If the offer is rejected licensor gets $E\Pi_2$. The above relation [29] implies that licensor must always reject the offer given belief, $\mu(F = 0)$, after observing $F = 0$. Hence, $F = 0$ is the equilibrium, but the technology will never be transferred as licensor will always reject the offer.

**Proposition 3:** *Technology will not be transferred as the licensee will offer $F = 0$ which the licensor always rejects.*

This happens, because the expected profit of licensor if it rejects the offer ($F_0 > 0$) is always more than its expected profit in the pre-licensing stage, as then according to the belief the expected cost of licensee ($Ec_1|_{\mu(F_0)}$) is greater than $Ec_1|_{\mu}$. After receiving any offer ($F_0 > 0$), thus the reservation pay-off of licensor is much higher than what it gets in the pre-licensing stage, as it consider that licensee's unit cost is much higher ($c_1 \geq \hat{c}_1$). Moreover, for the transfer of technology, the profit of licensor if the offer is accepted must be more than the expected profit (reservation pay-off) if its reject the offer. This demands a very high fixed-fee ($F_{02}$), which is not possible for licensee to offer to license-in the technology. This implies that the licensor's gain is necessarily lower than the licensor's loss, and so no mutually agreeable lump-sum transfer can exist. This happens in case of fixed-fee licensing as after the transfer of technology the firms produce at zero cost, which increases the competition in the market and drives down the profit of licensor.

An important observation in the literature is that if the costs are common knowledge, under fixed-fee licensing, the low-cost will license its technology if the cost difference is low. However, from Proposition 1 & 3 it can be argued that if the cost of licensee is private knowledge, fixed-fee licensing will not ensure the transfer of technology irrespective of the cost difference between the firms.

## 4.2 Royalty Licensing

Consider now that the licensee first makes an offer of a per-unit royalty ($r$) to license-in the technology. Once again, after observing the offer $r$ made by licensee, licensor updates its belief and then decides whether to accept the offer or reject it. We denote the updated belief of licensor about licensee's costs after receiving the offer $r$ as $\mu(r)$. If licensor accepts the offer, the technology is transferred and a complete information Cournot game is played in the final stage. If licensor rejects the offer, then an asymmetric information Cournot game is played in the final stage with $\mu(r)$ being licensor's belief. We consider equilibrium in (weakly) monotonic strategies, i. e. higher cost types offer weakly higher royalties.

Suppose there exists an equilibrium in which the technology is transferred at $r = r_0$ $(>0)$. Then, it must be

$$\Pi_2^R \geq E\Pi_2|_{\mu(r_0)}, \ or \ \frac{(a+r_0)^2}{9} + \frac{r_0(a-2r_0)}{3} \geq \frac{(a+Ec_1|_{\mu(r_0)})^2}{9}, \tag{30}$$

where $\Pi_2^R = \frac{(a+r_0)^2}{9} + \frac{r_0(a-2r_0)}{3}$ is the profit of licensor after the transfer of technology via royalty if its accepts the offer. If the offer is rejected licensor gets $E\Pi_2|_{\mu(r_0)}$. The above relation [30] implies that licensor must be better-off after the transfer of technology given belief $\mu(r_0)$.

From the perspective of licensee it can be argued that if $r = r_0$ is the equilibrium such that technology is transferred then

$$\Pi_1^R \geq \Pi_1(c_1), \ or \ \frac{(a-2r_0)^2}{9} \geq \frac{(2a-3c_1-Ec_1|_{\mu(r_0)})^2}{36}, \tag{31}$$

where $\Pi_1^R = \frac{(a-2r_0)^2}{9}$ is the profit of licensee if the offer is accepted. If the offer is rejected licensee gets $\Pi_1(c_1)$. Relation [31] implies that licensee must also be better-off after the transfer of technology given belief $\mu(r_0)$ of licensor. Notice that if $c_1 = \hat{c}_1$ offers $r_0$, such that licensor accepts, then the higher cost-types, $c_1 \in (\hat{c}_1, \bar{c}_1)$, also have an incentive to offer $r_0$. Since, $\Pi_1(c_1)$ falls as $c_1$ increases given $\mu(r_0)$.

Given our assumption about monotonic strategies, it must be true that if $r_1 < r_0$, then $Ec_1|_{\mu(r_1)} \leq Ec_1|_{\mu(r_0)}$. Moreover, if there exists $r_1(<r_0)$, which licensor accepts, then $r_0$ cannot be an equilibrium. This is because, every cost type that offers $r_0$ has an incentive to offer $r_1$ and increase its pay-off (as discussed in the previous section). Thus, if $r_0$ is an equilibrium offer, then it must be the case that any offer below $r_0$ is rejected by licensor.

Suppose, $\hat{c}_1$ is the lowest cost type that offers $r_0$. Then, $\hat{c}_1$ must be indifferent between acceptance by licensor at $r_0$ and rejection. Hence, it must be true that

$$\begin{aligned} &\frac{(a-2r_0)^2}{9} = \frac{(2a-3\hat{c}_1-Ec_1|_{\mu(r<r_0)})^2}{36} = \frac{1}{36}\left[2a-3\hat{c}_1-\frac{\hat{c}_1}{2}\right]^2 \\ &or, \ r_0 = \frac{7\hat{c}_1}{8}, \end{aligned} \tag{32}$$

as $Ec_1|_{\mu(r<r_0)} = \frac{\hat{c}_1}{2}$, since in equilibrium every type above $\hat{c}_1$ offers $r_0$ (and due to the assumption of uniform distribution).[19] Moreover, if $c_1 < \hat{c}_1$ then firm will set

19 This is because after receiving any offer below $r_0$, where $r_0$ (say) is the equilibrium offer of the cost type $\hat{c}_1$, licensor cannot separate the types whose cost are below $\hat{c}_1$, as the higher cost type in this range will mimic the firm whose cost is close to zero.

$r < r_0$ as $Ec_1|_{\mu(r<r_0)} = \frac{\hat{c}_1}{2} < Ec_1|_{\mu(r_0)} = \frac{\hat{c}_1 + \bar{c}_1}{2}$. In such a situation licensee will be better-off than in the pre-licensing stage as the profit of licensee in absence of licensing decreases in $Ec_1$ (see eq. [3]). On the other hand for $c_1 > \hat{c}_1$, comparing eqs [3] and [32], it can be said that licensee is better-off after licensing than in the pre-licensing stage as it results in higher profits to licensee.

Since, licensee makes offer and lowering $r$ increases licensee's pay-off on acceptance, $\hat{c}_1$ will choose $r_0$ so that licensor weakly accepts $r_0$. Thus, in equilibrium $r_0$ must be such that

$$\Pi_2^R = E\Pi_2|_{\mu(r_0)} \Rightarrow 9a^2 + 20a\hat{c}_1 + 4\hat{c}_1{}^2 - 80ar_0 + 80r_0^2 = 0, \qquad [33]$$

where $E\Pi_2|_{\mu(r_0)} = \frac{(a + Ec_1|_{\mu(r_0)})^2}{9}$ is the expected profit of licensor if it rejects the offer, given the expected cost according to the belief is $Ec_1|_{\mu(r_0)} = \frac{\hat{c}_1 + \bar{c}_1}{2}$ (observing $r_0$ licensor believes that $c_1$ is distributed uniformly in $[\hat{c}_1, \bar{c}_1)$), and the profit of licensor after the transfer of technology is $\Pi_2^R = \frac{(a + r_0)^2}{9} + \frac{r_0(a - 2r_0)}{3}$.

Substituting eq. [32] in eq. [33], we find two values of $\hat{c}_1$ say $c_1{}^a$ and $c_1{}^b$ in $(0, \bar{c}_1)$ such that eq. [33] is satisfied. When $\hat{c}_1 = c_1{}^b = 0.28897a$ (Case B), then $r_0 = r_b = 0.25284a$ and when $\hat{c}_1 = c_1{}^a = 0.477304a$ (Case A), then $r_0 = r_a = 0.41764a$ (from eq. [32]). Therefore, multiple equilibria exist in this context that such technology is transferred if $c_1 \in [\hat{c}_1, \bar{c}_1)$, where $\hat{c}_1$ can be $c_1{}^a$ or $c_1{}^b$.

**Proposition 4:** *When the licensor makes the first offer, there exist two equilibria at which technology is transferred under royalty licensing.*

This happens, because the expected profit of licensor if it rejects the offer ($r_0 > 0$) is always more than its expected profit in the pre-licensing stage, as then according to the belief the expected cost of licensee ($Ec_1|_{\mu(r_0)}$) is greater than $Ec_1|_{\mu}$. This happens due to adverse selection, as the higher cost type also offer $r_0$ to mimic $\hat{c}_1{}^{th}$ type. After receiving any offer ($r_0 > 0$), thus the reservation pay-off of licensor is much higher than what it gets in the pre-licensing stage. Further, for the transfer of technology, the profit of licensor if the offer is accepted must be more than the expected profit (reservation pay-off) if its reject the offer. These phenomena are true also in fixed-fee licensing. This demands a very high royalty rate ($r_b$ or $r_a$), which is possible for licensee to offer to license-in the technology. This happens in the case of royalty licensing as after the transfer of technology the licensee produces at $r_0$, which decreases the competition in the market and increases the profit of licensor. However, in case of fixed-fee licensing both the firms produce at zero cost if the technology is transferred, which increases competition in the market and reduces the profit of licensor (excluding fee). This demands very high fixed-fee which is not possible (incentive compatible) for licensee to offer.

If the information is complete, under royalty licensing, licensor will license its technology to licensee if the innovation is non-drastic ($0 < c_1 < \bar{c}_1$). Contrarily, under royalty licensing if licensee offers a per-unit royalty and begins the contract, when the cost of licensee is private knowledge, technology will be transferred only if the cost difference between the firms is sufficiently high as it demands higher royalty rates (which higher cost types can only offer) such that it is accepted by licensor. Contrary to what happens if the information is complete, the presence of private information restricts the possibility of transfer via royalty for $c_1 \in (0, \hat{c}_1)$. Moreover, the present analysis shows that the licensee will also prefer royalty licensing in comparison to fixed-fee licensing or licensing by a combination of fixed-fee and per-unit royalty (two-part tariff).[20]

### 4.2.1 Comparing Incentives to Offer

Finally from Proposition 2 & 4, we conclude that under royalty licensing when the cost of licensee is private knowledge, technology will be transferred only if the cost difference between the firms is high.[21] This result holds irrespective of who offers first, either licensee or licensor. In the present context as the information to licensee is private,[22] licensee behaves differently in different cost ranges, but licensor behaves uniformly and would offer $r_2$ based on the prior belief. As it has been said that royalty licensing is always preferred by both the firms, here we discuss which firm has the bigger incentive to offer a contract, the licensee or the licensor, in the context of royalty licensing.

In this regard it can be said that if $c_1 \in (0, {c_1}^b)$, then any offer $r < r_b (< r_2)$, will be rejected by licensor, but still licensee gains as it signals that it has a lower cost and licensor will loose, as the expected profit of licensor is positively related to the expected cost of licensee. In this cost range the offer of licensor ($r_2$) will also be rejected by licensee, hence licensee will gain and licensor will lose as argued before. On the other hand, if $c_1 \in [{c_1}^b, \hat{c}_1(r_2))$, the offer of licensor ($r_2$) will be rejected by licensee, with similar effects on the profits of the firms. However, licensee will offer $r_b$ and licensor will accept (both the firms are better-off in comparison to pre-licensing stage). Lastly, for the higher cost ranges ($c_1 \geq \hat{c}_1(r_2)$) both the firms are always better-off, as both the firms will offer which

20 For the analysis on two-part tariff, kindly see Appendix.

21 We thank an anonymous referee of this journal for suggesting to compare the incentives of the firms to offer a contract.

22 We assume that licensee will offer the lower royalty rates $r_b$, even if $c_1 \geq {c_1}^a$, as it is acceptable by licensor.

is accepted by the other firm. However, licensee likes to offer first as in such case it has to pay a lower royalty rate.

Moreover, the expected profit of licensor, if licensee offers (ex-ante) is

$$E\Pi_2^\star = \int_0^{\hat{c}_1} E\Pi_2|_{\mu(r<r_b)} f(c_1)dc_1 + \int_{\hat{c}_1}^{\bar{c}_1} \Pi_2^R(r_b) f(c_1)dc_1$$
$$= \frac{1}{9\bar{c}_1}\left[\hat{c}_1\left(a+\frac{\hat{c}_1}{2}\right)^2 + (\bar{c}_1-\hat{c}_1)\left(a+\frac{\bar{c}_1+\hat{c}_1}{2}\right)^2\right] = 0.1753a^2, \quad [34]$$

such that any offer for which $r<r_b$ is rejected and $r=r_b$ is accepted. Comparing with the expected profit of licensor ($J(r_2)$ [23]) if it offers $r_2$, with the expected profit of licensor if licensee offers ($E\Pi_2^\star$), we find that $E\Pi_2^\star > J(r_2) = 0.17505a^2$. This, implies that licensor has no incentive to offer first. Licensee will offer first always and technology will be transferred if $r=r_b$ or $c_1 \geq c_1{}^b$.

## 4.3 Welfare Analysis

As we observe the presence of a multiple equilibrium in the case of royalty licensing, we discuss the impact on the welfare for the equilibrium Case B as for Case A we observe a similar result. Consider Case B, where $\hat{c}_1 = c_1{}^b = 0.28897a$ and $r_0 = r_b = 0.25284a$. If $c_1 \geq \hat{c}_1 = 0.28897a$, then technology will be transferred at per-unit royalty $r_b = 0.25284a$ and the industry output will be

$$q_1 + q_2 = \frac{a-2r_b}{3} + \frac{a+r_b}{3} = 0.58239a. \quad [35]$$

On the other hand in the pre-licensing situation the industry output is

$$q_1^\star(c_1) + q_2^\star = \frac{4a-3c_1+Ec_1|_\mu}{6} = \frac{17a-12c_1}{24} \quad [36]$$

where $Ec_1|_\mu = \frac{\bar{c}_1}{2} = \frac{a}{4}$. Comparing eqs [35] and [36], it can be said that if $c_1 \geq \hat{c}_1$, then the realized output in the pre-licensing case is always less than the output after the transfer of technology. On the other hand, if $c_1 < \hat{c}_1$, technology will not be transferred as licensor will reject the offer of licensee $(r<r_b)$, then the industry output will be

$$q_1^\star(c_1) + q_2^\star = \frac{4a-3c_1+Ec_1|_{\mu(r<r_b)}}{6} = \frac{4.14449a-3c_1}{6} \quad [37]$$

**23** See eq. [16].

where $Ec_1|_{\mu(r<r_b)} = \frac{\hat{c}_1}{2} = 0.14449a$. Comparing eqs [35], [36] and [37], it can be said that the realized output in the pre-licensing stage is always less than the expected output (ex-ante) if licensee offers. This implies that the expected industry output as well as the consumer surplus will always be more, if licensee offers any $r$ for licensing-in the technology, than in the pre-licensing stage.

Moreover, as the expected profit of licensor if licensee offers, is greater than the expected profit of licensor in the pre-licensing stage ($E\Pi_2^* > E\Pi_2$, see eqs [34] and [3]), licensor is also better-off compared to the pre-licensing stage if licensee offers first. The realized profit of licensee also increases after the offer, not only when the offer is rejected by licensor, but also when it is accepted. Therefore, the social welfare (ex-ante offer by licensee) is more than in the pre-licensing stage, as the expected industry profit and the expected consumer surplus are also more than in the pre-licensing stage.

# 5 Role of Inspection

Since technology is not transferred by fixed-fee (see Proposition 1 & 3), this section discusses the implications of fixed-fee licensing contract, if licensee allows licensor to inspect its technology (royalty licensing is discussed later). This section re-examines the fixed-fee licensing contract when licensee decides whether to allow licensor to inspect its technology before the offer is made.

**The game has the following stages:**
Stage 1: Licensee decides whether to allow inspection of technology by licensor.
Stage 2: Licensor decides whether to undertake inspection.
Stage 3: Licensee makes the offer $F$.
Stage 4: Licensor either accepts or rejects the offer.[24]
Stage 5: Outputs are produced and profits realised.

**Description of the game:**
Licensee first decides whether to allow inspection ($I_1$) or not ($N_1$). If licensee allows inspection ($I_1$), then in stage 2 licensor either inspects ($I_2$) the technology of licensee or does not ($N_2$). Licensor incurs a cost $(K)$ if it inspects technology of licensee. Licensee in stage 3 offers a fixed-fee ($F \geq 0$). Observing $F$, in stage 4 licensor either accepts ($A$) or rejects ($R$) the offer and updates its belief about

24 If we assume instead that in stage 3, licensor makes the offer $F$ and in stage 4 licensee either accepts or rejects the offer, then also the major findings of this section remains unchanged.

licensee's type. If licensor accepts the offer both firms produce with zero unit cost in stage 5. If the offer is rejected the firms produce output under incomplete information in stage 5.

**Strategy of licensee:**
As in the previous section the present section also focuses on the equilibrium in monotonic strategy:

i) *Licensee chooses* $I_1$ if and only if $c_1 \le \tilde{c}_1$.
ii) *If* $c_1^1$ *offers* $F_1$, $c_1^0$ *offers* $F_0$ *and* $F_1 \le F_0$ *then* $c_1^1 \le c_1^0$.

## 5.1 Inspection not Allowed

Suppose licensee doesn't allow inspection. In this case, licensor believes that $c_1$ is uniformly distributed in $(\tilde{c}_1, \bar{c}_1)$.[25] Following the same argument as in Section 4.1, it can be shown that there doesn't exist any $F > 0$ at which technology is transferred. This means that in equilibrium, the profits of licensee and licensor are

$$\Pi_1(c_1) = \left(\frac{2a - 3c_1 - \frac{\tilde{c}_1 + \bar{c}_1}{2}}{6}\right)^2 \text{ and } E\Pi_2 = \frac{\left(a + \frac{\tilde{c}_1 + \bar{c}_1}{2}\right)^2}{9} \qquad [38]$$

respectively.

## 5.2 Inspection Allowed

If licensee allows inspection ($I_1$) then the licensor may either inspect ($I_2$) or not ($N_2$).

### 5.2.1 Inspection not Undertaken

Let us begin with the case when inspection is not undertaken by the licensor ($N_2$) (presumably because $K$ is very large). If inspection is allowed, licensor believes that $c_1 \in (0, \tilde{c}_1]$ and uniformly distributed. Once again, it can be showed that there doesn't exist any $F > 0$ at which technology is transferred as in Section 4.1. This means that in equilibrium, the profits of licensee and licensor are

25 Throughout this section we assume that in equilibrium beliefs are updated following Bayes' Rule from the strategies.

$$\Pi_1(c_1) = \left(\frac{2a - 3c_1 - \frac{\tilde{c}_1}{2}}{6}\right)^2 \textit{and } E\Pi_2 = \frac{\left(a + \frac{\tilde{c}_1}{2}\right)^2}{9} \qquad [39]$$

respectively.

### 5.2.2 Inspection Undertaken

Let us consider that licensor decides to inspect the technology, thereby incurring a cost $K$, when inspection is allowed ($I_1$). This implies that after inspection the costs are common knowledge. In such a situation $\frac{(a-2c_1)^2}{9}$ and $\frac{(a+c_1)^2}{9}$ are the profits of licensee and licensor respectively in absence of licensing. Licensee will hence set $F$ as low as possible such that licensor weakly accepts the offer i. e.

$$\Pi_2^F + F = \frac{(a+c_1)^2}{9} \Rightarrow F^\star = \frac{(a+c_1)^2}{9} - \frac{a^2}{9}, \qquad [40]$$

Therefore, under such an offer of fixed-fee ($F^\star$) licensee will get

$$\Pi_1^F - F^\star = \frac{2a^2}{9} - \frac{(a+c_1)^2}{9}.$$

Hence, technology will be transferred if $\Pi_1^F - F^\star \geq \frac{(a-2c_1)^2}{9}$ or $c_1 \leq \frac{2a}{5}$.

## 5.3 Inspection Decision of Licensor

We now consider the licensor's inspection decision when inspection is allowed. In this case licensor believes that $c_1$ is uniformly distributed in $(0, \tilde{c}_1]$. If licensor chooses $N_2$ then its expected profit will be

$$E\Pi_2 = \frac{\left(a + \frac{\tilde{c}_1}{2}\right)^2}{9}. \qquad [41]$$

On the other hand, if licensor inspects ($I_2$), it gets $\frac{(a+c_1)^2}{9}$.[26] Therefore, its expected profit from inspection is

$$\int_0^{\tilde{c}_1} \frac{(a+c_1)^2}{9} \cdot \frac{1}{\tilde{c}_1} dc_1 - K. \qquad [42]$$

26 This is what licensor gets whether technology is transferred or not, because if technology is transferred licensee will set the fixed-fee as low as possible such that licensor remains indifferent between licensing and no-licensing.

Comparing eqs [41] and [42], it can be argued that licensor will inspect if and only if $K \le \frac{\tilde{c}_1^{\,2}}{108}$.

## 5.4 Licensee's Decision in Stage 1

In the first stage licensee decides whether to allow inspection of the technology. Notice that for consistency of belief, it must be the case that in equilibrium $\tilde{c}_1$ type must be indifferent between $I_1$ and $N_1$. If $\tilde{c}_1$ type chooses $N_1$, its pay-off is

$$\Pi_1^N(\tilde{c}_1) = \left(\frac{2a - 3\tilde{c}_1 - \frac{\tilde{c}_1 + \bar{c}_1}{2}}{6}\right)^2. \qquad [43]$$

If $\tilde{c}_1$ type chooses $I_1$ and licensor doesn't inspect $\left(K > \frac{\tilde{c}_1^{\,2}}{108}\right)$, then the profit of $\tilde{c}_1$ type licensee is

$$\Pi_1^I(\tilde{c}_1) = \left(\frac{2a - 3\tilde{c}_1 - \frac{\tilde{c}_1}{2}}{6}\right)^2. \qquad [44]$$

Since in this case $\Pi_1^I(\tilde{c}_1) > \Pi_1^N(\tilde{c}_1)$ for every $\tilde{c}_1 \in [0, \bar{c}_1)$, licensee will always allow inspection.

On the other hand, if licensor inspects in stage 2 $\left(K \le \frac{\tilde{c}_1^{\,2}}{108}\right)$, then technology is transferred if and only if $c_1 \le \frac{2a}{5}$. Notice that here the output game that follows is played under complete information. If $\tilde{c}_1 > \frac{2a}{5}$, then technology will not be transferred post agreement and licensee's profit is $\frac{(a-2\tilde{c}_1)^2}{9}$. It can be easily verified that $\frac{(a-2\tilde{c}_1)^2}{9} > \Pi_1^N(\tilde{c}_1)$ for $0 < \tilde{c}_1 < \bar{c}_1$ and $\frac{(a-2\tilde{c}_1)^2}{9} = \Pi_1^N(\tilde{c}_1)$ if $\tilde{c}_1 = \bar{c}_1$. Suppose $\tilde{c}_1 \le \frac{2a}{5}$. In this case, $\tilde{c}_1$ type licensee definitely is strictly better off from allowing inspection since it extracts the surplus completely from the transfer agreement (since $\Pi_1^F - F^* > \frac{(a-2\tilde{c}_1)^2}{9}$). Hence, in equilibrium, every $c_1 \in [0, \bar{c}_1)$ allows inspection, which is discussed in the following proposition.

**Proposition 5:** *Under fixed-fee licensing, if the cost of the licensee is private knowledge, the licensee will always allow the licensor to inspect its technology before licensing.*

This idea is in consonance to Shapiro (1986) where firms decide for sharing their private information about their costs with one another. As a licensee with lower cost will always allow inspection, and it thereby induces the higher cost types to do so. This type of behaviour is observed in the present model from a lower cost type firm (licensee), as the act of allowing inspection easily passes important signal to the licensor, that the licensee has a lower cost. However, the licensor does not get any additional information regarding the licensee's cost if it does not inspect, as all the cost types at the equilibrium will allow inspection.

## 5.5 Final Inspection Decision of Licensor

Notice that since all cost types allow inspection (see Proposition 5), $\tilde{c}_1 = \bar{c}_1 = \frac{a}{2}$ is the modified belief (strategy). If licensor does not inspects ($N_2$), then its expected profit will be

$$E\Pi_2 = \frac{(a + Ec_1)^2}{9} = \frac{25a^2}{144} \qquad [45]$$

as technology will not be transferred, where $Ec_1 = \frac{\bar{c}_1}{2}$ is the expected cost of licensee according to the updated belief of licensor. On the other hand if licensor inspects ($I_2$), it gets $\frac{(a+c_1)^2}{9}$,[27] therefore its expected profit from inspection is

$$\int_0^{\bar{c}_1} \frac{(a + c_1)^2}{9} f(c_1) dc_1 - K = \frac{19a^2}{108} - K \qquad [46]$$

where $f(c_1) = \frac{\bar{c}_1}{2}$ is the density as $c_1$ is distributed uniformly in $(0, \bar{c}_1)$. If $K \le \frac{a^2}{432}$, then the expected profit from inspection ($I_2$) is always greater than $N_2$, i. e. $\frac{25a^2}{144}$. Hence, if the inspection cost ($K$) is less licensor will always inspect and the technology will be transferred if the cost difference is less or $c_1 \le \frac{2a}{5}$. This proves that if under fixed-fee licensing the cost difference is low, then only the technology may be transferred even when the technologically backward firm's cost is privately known. Contrarily, if the inspection cost is high, licensor will not inspect ($N_2$) and the technology will not be transferred. Hence, licensor undertakes inspection if and only if $K \le \frac{a^2}{432}$.

**Proposition 6:** *Under fixed-fee licensing technology will be transferred, when the cost of licensee is private knowledge, if and only if*
i. *inspection cost (K) of licensor is low and*
ii. *the cost difference between the firms is less or* $c_1 \le \frac{2a}{5}$.

The above proposition states that licensing is only possible if the low-cost firm inspects. If inspection is allowed and carried on, technology transfer via fixed-fee will take place if the cost difference between the firms is low.

27 This is what licensor gets whether technology is transferred or not, as argued before.

## 5.6 Welfare Analysis

Let us now consider the impact on the welfare if $K \le \frac{a^2}{432}$, such that licensor inspects. After inspection, if it is observed that $c_1 \le \frac{2a}{5}$, technology will be transferred, thus the industry output will be $q = q_1 + q_2 = \frac{2a}{3}$ and the consumer surplus will be $CS = \frac{2a^2}{9}$. However, if $c_1 > \frac{2a}{5}$, as technology will not be transferred the industry output is $q = q_1 + q_2 = \frac{2a - c_1}{3}$ and the consumer surplus is $CS = \frac{(2a - c_1)^2}{18}$. Hence, the Expected CS (ex-ante inspection) is

$$\begin{aligned} ECS &= \int_0^{\frac{2a}{5}} CSf(c_1)dc_1 + \int_{\frac{2a}{5}}^{\bar{c}_1} CSf(c_1)dc_1 \\ &= \frac{1}{\bar{c}_1}\int_0^{\frac{2a}{5}} \frac{2a^2}{9} dc_1 + \frac{1}{\bar{c}_1}\int_{\frac{2a}{5}}^{\bar{c}_1} \frac{(2a - c_1)^2}{18} dc_1 = 0.20448a^2. \end{aligned} \tag{47}$$

Moreover, after inspection the industry profit (IP) is $\frac{2a^2}{9}$ if $c_1 \le \frac{2a}{5}$ and $\frac{(a + c_1)^2}{9} + \frac{(a - 2c_1)^2}{9}$ otherwise. Therefore, the Expected IP (ex-ante inspection) is

$$\begin{aligned} EIP &= \int_0^{\frac{2a}{5}} IPf(c_1)dc_1 + \int_{\frac{2a}{5}}^{\bar{c}_1} IPf(c_1)dc_1 \\ &= \frac{1}{\bar{c}_1}\int_0^{\frac{2a}{5}} \frac{2a^2}{9} dc_1 + \frac{1}{\bar{c}_1}\int_{\frac{2a}{5}}^{\bar{c}_1} \left[\frac{(a + c_1)^2}{9} + \frac{(a - 2c_1)^2}{9}\right] dc_1 = 0.22482a^2. \end{aligned} \tag{48}$$

Hence, the Expected Welfare (ex-ante inspection) is $EW = ECS + EIP = 0.4293a^2 - K$.

On the other hand if $K$ is high, such that licensor does not inspect, then technology will never be transferred and the belief of licensor is not updated. In such a context, the actual welfare is $W_{PL}$ and the Expected Welfare is $EW_{PL} = 0.37934a^2$ (see eq. [7]). Moreover, as $EW > EW_{PL}$ for any $K \le \frac{a^2}{432}$, inspection is always welfare improving in the present model.

## 5.7 Role of Inspection: Per-Unit Royalty

In the present section we discuss what will happen if licensee intends to pay a per-unit royalty instead of a fixed-fee.[28] As the idea is more or less similar to the previous case, where we have discussed the role of inspection and licensing via fixed-fee, here we present the observation analogically restraining from its intricacies.

**28** Two-part tariff is also not possible in the present context.

Similar to what has been observed in case of fixed-fee licensing, it can be shown that if the cost information of the licensee is private, the licensee will always allow the licensor to inspect its technology before licensing. This is because, a licensee with lower cost (close to zero) will always allow inspection, and this will induce higher cost types to do so. As licensee will always allow the other firm to inspect its cost, licensor will do so only if the inspection cost ($K$) is low. Moreover, under royalty licensing, technology will always be transferred if licensor inspects. This is because, when the cost information is complete, technology is always transferred via per-unit royalty (see Wang (1998)). However, if licensor does not inspect (if $K$ is much higher) then we get an exactly similar result as discussed in Proposition 4, but this is starkly opposite to what happens in case of fixed-fee licensing. If licensor restrains from the inspection and the licensee makes the first offer, there exist two equilibria at which technology is transferred under royalty licensing. If instead of licensee, licensor makes the first offer in the second stage (if the inspection is not undertaken), then also technology will be transferred if and only if the cost difference is high as discussed in Proposition 2. Moreover, inspection is always welfare improving in the present model, as it has been observed in case of fixed-fee licensing.

# 6 Conclusion

This paper extends the technology licensing scheme in Cournot duopoly model under incomplete cost information, where only the cost of the licensee (high-cost firm) is privately known. It is shown that technology is never transferred via fixed-fee if inspection of the licensee's technology by the licensor (low cost-firm) is not possible. On the other hand, is such a set-up, in the case of royalty licensing if the low-cost firm charges a per-unit royalty and begins the contract, technology will be transferred only if the cost difference between the firms is sufficiently high. Similarly, under royalty licensing if the high-cost firm offers a per-unit royalty and begins the contract technology will be transferred only if the cost difference between the firms is sufficiently high. In the following *Appendix* it is also shown that two-part tariff is not possible.

If the information is complete, then royalty licensing is always possible (whoever offers first: licensor or licensee). However, fixed-fee licensing is possible in such context, only if the cost difference between the firms is low. The possibility of fixed-fee licensing vanishes if the licensee's initial unit cost is too high, as it leads to severe competition in the market for which the industry profit falls after the technology is licensed. Hence, it is meaningful to verify whether in the present context licensing is actually possible via fixed-fee. Cournot markets do not provide adequate gains in producer surplus to incentivize fixed-fee licensing in the presence of incomplete information. Therefore, in comparison to what happens if the information is complete, fixed-fee licensing is never possible in the present model.

However, if inspection of the licensee's technology by the licensor is possible, then the licensee will always allow the licensor to inspect its technology irrespective of its cost and the form of licensing. This therefore highlights the role of inspection, which the high-cost firm uses as a signal to show that it has a lower unit cost. If the licensor inspects, then the technology is transferred via fixed-fee is the cost difference between the firms is low and via royalty technology is always transferred. However, if the licensor does not inspect, then technology is never transferred via fixed-fee. On the other hand, if the inspection is not undertaken, technology is transferred via royalty if the cost difference between the firms are high. If anyone of the firms offers first for the transfer of technology, welfare increases not only when inspection is possible, but also when it is not.

As a possible extension of the present model one might consider competitors with differentiated products. If the goods are differentiated and the information is complete, it is shown by Wang (2002) and Fauli-Oller and Sandonis (2002), that non-royalty contracts (fixed-fee or two-part tariff) may be superior to royalty licensing for the licensor. If the goods are highly differentiated, fixed-fee licensing will always be possible and preferable to royalty licensing. On the other hand, if the goods are slightly differentiated royalty licensing is preferable to the licensor. Even under incomplete information these results are likely to hold. For example, if the markets are highly differentiated (assume two separate markets: one served by the licensee and the other served by the licensor), then fixed-fee will dominate royalty as in such case royalty increases the post-licensing unit cost of the licensee and reduces the licensee's profit. Since the licensor faces no threat of competition from the licensee, it is optimal for her to maximize the licensee's profit and then extract it through fixed-fee. Thus under incomplete information, as the degree of product differentiation increases fixed-fee tends to dominate royalty in absence of the threat of competition from the licensee. Another possible future work may be to extend the current work to the case of multiple rival firms, where the owner of the innovation does not know the costs of rivals. Whether under incomplete information the innovation is completely diffused is an interesting topic that needs careful attention.

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# Appendix: Two-Part Tariff

It has been pointed out by Shapiro (1985) that "... under the antitrust laws, and for a good reason! ... a reasonable constraint to put on the two-part tariff contract is that the fixed-fee ($F$) be non-negative" and "... the licensing contract cannot raise the licensee's unit costs (production cost plus royalty ($r$))."[29] The present section therefore considers $F \geq 0$ and $c_1 \geq r \geq 0$.

## A.1 Licensor Offers

*Will the licensor first offer a two-part tariff: combination of a per-unit royalty (r) and fixed-fee (F) to license its technology?*

Licensor begins the game by offering a two-part tariff, to license its technology to licensee. Licensee accepts the offer (reject otherwise) if

$$\Pi_1^T(r,F) \geq \Pi_1(c_1) = \left(\frac{2a - 3c_1 - Ec_1|_{\mu(r,F)}}{6}\right)^2, \qquad [49]$$

where $\Pi_1^T(r,F) = \frac{(a-2r)^2}{9} - F$ is the profit of licensee after the technology is transferred and $\Pi_1(c_1)$ is its profit if the offer $(r,F)$ is rejected. The profit of licensor after the transfer of technology is $\Pi_2^T(r,F) = \frac{(a+r)^2}{9} + \frac{r(a-2r)}{3} + F$. $Ec_1|_{\mu(r,F)}$ is the expected cost of licensee given belief $\mu(r,F)$. If licensee rejects $(r,F)$, licensor believes $(\mu(r,F))$ that $c_1 \in (0, \hat{c}_1(r,F)]$ and uniformly distributed. Comparing relation [49] with eq. [3], it can be argued that licensee is better-off than under the pre-licensing stage, not only when it accepts the offer, but also when it rejects the offer. For sequential rationality of licensee's strategy, $\hat{c}_1(r,F)$ type must be indifferent between acceptance and rejection. Licensee is indifferent

29 We thank an anonymous referee and the editor of this journal for suggesting to discuss the possibility of the two-part tariff licensing in the present model.

when the in eq. [49] holds with strict equality. Since $\Pi_1(c_1)$ is a decreasing function of $c_1$, $\hat{c}_1(r,F)$ can be solved uniquely from this equality. Thus,

$$\frac{(a-2r)^2}{9} - F = \left(\frac{2a - 3\hat{c}_1(r) - Ec_1|_{\mu(r,F)}}{6}\right)^2$$

$$\text{or, } \frac{(a-2r)^2}{9} - F = \frac{(4a - 6\hat{c}_1 - \hat{c}_1)^2}{144} \tag{50}$$

where $\hat{c}_1(r,F) \le \bar{c}_1 = \frac{a}{2}$, if $r < \frac{7a}{16}$. Since $\hat{c}_1(r,F)$ is indifferent between acceptance and rejection, every $c_1 < \hat{c}_1(r,F)$ is better off by rejecting the offer and every $c_1 \ge \hat{c}_1(r,F)$ is better off by accepting the offer.

**Lemma 3:** *If $r < \frac{7a}{16}$, the offer $(r,F)$ is accepted if and only if $c_1 \ge \hat{c}_1(r,F)$.*

Hence licensor's choice of $(r,F)$, consistent with belief (Lemma 3), must maximize its expected profit given by

$$\max_{r,F} J = \int_0^{\hat{c}_1} E\Pi_2 f(c_1)dc_1 + \int_{\hat{c}_1}^{\bar{c}_1} \Pi_2^T(r,F) f(c_1)dc_1 \tag{51}$$

subject $\hat{c}_1(r,F) < \bar{c}_1$. $E\Pi_2 = \frac{(a + Ec_1|_{\mu(r,F)})^2}{9}$ is the expected profit of licensor[30] when the offer is rejected and $\Pi_2^T(r,F)$ is the profit of licensor after the technology is transferred. Using Lemma 3, the objective function of licensor reduces to

$$\max_{r,F} J = \frac{1}{9\bar{c}_1}\left[\int_0^{\hat{c}_1} \left(a + \frac{\hat{c}_1}{2}\right)^2 dc_1 + \int_{\hat{c}_1}^{\bar{c}_1} (a^2 + 5ar - 5r^2 + 9F)dc_1\right]. \tag{52}$$

We now argue that $F > 0$ cannot be part of an equilibrium. For $F = 0$, solving eq. [52], we have got optimal $r = r_2$, as discussed in the Section 3.2. Suppose on the contrary $F > 0$. Notice that licensee can raise $F$ ($dF > 0$) above 0 and lower $r$ ($dr < 0$) to keep $\hat{c}_1$ and $\Pi_1^T$ constant (and hence the belief structure of licensor remains same after rejection) such that

$$-\frac{4(a-2r)}{9}dr = dF, \tag{53}$$

which is obtained from totally differentiating eq. [50]. However, this will lower $J$ below $J(r_2,F)$ as $\Pi_2^T$ now becomes less than $\Pi_2^T(r_2,0)$. This can be seen from totally differentiating $\Pi_2^T(r,F) = \frac{(a+r)^2}{9} + \frac{r(a-2r)}{3} + F$ and substituting eq. [53]

**30** $Ec_1|_{\mu(r,F)} = \frac{\hat{c}_1}{2}$, as licensor believes that if the offer is rejected then $c_1$ is uniformly distributed in $(0, \hat{c}_1)$.

$$\begin{aligned} d\Pi_2^T &= \frac{2(a+r)}{9}dr + \frac{(a-4r)}{3}dr + dF \\ &= \frac{2(a+r)}{9}dr + \frac{(a-4r)}{3}dr - \frac{4(a-2r)}{9}dr \\ &= \frac{(a-2r)}{9}dr < 0, \end{aligned}$$

since $dr < 0$. Hence, given $\hat{c}_1$, to be the lowest-cost type who accepts the offer, keeping $\hat{c}_1$ constant, if licensor increases $F$ marginally above 0 and reduces $r$ (such that $r < r_2$), then licensor's profit will reduce below $J(r_2, 0)$. Hence, licensor will always keep $F = 0$ and charge $r_2(>0)$. This implies that two-part tariff is never possible in the present context. Thus, in an equilibrium $F$ must be equal to 0, but then we are precisely in the royalty licensing case. This argument is similar to what has been observed in Fauli-Oller and Sandonis (2002), where the licensor charges only per-unit royalty (fixed-fee zero) to transfer its technology when the cost information is complete. This happens as higher royalty rates softens competition in the market, which helps the licensor to get more profit after the technology is transferred.

## A.2 Licensee Offers

*Will the licensee first offer a two-part tariff: combination of a per-unit royalty (r) and fixed-fee (F) to license-in the technology?*

Licensee initiates the game with an offer of $(r, F)$. After observing the offer, licensor updates its belief and then decides whether to accept the offer or reject it. The updated belief of licensor about licensee's costs after receiving the offer is denoted by $\mu(r, F)$ which is clarified below in details. If licensor accepts the offer, the technology is transferred and a complete information Cournot game is played in the final stage. If licensor rejects the offer, then an asymmetric information Cournot game is played in the final stage, with $\mu(r, F)$ being licensor's belief. We consider equilibrium in (weakly) monotonic strategies, i. e. higher cost types offer weakly higher *payments* $(r, F)$. A payment is defined to be higher if licensee receives lower profit when the technology is transferred, e. g. if $\Pi_1^T(r_1, F_1) > \Pi_1^T(r_0, F_0)$, then we will call $(r_0, F_0)$ as higher payment relative to $(r_1, F_1)$. In other words, every offer $(r, F)$ corresponds to a post-transfer pay-off $\Pi_1^T(r, F)$ for licensee and we consider equilibrium in strategies in which higher cost types offer (receives itself) lower $\Pi_1^T(r, F)$.

Suppose an equilibrium exists, such that technology is transferred at $r = r_0$ and $F = F_0$. Then,

$$\Pi_2^T \geq E\Pi_2|_{\mu(r_0,F_0)},\ or\ \frac{(a+r_0)^2}{9}+\frac{r_0(a-2r_0)}{3}+F_0 \geq \frac{(a+Ec_1|_{\mu(r_0,F_0)})^2}{9}, \qquad [54]$$

where $\Pi_2^T = \frac{(a+r_0)^2}{9}+\frac{r_0(a-2r_0)}{3}+F_0$ is the profit of licensor after the transfer of technology. If licensor rejects the offer, it gets $E\Pi_2|_{\mu(r_0,F_0)}$. Moreover, for licensee if $(r_0,F_0)$ is the equilibrium such that technology is transferred, then

$$\Pi_1^T \geq \Pi_1(c_1),\ or\ \frac{(a-2r_0)^2}{9}-F_0 \geq \frac{(2a-3c_1-Ec_1|_{\mu(r_0,F_0)})^2}{36}, \qquad [55]$$

where $\Pi_1^T = \frac{(a-2r_0)^2}{9}-F_0$ is the profit of licensee if the offer is accepted. Licensee gets $\Pi_1(c_1)$ otherwise. Moreover, if $c_1=\hat{c}_1$ offers $(r_0,F_0)$ resulting in $\Pi_1^T(r_0,F_0)$ for itself which licensor accepts, then the higher cost-types, $c_1 \in (\hat{c}_1,\bar{c}_1)$, will also offer $(r_0,F_0)$, since $\Pi_1(c_1)$ falls as $c_1$ increases given $\mu(r_0,F_0)$.

Since the strategies are monotonic, it must be true that if $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$, then $Ec_1|_{\mu(r_1,F_1)} \leq Ec_1|_{\mu(r_0,F_0)}$. Moreover, if there exists $(r_1,F_1)$ such that $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$, which licensor accepts, then $(r_0,F_0)$ cannot be an equilibrium. This is because, every cost type that offers $\Pi_1^T(r_0,F_0)$ then has an incentive to offer $\Pi_1^T(r_1,F_1)$ and increase its pay-off. Thus, if $(r_0,F_0)$ is an equilibrium offer, then it must be the case that any other offer $(r_1,F_1)$, such that $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$, is rejected by licensor.

Suppose, $\hat{c}_1$ is the lowest cost type that offers $(r_0,F_0)$. We can now clarify the equilibrium belief of the licensor upon receiving an offer. If licensee offers $(r_0,F_0)$ resulting in $\Pi_1^T(r_0,F_0)$ for itself then licensor believes that $c_1 \in (\hat{c}_1,\bar{c}_1)$. For any other offer $(r_1,F_1)$ such that $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$ then licensor believes $c_1<\hat{c}_1$. This is because licensor cannot separates the types for $c_1 \in (0,\hat{c}_1)$, as the higher cost type in this range will mimic the firm whose cost is close to zero by offering lower payment.

Since $\hat{c}_1$ is the lowest cost type that offers $(r_0,F_0)$, $\hat{c}_1$ must be indifferent between acceptance of the offer by licensor and rejection, or in other words between making the offers $(r_0,F_0)$ and $(r_1,F_1)$ such that $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$. Hence, it must be true that

$$\frac{(a-2r_0)^2}{9}-F_0=\frac{(2a-3\hat{c}_1-Ec_1|_{\mu(r_1,F_1)})^2}{36}=\frac{1}{36}\left[2a-3\hat{c}_1-\frac{\hat{c}_1}{2}\right]^2, \qquad [56]$$

as $Ec_1|_{\mu(r_1,F_1)}=\frac{\hat{c}_1}{2}$, where $\Pi_1^T(r_1,F_1)>\Pi_1^T(r_0,F_0)$, since in equilibrium every type above $\hat{c}_1$ offers $(r_0,F_0)$. Since, licensee makes offer and lowering *payment* increases licensee's pay-off on acceptance, $\hat{c}_1$ will choose $(r_0,F_0)$ so that licensor weakly accepts the offer. Thus, in equilibrium $(r_0,F_0)$ must be such that

$$\Pi_2^T = E\Pi_2|_{\mu(r_0, F_0)}, \text{ or}$$

$$\frac{(a+r_0)^2}{9} + \frac{r_0(a-2r_0)}{3} + F_0 = \frac{(a+Ec_1|_{\mu(r_0,F_0)})^2}{9}, \qquad [57]$$

where $E\Pi_2|_{\mu(r_0,F_0)} = \frac{(a+Ec_1|_{\mu(r_0,F_0)})^2}{9}$ is the expected profit of licensor if it rejects the offer, given the expected cost according to the belief is $Ec_1|_{\mu(r_0,F_0)} = \frac{\hat{c}_1+\bar{c}_1}{2}$.

We now argue that $F_0 > 0$ cannot be part of an equilibrium. For $F_0 = 0$, solving eqs [57] and [56], we get two values of $r_0$ ($r_a$ and $r_b$ respectively), as discussed in the Section 4.2. Suppose on the contrary $F_0 > 0$. Notice that licensee with cost type $\hat{c}_1$ can raise $F_0$ ($dF_0 > 0$) above 0 and lower $r_0$ ($dr_0 < 0$) to keep $\Pi_1^T$ constant (and hence the belief structure of licensor remains same) such that

$$-\frac{4(a-2r_0)}{9}dr_0 = dF_0, \qquad [58]$$

which is obtained from totally differentiating eq. [56]. However, this will lower $\Pi_2^T$ below $E\Pi_2|_{\mu(r_0,F_0)}$ since $\mu(r_0, F_0)$ does not change as long as $\Pi_1^T$ remains same. This can be seen from totally differentiating the left hand side of eq. [57] and substituting eq. [58]

$$\begin{aligned} d\Pi_2^T &= \frac{2(a+r_0)}{9}dr_0 + \frac{(a-4r_0)}{3}dr_0 + dF_0 \\ &= \frac{2(a+r_0)}{9}dr_0 + \frac{(a-4r_0)}{3}dr_0 - \frac{4(a-2r_0)}{9}dr_0 \\ &= \frac{(a-2r_0)}{9}dr_0 < 0, \end{aligned}$$

since $dr_0 < 0$. Hence, given $\hat{c}_1$, to be the lowest-cost type who offers, keeping $\hat{c}_1$ constant, if licensee increases $F_0$ marginally above 0 and reduces $r_0$ (such that $r_0 < r_b$ (say) and the payment is constant), then licensor will always reject the offer. Hence, $\hat{c}_1{}^{th}$ type firm will always keep $F_0 = 0$ and charge $r_0(>0)$. This implies that two-part tariff is never possible in the present context. Thus, in an equilibrium $F_0$ must be equal to 0, but then we are precisely in the royalty licensing case.

*From the present discussion in the Appendix it can be concluded that royalty licensing is always preferred by both the firms (licensor, as well as the licensee) for the transfer of technology in the present context (see Proposition 2 & 4). This is as because licensing fails via fixed-fee (as in Proposition 1 & 3) and two-part tariff is not optimal for the firms.*

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