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# Licensing in Stackelberg markets under asymmetric information of technology value

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**Abstract:** This paper proposed a model to analyze the licensing schemes when the patentee had private information about its technology value. In this model, the patentee was considered as an insider in Homogenous Stackelberg Market instead of an independent R&D institute. Based on this model, this paper presented the patentee's optimal licensing option for maximizing its profit under the condition that the licensee may accept the contract. In the same way, this paper analyzed the fixed fee, royalty and the profit of the patentee in the model, respectively. This paper aims at proposing an idea for the participants to advance the efficiency of licensing.

**Key words:** technology quality; asymmetric information; homogeneous Stackelberg; licensing

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## 技术质量信息不对称下 Stackelberg 市场中的许可

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**摘要**: 运用数学建模和博弈论分析方法, 研究同质 Stackelberg 市场中技术许可方对其专利技术质量拥有私人信息时的许可行为. 模型中, 许可方不再是独立的研发机构, 而是作为市场中的内部创新者参与生产和竞争. 在满足被许可方能接受许可的情况下, 使许可方利润最大化, 确定固定转让费、单位转让费以及混同合约与分离合约的最优选择. 为参与主体提供理论参考, 以提高技术许可效率.

**关键词**: 技术质量; 信息不对称; 同质 Stackelberg; 许可

## 0 Introduction

Generally speaking, the patentees of licensing are divided into two kinds: the outsider and the insider. The outsiders such as R & D institutes hold patents but don't access production because they are independent of product markets. In China, technology engineering centers of colleges usually belong to this kind. The insiders are also called manufacture innovators such

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as IBM Co., ltd. and Texas Instruments Co., ltd. They are inside the market of operation and naturally become competitors in the product markets. In the chains of innovations, enterprises play important roles in product exploitation, art, mid-test, commercialization, operation and distribution. Such chains are parts of most investments and risks. As a result, the success of R&D is determined by the enterprises in licensing transactions.

It is found that during the process of technology industrialization there exist far-ranging uncertainties, including the uncertainty of the future demand in product market, the complex behavior of the competitors, and the change of economic environment. Such uncertainties will bring on asymmetric information, which is defined as that one party possesses information or knowledge unknown to the other party. People who have limited sense hardly acquire the full information on technology transactions because of uncertainties of the environment and the future. Both the patentee and the licensee have to face problems in asymmetric information. The licensee may have private information on its own production and profit by using the licensed technology. In the same way, the patentee may have private information on the value of its own technology. As a result, asymmetric information will cause higher transaction costs and more transaction difficulties. As an important part of China's economy, transactions of high-tech should be carefully researched especially on its efficiency.

Many foreign scholars have been paying attention to researches of licensing options under asymmetric information, especially technology transfer with moral hazard or converse selection. Gallini and Wright (1990)[1] considered a signaling game where the patentee had private information about the actual value of the patent and explained that royalty rate in the contract could act as a signaling device for the patentee. Other studies, which try to research the problems of licensing under asymmetric information, are Beggs (1992)[2], Macho-Stadler among others (1996)[3] and Patrick W. Schmitz (2002)[4], while most of them regarded that asymmetric information could lead the patentee to prefer royalty. Choi (2001)[5] took the matter of technology transfer with moral hazard into account. Manel Antelo (2003)[6] debated the problems of licensing a non-drastic innovation under double information asymmetry. And Bousquet (1998)[7] were of the opinion that royalty was better than fixed fee in that the former could provide a mechanism of risk sharing. Sougata Poddar and Uday Bhanu Sinha (2002)[8] constructed a model to analyze the licensing schemes of the patentee as an outsider when the licensee possessed private information about its market demand, which was unknown to the patentee except for some prior belief about it.

However, domestic studies on licensing were almost from the view of practice or legislation. Shi-jian Fang and Chun-mao Shi (2003)[9] analyzed the origination of adverse-selection in Chinese technology market and concluded that under certain constraints, the participation of middlemen could increase trade efficiency and promote technology transmission. Feng-xiang Zhang and Rui-hua Huang (2004)[10] established a game model of supervising moral risk occurred in patent transactions and theoretically devised a way to keep away the moral risk based on the analysis of pure strategy equilibrium and mixed strategy equilibrium. Qing-You Yan, Juan-Bo Li, and Ju-Liang Zhang (2007)[11] researched the subject of licensing schemes in

Stackelberg model under asymmetric information of product costs.

The model of Sougata Poddar and Uday Bhanu Sinha (2002) aimed at analyzing the optimal licensing schemes of the patentee as an outsider when the licensee possessed private information about its market demand, which was unknown to the patentee. Based on the conclusion proposed by Sougata Poddar and Uday Bhanu Sinha, we apply the model into Homogeneous Stackelberg to analyze the licensing option of the patentee.

## 1 The basic model and equilibrium before licensing in homogeneous Stackelberg

In the model of Stackelberg, the leader has the advantage of production. This model is based on such assumptions: (1) The patentee deals with the licensee directly. (2) The patentee is an insider in the market. (3) The licensee has no chance to bargain with the patentee. (4) The demand function of product market is linear. We define the patentee as firm 1 (the leader) and the licensee as firm 2 (the follower). Then, the market demand function is

$$p_1 = a - q_1 - q_2, p_2 = a - q_2 - q_1, \tag{1}$$

where $a$, $p_i$ and $q_i(i = 1, 2)$ represents market capability, price and demand respectively. Thus, the profit function is

$$\pi_1(q_1, q_2) = (a - q_1 - q_2 - c_1)q_1, \pi_2(q_2, q_1) = (a - q_2 - q_1 - c_2)q_2. \tag{2}$$

In order to maximize the profit, we substitute (1) into (2).

$$\pi_1^{NL} = (q_1^{NL})^2 = (1/16\ )(a - 3\ c_1 + 2\ c_2)^2, \pi_2^{NL} = (1/2)(q_2^{NL})^2 = (1/8)(a - 2c_2 + c_1)^2, \tag{3}$$

where $NL$ means no licensing.

## 2 The licensing schemes of the patentee to the licensee

Generally speaking, there are three schemes for licensing charges: a fixed fee, a royalty, or a combination of fixed fee and royalty. The fixed fee is independent of the production by using the licensed technology, which is just a fixed rent charged by the patentee from the licensee. The royalty is based on per unit of the licensee's production by using the licensed technology. Rostoker (1983) found that the schemes of royalty plus fixed fee, royalty and fixed fee accounted for 46 %, 39 % and 13 %, respectively. This paper focuses on the optimal licensing scheme under asymmetric information.

It is assumed that the patentee holds a new technology which helps reducing the marginal production cost by $\varepsilon$. The value of the new technology is just a prediction instead of accurate information to the licensee. With probability $\theta$, the licensee believes the technology value is high which can reduce the marginal production cost by $\varepsilon_h$. With probability $(1-\theta)$, it believes the technology value is low which can reduce the marginal production cost by $\varepsilon_l$.

$$\varepsilon = \begin{cases} \varepsilon_h, & \text{with} \quad \text{probability} \quad \theta, \\ \varepsilon_l, & \text{with} \quad \text{probability} \quad (1-\theta), \end{cases} \quad \varepsilon_h > \varepsilon_l, \theta \in (0, 1). \tag{4}$$

The production should satisfy

$$q_1=\begin{cases} q_{1h}, & \text{with} \quad \text{probability} \quad \theta, \\ q_{1l}, & \text{with} \quad \text{probability} \quad (1-\theta). \end{cases} \tag{5}$$

The marginal production cost of the patentee is $(c-\varepsilon_i)(i=h,l)$ when licensing charge is a fixed fee. We replaced $c$ with $c_1$ to simplify the following functions. Because the licensee's profit is just a prediction, the corresponding production and profit are

$$\begin{aligned} &\pi_{1h}^F(q_{1h},q_2)=[a-q_{1h}-q_2-(c-\varepsilon_h)]q_{1h}, \pi_{1l}^F(q_{1l},q_2)=[a-q_{1l}-q_2-(c-\varepsilon_l)]q_{1l}, \\ &\pi_2^F(q_2,q_1) \ =\theta\ [a-q_2-q_{1h}-(c-\varepsilon_h)]q_2+(1-\theta)[a-q_2-q_{1l}-(c-\varepsilon_l)]q_2. \end{aligned} \tag{6}$$

So, the maximum profits are

$$\begin{aligned} \pi_{1h}^F &= (q_{1h}^F)^2=(1/16\ )[a-c-(\theta-2)\ \varepsilon_h-(1-\theta)\ \varepsilon_l]^2, \pi_{1l}^F=(q_{1l}^F)^2 \\ &= (1/16\ )[a-c-\theta\ \varepsilon_h+(1+\theta)\varepsilon_l]^2, \\ \pi_2^F &= (1/2)(q_2^F)^2=(1/8)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l]^2. \end{aligned} \tag{7}$$

When a royalty $r$ is charged, the patentee's and the licensee's marginal production costs are $(c-\varepsilon_i)(i=h,l)$ and $(c-\varepsilon_i+r)(i=h,l)$ separately, and the production and profit are

$$\begin{aligned} \pi_{1h}^R &= (q_{1h}^R)^2=(1/16\ )[a-c-(\theta-2)\varepsilon_h-(1-\theta)\varepsilon_l+2r]^2, \pi_{1l}^R=(q_{1l}^R)^2 \\ &= (1/16\ )[a-c-\theta\varepsilon_h+(1+\theta)\varepsilon_l+2r]^2, \\ \pi_2^R &= (1/2)(q_2^R\ )^2=(1/8)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l-2r]^2. \end{aligned} \tag{8}$$

### 2.1 Pooling contract for licensing

Pooling contract means the patentee provides the same licensing scheme to the licensee whether the technology value is high or low. Under asymmetric information, the licensee has to face the problems of adverse selection and moral hazard. So, the design of licensing contract is becoming more difficult and important.

#### 2.1.1 Fixed fee model

If the patentee charges a fixed fee $T(T\leqslant\pi_2^F-\pi_2^{NL})$, the licensee will accept the offer whether the technology value is high or low. Thus, the patentee's profit is $\pi_1^F=\theta\pi_{1h}^F+(1-\theta)\pi_{1l}^F+T$. If $T>\pi_2^F-\pi_2^{NL}$, the licensing trade-off will be cancelled. Thus, the patentee's profit is $\pi_1=\pi_1^{NL}$. So, the optimal fixed fee is $T=\pi_2^F-\pi_2^{NL}$.

#### 2.1.2 Fixed fee plus royalty model

If fixed fee plus royalty is charged, the linear pooling contract is $(F+rq_2)$ and the patentee's profit is

$$\pi_{1p}^{FR}=\theta\pi_{1h}^R+(1-\theta)\pi_{1l}^R+F+rq_2^R, \quad \pi_2^R-F\geqslant\pi_2^{NL}. \tag{9}$$

To both sides, the maximum fixed fee is

$$F=\pi_2^P-\pi_2^{NL}. \tag{10}$$

When $\pi_{1p}^{FR}$ is maximized, the royalty, the licensee's production and profit are $r=[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l]/2$, $q_2^R=0$ and $\pi_2^R=0$, respectively. Considering $r\leqslant\theta\varepsilon_h+(1-\theta)\varepsilon_l$, the optimal royalty is $r^*=\theta\varepsilon_h+(1-\theta)\varepsilon_l$, and the patentee's profit meets $\pi_{1p}^{FR}-[\theta\pi_{1h}^F+(1+\theta)\pi_{1l}^F+\pi_2^F-\pi_2^{NL}]=\{(a-c)[\theta\varepsilon_h+(1-\theta)\varepsilon_l]\}/4>0$. It means the patentee get more profit with the scheme of fixed fee plus royalty than profit with the fixed fee scheme.

**Proposition 1** Above calculation shows that $\pi_{1p}^{FR}>\theta\pi_{1h}^F+(1-\theta)\pi_{1l}^F+\pi_2^F-\pi_2^{NL}$ and $\pi_{1p}^{FR}>\theta\pi_{1h}^F+(1-\theta)\pi_{1l}^F+T$. In the pooling contract, the patentee gets more profit with the scheme of fixed fee plus royalty than profit with the fixed fee scheme. So, the patentee prefers the pooling contract of fixed fee plus royalty.

### 2.2 Separating contract for licensing

Separating contract means the patentee offers discriminatory contracts for different technology value. In technology market, the patentees are divided into two types according to their technology value. Here, licensing contract $(F_h,r_h)$ means high technology value, licensing contract $(F_l,r_l)$ means low technology value. The two contracts satisfy $F_h\geqslant F_l, r_h\neq r_l$ and

$$\begin{aligned}\pi_{1hS}^R&=(q_{1hS}^R)^2=(1/16)[a-c-(\theta-2)\varepsilon_h-(1-\theta)\varepsilon_l+2\theta r_h+2(1-\theta)r_l]^2,\\ \pi_{1lS}^R&=(q_{1lS}^R)^2=(1/16)[a-c-\theta\varepsilon_h+(1+\theta)\varepsilon_l+2\theta r_h+2(1-\theta)r_l]^2,\\ \pi_{2S}^R&=(1/2)(q_{2S}^R)^2=(1/8)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l-2\theta r_h-2(1-\theta)r_l]^2.\end{aligned}\tag{11}$$

The two types of patentees should satisfy the incentive compatibility constraints to achieve the separating equilibrium. One type shouldn't pretend to be the other one. So, the compatibility constraints are

$$\begin{aligned}\pi_{1hS}^R+F_h+r_hq_{2S}^R\geqslant{}&(1/16)[a-c-(\theta-2)\varepsilon_h-(1-\theta)\varepsilon_l+2\theta r_l+2(1-\theta)r_h]^2\\ &+F_l+(r_l/2)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l-2\theta r_l-2(1-\theta)r_h],\end{aligned}\tag{IC1}$$

$$\begin{aligned}\pi_{1lS}^R+F_l+r_lq_{2S}^R\geqslant{}&(1/16)[a-c-\theta\varepsilon_h+(1+\theta)\varepsilon_l+2\theta r_l+2(1-\theta)r_h]^2\\ &+F_h+(r_h/2)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l-2\theta r_l-2(1-\theta)r_h].\end{aligned}\tag{IC2}$$

To assure the licensee accept the contracts and the patentee get profit, the optimal $F_h$, $F_l$ should be

$$F_h=F_l=\pi_{2S}^R-\pi_2^{NL}.\tag{12}$$

We substitute (12) into (IC1) and (IC2), and then obtain

$$\begin{aligned}\pi_{1lS}^R&+r_lq_{2S}^R-(1/16)[a-c-\theta\varepsilon_h+(1+\theta)\varepsilon_l+2\theta r_l+2(1-\theta)r_h]^2\\ &-(r_h/2)[a-c+\theta\varepsilon_h+(1-\theta)\varepsilon_l-2\theta r_l-2(1-\theta)r_h]=0.\end{aligned}$$

For $r_h\neq r_l$, we deduce that

$$r_h=\frac{(2\theta-3)(a-c)-(2\theta^2+\theta)\varepsilon_h+(2\theta^2+3\theta-3)\varepsilon_l}{2\theta-3}-r_l.\tag{13}$$

The profit function of the patentee is

$$\pi_{1S}^{FR}=\theta[\pi_{1hS}^R(r_h,r_l)+F_h+r_hq_{2S}^R(r_h,r_l)]+(1-\theta)[\pi_{1lS}^R(r_h,r_l)+F_l+r_lq_{2S}^R(r_l,r_h)].\tag{14}$$

When $\pi_{1S}^{FR}$ is maximized, we can deduce results as follows:

(1) When $\theta = 0.5$, the optimal royalties are $r_{h1} = \varepsilon_h, r_{l1} = \varepsilon_l$ for $r_h \leqslant \varepsilon_h, r_l \leqslant \varepsilon_l$. We can prove that $\pi_{1S1}^{FR} - \pi_{1p}^{FR} = 0$.

**Proposition 2** When the probability of high technology value is 0.5, the patentee's profit in the pooling contract is the same as profit in the separating contract with fixed fee plus royalty scheme, which is more than profit in pooling contract with fixed fee scheme.

(2) When $\theta \neq 0.5$, the optimal royalty is

$$r_{l2} = \frac{(2\theta - 3)(a - c) - \theta(2\theta + 3)\varepsilon_h + (\theta + 3)(2\theta - 1)\varepsilon_l}{2(2\theta - 3)(2\theta - 1)}.$$

Here, we denote $\Delta$ as$\Delta = r_{l2} - \varepsilon_l$ in the following discussions:

① For $\Delta \leqslant 0$, we obtain $q_{2S}^{R} = 0$ and $\pi_{2S}^{R} = 0$. So, licensing fails.

**Proposition 3.1** When $r_l$ takes the value of $r_{l2}$, the licensee has no production or profit, and thus the licensing is cancelled.

② For $\Delta > 0$, we obtain $r_{l3} = \varepsilon_l$ and $\pi_{1S3}^{FR} > \pi_{1p}^{FR}$ for $\theta \in (0, 1)$.

**Proposition 3.2** When $r_{l3} = \varepsilon_l$, $\pi_{1S3}^{FR} > \pi_{1p}^{FR} > \theta\pi_{1h}^{F} + (1 - \theta)\pi_{1l}^{F} + T$ always exists for $\theta \in (0, 1)$. Thus, the patentee prefers the separating contract to the pooling contract.

# 3 Main results

This paper studies the schemes of fixed fee or/and royalty charged by the patentee in pooling contract or separating contract, analyzes the profits gained by the patentee and the licensee, compares all contracts and chooses the optimal licensing scheme in Stackelberg market. (1) In the pooling contract, the patentee gets more profit with the scheme of fixed fee plus royalty than profit with the fixed fee scheme. So, the patentee prefers the pooling contract of fixed fee plus royalty. (2) When the probability of high technology value is 0.5, the patentee's profit in pooling contract is the same as profit in separating contract with fixed fee plus royalty scheme, which is more than profit in pooling contract with fixed fee scheme. (3) When the probability of high technology value is not 0.5 and $r_l$ takes the value of $r_{l2}$, the licensee has no production or profit, and thus the licensing is cancelled. (4) When the probability of high technology value is not 0.5 and $r_{l3} = \varepsilon_l$, the patentee prefers the separating contract to the pooling contract. Here, royalty in licensing contracts plays the role as a signaling device.

The design of licensing schemes is very important in technology markets. It is necessary for enterprises to know how to maximize their profits, take in new technologies and expand production effectively. As global technology competition is increasing, economic environment uncertainties become more complex. So, we should pay more attention to the studies of licensing. This paper aims at proposing an idea for the participants to advance the efficiency of licensing.

There are many other relevant subjects for us to talk about in the future, for example, the optimal licensing schemes in Bertrand or Cournot markets under asymmetric information. Through these studies, we hope to propose good ideas for the participants to deal with licensing transactions effectively.

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