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# Drastic innovations and multiplicity of optimal licensing policies

Debapriya Sen [a,*], Giorgos Stamatopoulos [b]

[a] Department of Economics, Ryerson University, 350 Victoria Street, Toronto, Ontario, Canada M5B 2K3
[b] Department of Economics, University of Crete, 74100 Rethymno, Crete, Greece

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ABSTRACT

Considering the licensing of a drastic cost-reducing innovation by an outside innovator in an $n$-firm Cournot oligopoly, we show that when the innovator uses combinations of fees and royalties, there are either $n-1$ or $n$ optimal licensing policies.



## 1. Introduction

A patent grants an innovator monopoly rights over the use of an innovation for a given period of time. Licensing is a standard way of diffusing an innovation. Initiated by Arrow (1962), the theoretical literature of patent licensing has grown ever since.[1] Most papers have studied licensing under the framework where (i) the potential users of the innovation are firms in an oligopoly that operate under identical marginal cost prior to the innovation, (ii) the innovation leads to a reduction in the cost, (iii) the innovator is an outsider to the industry and (iv) the innovation is licensed by means of upfront fees (which may be collected via auctions), royalties, or combinations of the two.

A cost-reducing innovation is *drastic* (Arrow, 1962) if it is significant enough to create a monopoly when only one firm has the innovation; otherwise it is non-drastic. Thus for a drastic innovation, one optimal licensing policy of an outside innovator in an oligopoly is to sell only one license and collect the entire monopoly profit from the sole licensee through an auction. Perceiving it to be the *unique* optimal policy for drastic innovations, the existing literature shifted its focus to the study of non-drastic innovations (e.g., Kamien et al., 1992; Sen and Tauman, 2007). This paper shows that this perception is incomplete. Specifically we show that if an outside innovator of a drastic innovation sells licenses using combinations of upfront fees and royalties, in an $n$-firm Cournot oligopoly under a broad class of general demand functions: (i) the number of optimal policies is either $n-1$ or $n$, (ii) all policies except one involve setting a positive royalty, (iii) when $k$ licenses are sold, a $k$-firm natural oligopoly is created with $k$ licensees, and the $n$–$k$ non-licensees drop out of the market and (iv) under any optimal policy, the Cournot price equals the post-innovation monopoly price, the innovator's payoff is the post-innovation monopoly profit and all firms obtain zero net payoff.

To see the intuition, consider an $n$-firm oligopoly where prior to the innovation all firms operate under constant marginal cost $c$. An outside innovator has a drastic innovation that reduces the cost from $c$ to $c-\varepsilon$. Let $p_M$ and $Q_M$ be the monopoly price and output under cost $c-\varepsilon$. Since $p_M \le c$ for a drastic innovation, a sole user of the innovation drives all other firms out of the market. If more than one firm has the innovation, the price falls further below $c$ and any firm without the innovation still drops out of the market. This results in zero reservation payoff for any firm. Consequently, if $k \ge 1$ licenses are auctioned off without any royalty (with a minimum bid for $k=n$), each licensee pays its entire Cournot profit as winning bid and the

* Corresponding author. Tel.: +1 416 979 5000x2662; fax: +1 416 598 5916.
*E-mail addresses:* dsen@arts.ryerson.ca (D. Sen), gstamato@econ.soc.uoc.gr (G. Stamatopoulos).

[1] Licensing under oligopoly was first analyzed by Kamien and Tauman (1984, 1986) and Katz and Shapiro (1985, 1986). The literature is large (Gallini, 1984; Gallini and Winter, 1985; Katz and Shapiro, 1987; Muto, 1993, to name only a few) and we do not attempt to summarize it here. See Kamien (1992) for a survey of the early literature. Some of the issues addressed in the later papers are informational asymmetry (e.g., Gallini and Wright, 1990; Rockett, 1990) and incumbent innovators (e.g., Shapiro, 1985; Marjit, 1990; Wang, 1998). Some recent papers include Sen (2005), Watanabe and Tauman (2007) and Giebe and Wolfstetter (2008).

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innovator obtains the entire $k$-firm industry profit. Thus, as is well known, the innovator can obtain the post-innovation monopoly profit $\Pi_M$ by choosing $k=1$. If $k\geq 2$, the $k$-firm oligopoly price falls below the monopoly price $p_M$. This is where royalty plays a role since a unit royalty $r$ ensures that each licensee effectively operates under the cost $c-\varepsilon+r>c-\varepsilon$. By choosing $r$ appropriately, the innovator raises the $k$-firm oligopoly price to equal $p_M\leq c$. All non-licensee firms still drop out of the market and a $k$-firm natural oligopoly is created where the total oligopoly profit is $p_M Q_M-(c-\varepsilon+r)Q_M$. When $k<n$, each licensee pays its Cournot profit as equilibrium winning bid and the innovator obtains the total oligopoly profit as fees. It also obtains the royalty payments $rQ_M$, so its payoff is $p_M Q_M-(c-\varepsilon)Q_M=\Pi_M$. Thus for any $1<k<n$, the innovator can obtain the monopoly profit by auctioning off $k$ licenses together with a suitable choice of royalty. Now consider $k=n$. Unlike the case of $k<n$, here a firm can reduce the number of licensees to $n-1$ by choosing to not have a license. As a result the reservation payoff of a firm for $k=n$ is the Cournot profit of a non-licensee in the oligopoly where there are $n-1$ licensees. While this reservation payoff is zero for any drastic innovation when the full magnitude $\varepsilon$ of the innovation is utilized, this is not necessarily the case when there is a distortion due to a royalty $r>0$. For the reservation payoff to be zero even under the distorted magnitude $\varepsilon-r$, the innovation has to be sufficiently more significant than just being drastic. We show that there is a threshold level $\overline{T}$ such that for drastic innovations beyond that threshold ($\varepsilon\geq\overline{T}$), the reservation payoff of a firm is zero also under $k=n$, enabling the innovator to extract the entire surplus and obtain $\Pi_M$. The upshot is that the number of optimal licensing policies for a drastic innovation of magnitude $\varepsilon$ is $n-1$ if $\varepsilon<\overline{T}$ and $n$ if $\varepsilon\geq\overline{T}$.

The paper is organized as follows. We present the model in Section 2. The main result is stated and proved in Section 3. We conclude in Section 4 by discussing some implications of our result on the rate of diffusion of innovations.

## 2. The model

Consider a homogenous good Cournot oligopoly consisting of $n\geq 2$ firms where $N=\{1,\ldots,n\}$ is the set of firms. Initially all firms produce under the same constant marginal cost $c>0$. An outside innovator (i.e., an innovator that is not one of the firms) has a patent for a new technology that reduces the cost from $c$ to $c-\varepsilon$ ($0<\varepsilon<c$), so $\varepsilon$ is the magnitude of the innovation. The innovator can license the technology to some or all firms of the industry. For $i\in N$, let $q_i$ be the quantity produced by firm $i$ and let $Q=\sum_{i\in N}q_i$. The following assumptions are maintained throughout. Similar assumptions are maintained in Kamien et al. (1992).

A1. The price function or the inverse demand function $p(Q)$: $R_+\rightarrow R_+$ is decreasing.
A2. $\exists\, Q^0>0$ such that $p(Q)=0$ for all $Q\geq Q^0$.
A3. For $Q\in[0,Q^0]$, $p(Q)$ is strictly decreasing and twice continuously differentiable.
A4. $\exists\, 0<Q^c<Q^{c-\varepsilon}<Q^0$ such that $p(0)>p(Q^c)=c>p(Q^{c-\varepsilon})=c-\varepsilon>0$.
A5. For $Q\in[0,Q^0]$, the revenue function $Qp(Q)$ is strictly concave: $2p'(Q)+Qp''(Q)<0$.
A6. For $p\in[0,p(0))$, the price elasticity $\eta(p):=-pQ'(p)/Q(p)$ is increasing.

### 2.1. The licensing schemes

The set of licensing schemes available to the innovator is the set of all combinations of a non-negative upfront fee and a non-negative per-unit linear royalty. For any royalty, the innovator determines the upfront fee to extract the maximum possible surplus from the licensees. The best way to do this is through an *auction plus royalty* (AR) policy where the innovator first announces the level of royalty and then auctions off one or more licenses (possibly with a minimum bid)[2] so that the upfront fee that a licensee pays is its winning bid. So a typical AR policy is $(k,r)$ for $1\leq k\leq n-1$ and $(n,r,\underline{b})$ for $k=n$, where $k$ is the number of licenses auctioned off, $r\geq 0$ is the per-unit uniform royalty and $\underline{b}\geq 0$ is the minimum bid.

When an innovation of magnitude $\varepsilon$ is licensed with rate of royalty $r$, the effective unit cost of a licensee is $c-(\varepsilon-r)$. As no firm will accept a policy with $r>\varepsilon$, we consider $r\in[0,\varepsilon]$. Define $\delta:=\varepsilon-r$. The variable $\delta\in[0,\varepsilon]$ is the *effective magnitude* of the innovation when the rate of royalty is $r$. Henceforth the licensing policies will be expressed in terms of $\delta$ and will be denoted by $(k,\delta)$ and $(n,\delta,\underline{b})$.

### 2.2. The licensing game G

The strategic interaction between the innovator and the firms is modeled as a three-stage game in extensive form: the *licensing game* $G$. In Stage 1, the innovator announces a policy $(k,\delta)$ or $(n,\delta,\underline{b})$. In Stage 2, firms bid simultaneously for the license and $k$ highest bidders win the license (ties are broken randomly). In Stage 3, firms compete in quantities. If a firm wins the license with bid $b$ and produces $q$, it pays the innovator $b+rq=b+(\varepsilon-\delta)q$. We confine to Subgame Perfect Nash Equilibrium (SPNE) outcomes of $G$.

### 2.3. The Cournot oligopoly game $C^n(k,\delta)$

Let $C^n(k,\delta)$ be the Cournot oligopoly game consisting of $n$ firms where $k$ firms (licensees) have effective marginal cost $c$-$\varepsilon$+$r$=$c$-$\delta$ and $n$-$k$ firms (non-licensees) have marginal cost $c$. To determine SPNE of $G$, we need to characterize Nash Equilibrium (NE) of $C^n(k,\delta)$ for all $k$ and $\delta$.

**Definition.** $k$-firm natural oligopoly: Let $1\leq k\leq n$-1 and $\delta\in[0,\varepsilon]$. We say that an NE of $C^n(k,\delta)$ results in a *k-firm natural oligopoly* if the NE price does not exceed $c$. Under such an NE, $k$ firms who have cost $c$-$\delta$ produce positive output and the remaining $n$-$k$ firms who have cost $c$ drop out of the market.

**Lemma 1.** *Let $1\leq k\leq n$ and $\delta\in[0,\varepsilon]$. The game $C^n(k,\delta)$ has a unique NE. The NE price $p^n(k,\delta)$ is continuous and strictly decreasing in $\delta$ and it has the following properties.*

(i) *Suppose $\delta<c/k\eta(c)$. Then $c<p^n(k,\delta)<p(0)$ and $p^n(k,\delta)$ is the unique solution of $p[1-1/n\eta(p)]=c-k\delta/n$ over $p\in[0,p(0))$. All firms obtain positive profit.*
(ii) *Suppose $\delta\geq c/k\eta(c)$. Then $c-\delta<p^n(k,\delta)\leq c$ [equality iff $\delta=c/k\eta(c)$] and $p^n(k,\delta)$ is the unique solution of $p[1-1/k\eta(p)]=c-\delta$ over $p\in[0,p(0))$. A k-firm natural oligopoly is created where only the $k$ licensees obtain positive profit and the $n$–$k$ non-licensees drop out of the market.*

**Proof.** See Kamien et al. (1992). □

Recall that a cost-reducing innovation is *drastic* (Arrow, 1962) if its sole user can become a monopolist with the reduced cost. Taking $k=1$ and $\delta=\varepsilon$, an innovation of magnitude $\varepsilon$ is drastic if $C^n(1,\varepsilon)$ is a natural monopoly. So by Lemma 1, an innovation of magnitude $\varepsilon$ is drastic if and only if $\varepsilon\geq c/\eta(c)$. Let $p_M(\varepsilon)$ be the monopoly price under the cost $c-\varepsilon$.

**Lemma 2.** *Consider a drastic innovation of magnitude $\varepsilon$, i.e., $\varepsilon\geq c/\eta(c)$. Then $c-\varepsilon<p_M(\varepsilon)\leq c$ with equality iff $\varepsilon=c/\eta(c)$. Moreover $p_M(\varepsilon)[1-1/\eta(p_M(\varepsilon))]=c-\varepsilon$.*

[2] The minimum bid is required when the innovation is licensed to all firms as without that, no firm will place a positive bid since each one is guaranteed to have a license.

**Proof.** Follows from Lemma 1 (ii) by taking $k=1$ and $\delta=\varepsilon$. □

*2.4. Willingness to pay for a license*

Let $q_L^n(k,\delta)$ and $q_O^n(k,\delta)$ be the respective Cournot outputs of a licensee and a non-licensee and $\Phi_L^n(k,\delta)$ and $\Phi_O^n(k,\delta)$ be the corresponding Cournot profits. It is well-known (see, e.g., Katz and Shapiro, 1985) that for $1\leq k\leq n-1$, the willingness to pay for a license under the policy $(k,\delta)$ is

$$b^n(k,\delta)=\Phi_L^n(k,\delta)-\Phi_O^n(k,\delta)=\left[p^n(k,\delta)-c+\delta\right]q_L^n(k,\delta)-\Phi_O^n(k,\delta). \tag{1}$$

For $k=n$, it is

$$b^n(n,\delta)=\Phi_L^n(n,\delta)-\Phi_O^n(n-1,\delta)=\left[p^n(n,\delta)-c+\delta\right]q_L^n(n,\delta)-\Phi_O^n(n-1,\delta). \tag{2}$$

For the policy $(n,\delta,\underline{b})$, it is optimal for the innovator to set $\underline{b}=b^n(n,\delta)$. Henceforth we denote a policy by simply $(k,\delta)$ where it will be implicit that for $k=n$, there is a minimum bid $b^n(n,\delta)$.

Under the policy $(k,\delta)$, in equilibrium: (i) the fee that the innovator obtains is $kb^n(k,\delta)$ and (ii) the royalty payment is $krq_L^n(k,\delta)=k(\varepsilon-\delta)q_L^n(k,\delta)$. Hence the payoff of the innovator is $\prod^n(k,\delta)=k(\varepsilon-\delta)q_L^n(k,\delta)+kb^n(k,\delta)$. From Eqs. (1) to (2), we have

$$\Pi^n(k,\delta)=\left[p^n(k,\delta)-c+\varepsilon\right]kq_L^n(k,\delta)-k\Phi_O^n(k,\delta)\text{ for }1\leq k\leq n-1\text{ and} \tag{3}$$

$$\Pi^n(n,\delta)=\left[p^n(n,\delta)-c+\varepsilon\right]nq_L^n(n,\delta)-n\Phi_O^n(n-1,\delta). \tag{4}$$

To determine SPNE of $G$, we go to Stage 1 where the problem of the innovator is to choose $(k,\delta)$ to maximize $\prod^n(k,\delta)$.

Let $F:[0,p(0)]\rightarrow R$ be the monopoly profit at price $p$ under the cost $c-\varepsilon$, i.e.,

$$F(p):=(p-c+\varepsilon)Q(p). \tag{5}$$

Lemma 3 shows that $F(p^n(k,\delta))$ forms an upper bound of the payoff of the innovator under the policy $(k,\delta)$.

**Lemma 3.** (i) *For any* $1\leq k\leq n$ *and* $\delta\in[0,\varepsilon]$, $\prod^n(k,\delta)\leq F(p^n(k,\delta))$.

(ii) *Suppose* $1\leq k\leq n\text{-}1$. *Then* (a) $\prod^n(k,\delta)<F(p^n(k,\delta))$ *if* $\delta<c/k\eta(c)$ *and* (b) $\prod^n(k,\delta)=F(p^n(k,\delta))$ *if* $\delta\geq c/k\eta(c)$.

(iii) *Suppose* $k=n$. *Then* (a) $\prod^n(n,\delta)<F(p^n(n,\delta))$ *if* $\delta<c/(n\text{-}1)\eta(c)$ *and* (b) $\prod^n(n,\delta)=F(p^n(n,\delta))$ *if* $\delta\geq c/(n\text{-}1)\eta(c)$.

**Proof.** Follows from (3), (4), (5) and Lemma 1. □

## 3. Multiplicity of optimal licensing policies

Since $F(p)$ is the monopoly profit at price $p$ under cost $c-\varepsilon$, its unique maximum is attained at $p=p_M(\varepsilon)$ and $F(p_M(\varepsilon))=\prod_M(\varepsilon)$ (the monopoly profit). By Lemma 3, the maximum that the innovator can obtain in any SPNE of $G$ is $\prod_M(\varepsilon)$.

**Definition.** For $1\leq k\leq n$ and $\delta\in[0,\varepsilon]$, a policy $(k,\delta)$ is an *optimal licensing policy* if it yields the payoff $\prod_M(\varepsilon)$ for the innovator in an SPNE of $G$.

For $1\leq k\leq n$, denote

$$\delta^\varepsilon(k):=\varepsilon/k+(1-1/k)[c-p_M(\varepsilon)]. \tag{6}$$

For a drastic innovation of magnitude $\varepsilon$, $0\leq c-p_M(\varepsilon)<\varepsilon$ (by Lemma 2). Hence $\delta^\varepsilon(k)\in[0,\varepsilon]$. The royalty under $(k,\delta^\varepsilon(k))$ is $r^\varepsilon(k)=\varepsilon-\delta^\varepsilon(k)=(1-1/k)[p_M(\varepsilon)-c+\varepsilon]$. Note that (i) $r^\varepsilon(1)=0$ so $(1,\delta^\varepsilon(1))$ is the policy of auctioning off only one license using zero royalty, (ii) for $2\leq k\leq n$, $r^\varepsilon(k)>0$, so $(k,\delta^\varepsilon(k))$ has positive royalty for $2\leq k\leq n$ and (iii) $r^\varepsilon(k)$ is increasing in $k$.

**Lemma 4.** *Let* $\varepsilon\geq c/\eta(c)$. *Consider a policy* $(k,\delta)$ *such that* $\delta\geq c/k\eta(c)$. *Then* $F(p^n(k,\delta))=\prod_M(\varepsilon)$ *if and only if* $\delta=\delta^\varepsilon(k)$ *where* $\delta^\varepsilon(k)$ *is given by Eq.* (6).

**Proof.** As $\varepsilon\geq c/\eta(c)$ and $c\geq p_M(\varepsilon)$, by Eq. (6) we have $\delta^\varepsilon(k)\geq c/k\eta(c)$. So setting $\delta=\delta^\varepsilon(k)$ is feasible for $\delta\geq c/k\eta(c)$. Observe by Lemma 1 (ii) that for $\delta\geq c/k\eta(c)$,

$$p=p^n(k,\delta)\Leftrightarrow p[1-1/k\eta(p)]=c-\delta. \tag{7}$$

Since $p_M(\varepsilon)$ is the unique maximizer of $F(p)$ and $F(p_M(\varepsilon))=\prod_M(\varepsilon)$, we have $F(p^n(k,\delta))=\prod_M(\varepsilon)$ iff $p^n(k,\delta)=p_M(\varepsilon)$ and by Eq. (7),

$$F(p^n(k,\delta))=\Pi_M(\varepsilon)\Leftrightarrow p_M(\varepsilon)[1-1/k\eta(p_M(\varepsilon))]=c-\delta. \tag{8}$$

Since $p_M(\varepsilon)[1-1/\eta(p_M(\varepsilon))]=c-\varepsilon$ (Lemma 2), we have

$$p_M(\varepsilon)[1-1/k\eta(p_M(\varepsilon))]=[(k-1)p_M(\varepsilon)+c-\varepsilon]/k. \tag{9}$$

By Eqs. (8) and (9),

$$F(p^n(k,\delta))=\Pi_M(\varepsilon)\Leftrightarrow[(k-1)p_M(\varepsilon)+c-\varepsilon]/k=c-\delta\Leftrightarrow\delta=\delta^\varepsilon(k).$$

This completes the proof. □

**Proposition 1.** *Consider a Cournot oligopoly consisting of* $n\geq 2$ *firms. Suppose an outside innovator has a drastic innovation of magnitude* $\varepsilon$, *i.e.,* $\varepsilon\geq c/\eta(c)$. *Let*

$$\mathbb{S}_{n-1}^\varepsilon=\{(k,\delta^\varepsilon(k))\,|\,k=1,\ldots,n-1\}\text{ and }\mathbb{S}_n^\varepsilon=\{(k,\delta^\varepsilon(k))\,|\,k=1,\ldots,n\}. \tag{10}$$

*Denote by* $\mathbb{S}^*(\varepsilon,n)$ *the set of all optimal licensing policies. There exists* $\overline{T}(n)>c/\eta(c)$ *such that*

(i) *If* $c/\eta(c)\leq\varepsilon<\overline{T}(n)$, *then* $\mathbb{S}^*(\varepsilon,n)=\mathbb{S}_{n-1}^\varepsilon$ *and if* $\varepsilon\geq\overline{T}(n)$, *then* $\mathbb{S}^*(\varepsilon,n)=\mathbb{S}_n^\varepsilon$.

(ii) *Under any optimal policy, the Cournot price equals the monopoly price* $p_M(\varepsilon)$, *all non-licensee firms drop out of the market and all firms obtain zero net payoff.*

**Proof.** (i) First let $1\leq k\leq n-1$. Since $\prod^n(k,\delta)<F(p^n(k,\delta))\leq\prod_M(\varepsilon)$ for $\delta<c/k\eta(c)$ (Lemma 3), consider $\delta\geq c/k\eta(c)$. Then $\prod^n(k,\delta)=F(p^n(k,\delta))$ and $(k,\delta)$ is optimal iff $F(p^n(k,\delta))=\prod_M(\varepsilon)$ which holds iff $\delta=\delta^\varepsilon(k)$ (Lemma 4). This proves that $\mathbb{S}_{n-1}^\varepsilon\subseteq\mathbb{S}^*(\varepsilon,n)$.

Now let $k=n$. Since $\prod^n(n,\delta)\leq F(p^n(n,\delta))\leq\prod_M(\varepsilon)$ if $\delta<c/(n-1)\eta(c)$ (Lemma 3), consider $\delta\geq c/(n-1)\eta(c)$. Then $\prod^n(n,\delta)=F(p^n(n,\delta))$ and by Lemma 4, a necessary condition for $(n,\delta)$ to be optimal is $\delta=\delta^\varepsilon(n)$. Thus $(n,\delta)$ is optimal iff $\delta=\delta^\varepsilon(n)\geq c/(n-1)\eta(c)$. By Eq. (6), $\delta^\varepsilon(n)$ is continuous and strictly increasing in $\varepsilon$. If $\varepsilon=c/\eta(c)$, then $p_M(\varepsilon)=c$, so Eq. (6) yields

$$\delta^{[\varepsilon=c/\eta(c)]}(n)=\varepsilon/n=c/n\eta(c)<c/(n-1)\eta(c). \tag{11}$$

If $\varepsilon=nc/(n-1)\eta(c)>c/\eta(c)$, then $p_M(\varepsilon)<c$, and again by Eq. (6),

$$\delta^{[\varepsilon=nc/(n-1)\eta(c)]}(n)>\varepsilon/n=c/(n-1)\eta(c). \tag{12}$$

By Eqs. (11) and (12), $\exists\,\overline{T}(n)\in(c/\eta(c),nc/(n-1)\eta(c))$ such that $\delta^\varepsilon(n)\geq c/(n-1)\eta(c)$ iff $\varepsilon\geq\overline{T}(n)$. This completes the proof of (i). Part (ii) follows from (i) and Lemma 3. □

## 4. Multiple optimal policies and diffusion of innovations

Our result shows that contrary to the perception of the existing literature, royalties can enable the innovator to sustain a specific market outcome even for drastic innovations. This paper also shows that very low and very high diffusion of drastic innovations can be sustained under an optimal policy of the innovator. Since the optimal policies are payoff-equivalent for all agents (consumers, firms and the innovator), there is no obvious way of choosing one policy over another within the present set-up. One immediate empirical question is whether the rate of diffusion is broad or limited for drastic innovations. The main problem here is the difficulty to empirically verify whether an innovation is drastic or not. In their empirical study of R&D investments of German firms for 1992–1995, Czarnitzki and Kraft (2004, p.158) discuss this problem in some detail:

> "The results of both basic theories—the patent race and the auction model—depend on the difference between drastic and non-drastic innovations… The theories are based on R&D activities… whose outcome is either drastic or non-drastic. We have no information on the outcome of particular R&D activities and are unable to say something about the results. In order to answer this question one would need a long times series of a panel of firms and the very sensible information concerning cost reductions… At present, we see no possibility to come close to data of this quality."

In actual licensing practices, several exogenous factors may tilt the scale in favor of one policy or another. If there is any small but positive contracting cost or if collecting royalties is costly (due to the difficulty in observing outputs), the innovator will prefer to sell an exclusive license via an upfront fee. On the other hand, in a growing market it may be more sensible to make the licensing contracts contingent on market performance and royalties can serve this purpose better.[3]

Other important incentives may arise in dynamic settings. If firms invest in R&D over time to develop superior innovations, it may be optimal to ensure a broad diffusion of the current innovation to increase the likelihood of better innovations (and higher profits) in the future. If an external innovator plans to seek alliances with existing firms to enter new markets, it may prefer licensing agreements with more than one firm as it may be too risky to have an exclusive contract with a single firm.

Finally, specific legal or institutional framework of licensing may also compel an innovator to choose a specific policy. One such framework is the provision of *compulsory licensing* under which it is legally binding for the innovator to license to all firms that ensures a broad diffusion of the innovation.[4] Our result that broader diffusion of drastic innovations necessarily involves higher rates of royalties is consistent with the observation that under compulsory licensing, the rates of royalties are higher than "reasonable" rates (see, e.g., Tandon, 1982, p.471).

[3] We are grateful to an anonymous referee for bringing these factors to our notice.

[4] See Tandon (1982) for a theoretical model of optimal patent life under compulsory licensing. For some empirical implications of compulsory licensing in the context of Japan–US technology transfer agreements, see Nagaoka (2005).

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