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Patents versus rewards: the implications of production inefficiency

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Abstract: It is believed that if there is no informational asymmetry between firms and the government, firms could be remunerated for innovation using optimal taxation rather than patents. We show that under reasonable conditions (such as the government's inability to customise the tax rate for each firm), patent protection is preferable to a tax/subsidy scheme if the marginal costs of the imitators are sufficiently higher than that of the innovator. Otherwise, the tax/subsidy scheme is preferable. These results hold under Cournot and Bertrand competition with product differentiation, but not for the case of Bertrand competition with homogeneous products. We rationalise these findings as the results of a trade-off between the distortions induced by monopoly under patents and production inefficiency under the tax/subsidy scheme.

Key words: Patent; Tax; Welfare
JEL classifications: D43; H25; L13; O34

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Patents versus rewards: the implications of production inefficiency

1. Introduction

Common wisdom suggests that patent protection is not required if the patent authority and innovators have similar information. As nicely summarized by Scotchmer (1999), "Firms have better information on the costs and benefits of R&D than the government has and can thus make better decisions. If the patent authorities were as well informed as firms, a better system would be to commission R&D directly. Firms could then be remunerated using optimal taxation rather than patents, which would reduce deadweight loss to consumers." [1]

There are two important aspects in the above quote: information asymmetry and optimal taxation. If the innovators have better information than the government, there is a debate on the usefulness of the patent system. On the one hand, the patent system may create duplication of R&D costs and, as Wright (1983) suggested, other reward systems may dominate the patent system. On the other hand, Loury (1979) suggested that the patent system may be beneficial by increasing R&D expenditures, which, in turn, accelerates innovation. Even if the benefits from higher expenditures dominate the costs of duplication, a patent system might not use private information efficiently. See also Gandal and Scotchmer (1993), Kremer (1998), O'Donoghue et al. (1998), Cornelli and Schankerman (1999), Minehart and Scotchmer (1999) and Scotchmer (1999) for the implications of informational problems in determining the relative benefits of patents and rewards.[2]

[1] It is generally believed that patent protection encourages innovation and increases social welfare, thus creating 'dynamic efficiency.' However, it also creates a 'static inefficiency' problem by increasing product market concentration. The optimal patent protection must balance the issue of static inefficiency against dynamic efficiency (Leffler and Leffler 2004, Ordover 1991, O'Donoghue and Zweimuller 2004, etc.).

[2] Under prizes, the innovator receives a lump sum and the innovation is put in the public domain (Weyl and Tirole, 2012).

We focus on the aspect of optimal taxation. We show that if there are no informational problems but optimal taxation is not possible (due to reasons discussed later), a patent system (creating a monopoly) is generally preferable to a reward (which is a tax/subsidy scheme under no patent protection) if the marginal cost difference between the innovator and the imitators is large.[3] The exception to this rule is the case of Bertrand competition with homogeneous products.

Lack of patent protection creates competition between the innovator and the imitators. However, the complexity of the technology, the presence of tacit knowledge, and the inefficiency of the imitators in imitating or adopting the new technology may make the imitation imperfect, resulting in higher marginal costs of the imitators compared to the innovator (see, Rockett, 1990 and Yang et al., 2016).[4] The marginal cost difference between the innovator and the imitators creates production inefficiency by shifting outputs from the low-cost innovator to the high-cost imitators. If the marginal cost difference between the innovator and the imitators is sufficiently (resp., not very) large, the patent system is preferable (resp., not preferable) to the tax/subsidy scheme since the production inefficiency effect under tax/subsidy dominates (resp., is dominated by) the market concentration effect under patent protection. This holds under Cournot and Bertrand competition with product differentiation, but does not hold for the case of Bertrand competition with homogenous goods (where the production inefficiency effect does not arise).

[3] There is a literature showing the effects of tax/subsidy policies on innovation and on investment in general. See Leahy and Neary (2009) for a nice survey of this literature. However, that literature does not consider how tax/subsidy policies perform in relation to patent policies, which is the focus of our paper.

[4] We assume that the imitators need to improve their technologies or improve their absorptive capabilities to benefit from the innovator's superior technology, and the cost reduction through imitation depends on the extent of technological improvements or absorptive capabilities. We assume here that all firms face the same input costs and the marginal cost difference is due to the difference in input productivities that depends on the technologies. Hence, to show our points in the simplest way, we ignore international aspects, which might allow the imitators to produce at a lower marginal cost than the innovator if the imitators face lower input costs (e.g., if the innovator is from a developed country and the imitators are from developing countries). The consideration of foreign firms also requires adjustments in the tax/subsidy scheme considered below, since the country of the innovator may be limited in its ability to tax foreign imitators.

We show that even if patent protection with a narrower patent breadth encourages imitation, the tax/subsidy scheme dominates the patent system if the production inefficiency effect is not very strong. This happens since a narrower patent breadth that is required to replicate the cost structure under the tax/subsidy scheme does not induce innovation under patent protection.[5]

We assume that the government cannot choose optimal taxation. If the government could choose optimal taxation, it could impose a discriminatory output-tax on the imitators to induce them to exit the market, thus eliminating production inefficiency. However, as mentioned in Coşgel (2006, p. 333), "The cost of administering a system with discriminatory rates can be very high when the characteristics of tax payers do not differ systematically or when these differences cannot be easily observed. It is generally easier to identify differences between the sectors of the economy than within each sector, making it harder to implement discriminatory rates within a sector." Heady (1993) also discusses the limitations of optimal taxation due to administrative and compliance costs. Hence, if the government needs to use a uniform tax, it is better for the government to use a non-distortionary lump-sum tax on profits and on the consumers, which we consider here.

There is a resurgence of interest in examining the relative benefits of patents and rewards. As mentioned in Galasso (2020), changes in government policies and an increase in philanthropists rewarding innovators have both motivated the revived interest in this topic.

Shavell and Ypersele (2001) show that intellectual property rights do not possess social benefits over rewards, and the optimal reward system (under which the innovator chooses between rewards and intellectual property rights) is better than intellectual property rights. Considering cumulative innovations, Hopenhayn et al. (2006) show that reward systems need

[5] For a literature on patent design, see Arrow (1962), Nordhaus (1969), Scherer (1972), Gilbert and Shapiro (1990), Klemperer (1990), and Gallini (1992). Langinier and Moschini (2002) provides a nice overview.

to assign monopoly rights and might involve payments between innovators. Chari et al. (2012) show that patent is necessary if the innovator can manipulate market signals that the planner can observe. Rewards are used when the innovator cannot manipulate market signals. Both patent and rewards may be optimal for the intermediate case of costly signal manipulation. Weyl and Tirole (2012) compare the screening benefit of market power and the distortion due to monopoly pricing in the presence of multidimensional private information. They show that it is appropriate to provide less than full monopoly power. Galasso et al. (2016) show that if the planner can learn about market outcomes over time, the optimal policy is a combination of a patent and a prize – it rewards the innovators through prices above the marginal costs initially but moves towards a cash prize and prices closer to, or reaching, marginal costs. Galasso et al. (2018) show that if only a subset of innovations can be measured and contracted upon, patents and cash rewards are complements, and grand innovation prizes may be preferable to patent races or rewards. Galasso (2020) shows that the optimal policy may be a price regulation system where the innovator owns intellectual property and receives a cash transfer if price equals marginal cost.[6]

Unlike the above-mentioned papers, which provide important insights in the presence of informational problems, we consider no informational problems and show how the distortions due to monopoly pricing under patents and production inefficiency under rewards affect the choice between patents and rewards, thereby providing a new perspective in this literature. Although the implications of production inefficiency are well studied in other areas, such as entry (Klemperer, 1988 and Lahiri and Ono, 1988), trade liberalisation (Clarke and Collie, 2003), and merger and technology licensing (Faulí-Oller, R. and J. Sandonís, 2003 and

[6] Penin (2005) argues that the debate on patents and rewards needs to consider the effects of patents on technology trading and inter-firm collaborations. Spulber (2015) discusses the factors, such as the planner's lack of knowledge and private interest, which might create distortions under the tax system. See Roin (2014) and Abramowicz (2019) for comprehensive discussions of these issues from a legal perspective.

Mukherjee and Mukherjee, 2005), the literature on patents and rewards has not paid attention to this aspect by considering either the same costs of the innovator and the imitators or a competitive industry under rewards. We show that the cost difference between the innovator and the imitators that generates the production inefficiency effect is relevant in determining how innovations will be rewarded, which has been previously overlooked in this literature.

The remainder of the paper is organised as follows. The general model is described and the case of Cournot competition is analysed in Section 2. The case of Bertrand competition is analysed in Section 3. Section 4 concludes.

2. The model and the results under Cournot competition

Assume that there is an innovator, called firm 1, which invests R to invent a new product.[7] We normalize the marginal cost of production for firm 1 to 0.

If there is no patent protection, we assume that $(n - 1)$ firms imitate the technology of firm 1, and each imitator produces its output at the marginal cost of $c \geq 0$, implying that imitation might be imperfect. As mentioned in the introduction, the complexity of the technology, the presence of tacit knowledge, and the inefficiency of the imitators in imitating or adopting the innovator's technology could each be the reason for imperfect imitation (see, e.g., Rockett, 1990 and Yang et al., 2016). We assume in this section that the firms compete like Cournot oligopolists. We consider Bertrand competition in Section 3.

If there is patent protection, we assume that firm 1 produces like a monopolist, implying that the patent breadth is large enough to eliminate imitation completely.

[7] Like many other papers in this literature (see, e.g., O'Donoghue et al., 1998, Scotchmer, 1999 and Cornelli and Schankerman, 1999, Shavell and Ypersele, 2001, Chari et al., 2012 and Galasso, 2020), we consider a single innovator, which eliminates the effects of a patent race mentioned above, and shows the implications of production inefficiency.

We discuss below the implications of a narrower patent breadth under patent protection. A narrower patent breadth under patent protection reduces the marginal costs of the imitators and allows them to compete with the innovator. The minimum patent breadth under patent protection will allow the imitators to produce at the cost *c*, which is the marginal cost they face under no patent protection. This concept of patent breadth is consistent with Gilbert and Shapiro (1990), suggesting that a larger patent breadth allows the patent holder to increase its price and the profit.

Assume that the inverse demand function faced by the ith firm, $i = 1, 2, \ldots, n$, is $P_i = 1 - kx_i - \gamma \sum_{j=1}^{n} x_j,\ i \neq j$, where $k = [1 + (n - 1)(1 - \gamma)]$, P_i and x_i are the price and output of the ith product, x_j is the output of the jth product and $\gamma \in [0,1]$ shows the degree of horizontal product differentiation. This demand function is like Shubik and Levitan (1980) and follows from the utility function $U = \sum_{i=1}^{n} x_i - \frac{1}{2}[k \sum_{i=1}^{n} {x_i}^2 - 2\gamma \sum_{i \neq j} x_i x_j]$. Under this demand structure, the market size is not affected by the number of products, thus helping us to concentrate on the production inefficiency effect which is the focus of this paper.

Like many other papers (see e.g., Muto, 1993, Faulí-Oller and Sandonís, 2002, Bagchi and Mukherjee, 2014 and Mukherjee, 2017), we consider that the products are horizontally differentiated due to the characteristics[8] of the products such as colour, brand name, packaging, differences in after-sales service, and customer's switching costs, but not by the technology of the product. For example, as suggested in Bagchi and Mukherjee (2014), consumers may view the laptops produced by Dell and HP as imperfect substitutes. Even if they introduce similar new generation laptops, consumers may consider them as imperfect substitutes due to their design, colour, and brand name. As another example, even if the wireless service provides AT&T, Verizon, and Sprint introduce similar products, customers may consider them as

[8] For a seminal work on product characteristics, one may refer to Lancaster (1966).

imperfect substitutes depending on the number of friends or relatives subscribed to those service providers. As suggested in Mukherjee (2017), if the car manufacturers BMW, Mercedes, Volvo, Audi, Honda, and Toyota introduce similar new generation cars, consumers may consider them as imperfect substitutes due to design and brand loyalty. If consumers consider the products to be perfect substitutes (isolated), it implies $\gamma = 1$ ($\gamma = 0$). If consumers consider the products to be imperfect substitutes, $\gamma \in (0,1)$, and a higher γ implies a greater degree of substitutability.

We assume $c < \frac{2n(1-\gamma)+\gamma}{2(n-\gamma(n-1))} \equiv c^{max}$ to ensure positive outputs of the imitators.

We also assume $\pi_1^{CNP} < R$, where

$$\pi_1^{CNP} = \frac{(n(1-\gamma)+\gamma)(\gamma(1-c)+n(2-(2-c)\gamma))^2}{(n(2-\gamma)+\gamma)^2(2n(1-\gamma)+\gamma)^2}.$$

The superscript *CNP* stands for 'no patent protection under Cournot competition'. It will follow from our analysis that if $R < \pi_1^{CNP,t}$, there is no need for patent protection or a tax/subsidy scheme to induce innovation, since the innovator has the incentive to innovate the technology even if *(n – 1)* firms imitate the technology and compete with the innovator.

2.1. Patent protection

If there is patent protection, straightforward calculation shows that the equilibrium net profit of firm 1 is $\pi_1^P = \frac{1}{4} - R$, since *k = 1* when *n = 1*. The superscript *P* stands for 'patent protection'. The equilibrium net profit of firm 1 is positive for $R < \frac{1}{4}$, and the corresponding equilibrium welfare is $W^P = \frac{3}{8} - R$.

If there is no patent protection, as shown below, the equilibrium net profit of firm 1 under innovation can be found as $(\pi_1^{CNP} - R)$. Since $\pi_1^{CNP} < R$ by assumption, firm 1 will not invent the technology in the absence of patent protection if there is no tax/subsidy scheme, and the corresponding welfare will be zero.

2.2. Tax/subsidy scheme

Now consider a situation with no patent protection, but assume that the government imposes a tax on profits and a lump-sum tax on the consumers, and uses the tax revenue to compensate the innovator, which can happen provided the sum of total gross industry profit and consumer surplus is higher than the cost of R&D.

If n firms (i.e., the innovator and $(n-1)$ imitators) produce like Cournot oligopolists, straightforward calculations give the equilibrium outputs of the innovator and the ith imitator respectively as

$$q_1^{CNP,t} = \frac{\gamma(1-c) + n(2-(2-c)\gamma)}{(n(2-\gamma)+\gamma)(2n(1-\gamma)+\gamma)}$$

and $$q_i^{CNP,t} = \frac{2n(1-c)(1-\gamma)+\gamma(1-2c)}{(n(2-\gamma)+\gamma)(2n(1-\gamma)+\gamma)},$$

$i = 2, \ldots, n$, where the superscript *CNP,t* stands for 'no patent protection with tax/subsidy under Cournot competition'. The corresponding equilibrium prices are respectively

$$p_1^{CNP,t} = \frac{(n(1-\gamma)+\gamma)(\gamma(1-c)+n(2-(2-c)\gamma))}{(n(2-\gamma)+\gamma)(2n(1-\gamma)+\gamma)}$$

and $$p_i^{CNP,t} = \frac{2(1+c)n^2 + n(3-2(2+c)n)\gamma + (n-1)(2n-1+c)\gamma^2}{(n(2-\gamma)+\gamma)(2n(1-\gamma)+\gamma)},$$

$i = 2, \ldots, n$. It can be shown that $p_1^{CNP,t}$ increases with c, which is consistent with the definition of patent breadth. The gross equilibrium profits of the innovator and the ith imitator are respectively

$$\pi_1^{CNP,t} = \frac{(n(1-\gamma)+\gamma)(\gamma(1-c)+n(2-(2-c)\gamma))^2}{(n(2-\gamma)+\gamma)^2(2n(1-\gamma)+\gamma)^2} = \pi_1^{CNP}$$

and $\pi_i^{CNP,t} = \frac{(n(1-\gamma)+\gamma)(2n(1-c)(1-\gamma)+\gamma(1-2c))^2}{(n(2-\gamma)+\gamma)^2(2n(1-\gamma)+\gamma)^2}$, $i = 2, \ldots, n$.[9]

The government can raise tax revenue to subsidise the innovator if the sum of total gross industry profit and consumer surplus is higher than the cost of R&D, i.e.,

$$W^{CNP,t,g} = \frac{\begin{array}{l}[2c(n-1)(2n(1-\gamma)+\gamma)^2(-3n+2(n-1)\gamma)-\\ n(2n(1-\gamma)+\gamma)^2(-3n+2(n-1)\gamma)+\\ c^2(n-1)(n(1-\gamma)+\gamma)(12n^2+4(4-5n)n\gamma+(n-1)(-5+8n)\gamma^2)]\end{array}}{2(n(2-\gamma)+\gamma)^2(2n(1-\gamma)+\gamma)^2} > R, \qquad (1)$$

where $W^{CNP,t,g}$ shows the gross welfare under Cournot competition with no patent protection but tax/subsidy. The superscript *g* stands for the gross value. In the absence of the superscript g, it shows the net value.

If the tax/subsidy scheme under no patent protection induces innovation, the net welfare under the tax/subsidy scheme is $W^{CNP,t} = W^{CNP,t,g} - R$.

2.3. Welfare comparison

Now compare welfare under 'patent protection' and 'no patent protection with tax/subsidy'.

The value of $W^{CNP,t,g}$ is less than or greater than $\frac{1}{4}$, depending on γ, *n* and *c*. For example, if $\gamma = 1$, we get $\frac{1}{4} < W^{CNP,t,g}$. However, on the other extreme where $\gamma = 0$, we get $\frac{1}{4} < (>) W^{CNP,t,g}$ for $c < (>) (1 - \frac{\sqrt{3-5n+2n^2}}{\sqrt{3}(n-1)})$.

If the combination of γ, *n*, and *c* are such that $W^{CNP,t,g} < \frac{1}{4}$ and $R \in (W^{CNP,t,g}, \frac{1}{4})$, the tax/subsidy scheme under no patent protection will not be able to create enough surplus in the economy to finance innovation. This happens because the absence of patent protection creates production inefficiency by shifting outputs from the low-cost innovator to the high-cost imitators, and this is not offset by the gain from increased competition. Further, higher product

[9] For simplicity, we impose tax on the gross profit of the innovator, i.e., excluding the R&D cost. The result will not be affected even if we impose tax on the net profit of the innovator, i.e., including the R&D cost.

differentiation reduces the benefit from competition. Hence, patent protection is desirable in this situation.

On the other hand, if $\frac{1}{4} < W^{CNP,t,g}$ and $R \in (\frac{1}{4}, W^{CNP,t,g})$, the patent system creates lower incentives for innovation compared to the tax/subsidy scheme. This happens since increased competition under no patent protection helps to create higher welfare compared to the monopoly profit of the innovator, and this extra surplus can be taxed to finance innovation under no patent protection.[10] Hence, the tax/subsidy scheme is desirable in this situation since it provides higher incentives for innovation compared to patent protection, which is in line with Kremer (1998), suggesting that "patents and copyrights create insufficient incentives for original research, since inventors cannot fully capture consumer surplus …"[11]

Now consider the situation where R is less than both $\frac{1}{4}$ and $W^{CNP,t,g}$, i.e., $\pi_1^{CNP} < R < min\{\frac{1}{4}, W^{CNP,t,g}\}$, so that innovation can be financed under both patent protection and the tax/subsidy scheme. In this situation, we get $W^{CNP,t} \gtreqless W^P$ if

$$\frac{[2c(n-1)(2n(1-\gamma)+\gamma)^2(-3n+2(n-1)\gamma)- n(2n(1-\gamma)+\gamma)^2(-3n+2(n-1)\gamma)+ c^2(n-1)(n(1-\gamma)+\gamma)(12n^2+4(4-5n)n\gamma+(n-1)(-5+8n)\gamma^2)]}{2(n(2-\gamma)+\gamma)^2(2n(1-\gamma)+\gamma)^2} - \frac{3}{8} \gtreqless 0. \qquad (2)$$

Due to the complexity of expression (2), we first consider the case of homogeneous products. We will use an example to show that similar results hold under imperfect substitutes.

If $\gamma = 1$, both the patent system and the tax/subsidy scheme induce innovation for $R \in (\frac{(1+(n-1)c)^2}{(n+1)^2}, \frac{1}{4})$. In this situation, we consider $c < \frac{1}{2} \equiv c^{max}$. We get $W^{CNP,t} > (<) W^P$ if

$$\frac{(1+(n-1)c)^2}{(n+1)^2} + \frac{(n-1)(1-2c)^2}{(n+1)^2} + \frac{(n-c(n-1))^2}{2(n+1)^2} - \frac{3}{8} > (<) 0$$

[10] If the authority uses a tax/subsidy scheme along with patent protection, it will help to provide further incentives for innovation under patent protection.
[11] It has been shown in Arrow (1962) and Dasgupta and Stiglitz (1980) that a monopolist's incentive to innovate is less than the socially desired level.

or $c < (>) \frac{3+n}{10+6n} \equiv c^*$, where $c^* \in (0, \frac{1}{2})$.

Hence, the patent system generates higher welfare and, therefore, is preferable compared to the tax/subsidy scheme for $c \in (c^*, \frac{1}{2})$.

The reason for the above result is due to the production inefficiency effect created by shifting outputs from the low-cost innovator to the high-cost imitators. On the one hand, higher competition under the tax/subsidy scheme increases total output compared to patent protection and tends to increase welfare. On the other hand, production inefficiency under the tax/subsidy scheme tends to reduce welfare by increasing the cost of production in the industry. This happens since the imitators steal business from the innovator, implying that some of the outputs produced by the innovator under the patent system will be produced by the relatively high-cost imitators under the tax subsidy/scheme. If the marginal costs of the imitators are sufficiently higher than that of the innovator, the production inefficiency effect dominates the competition effect and the tax/subsidy scheme reduces welfare compared to patent protection.[12] In this situation, patent protection with a maximum patent breadth that eliminated imitation is preferable to the tax/subsidy scheme even if there is no informational problem between the firms and the government.

The tax/subsidy scheme creates higher welfare and, therefore, is preferable compared to patent protection for $c \in (0, c^*)$ if the patent breadth is large enough to eliminate imitation. It may seem that the patent authority could choose an appropriate patent breadth under patent protection to replicate the cost structure and the welfare under the tax/subsidy scheme. However, that will not be the case, as shown in the following discussion.

As the patent breadth reduces, it reduces the profit of the innovator by reducing the costs of the imitators. Hence, under patent protection, the patent authority will be able to reduce

[12] In different contexts, Klemperer (1988) and Lahiri and Ono (1988) discussed similar effects of competition and production inefficiency under Cournot competition.

the patent breadth only up to the point that makes $\pi_1^P(\tilde{c}) = R$, where $\pi_1^P(\tilde{c})$ is the gross profit of the innovator when the imitators costs are $\tilde{c}$. Since $R > \pi_1^{CNP}(c)$ by assumption and the profit of the innovator is positively related to the marginal costs of the imitators, it must be true that $\tilde{c} > c$ for $\pi_1^P(\tilde{c}) = R > \pi_1^{CNP}(c)$, implying that the welfare will be higher under the tax/subsidy scheme compared to patent protection. This is further explained by **Figure 1**.

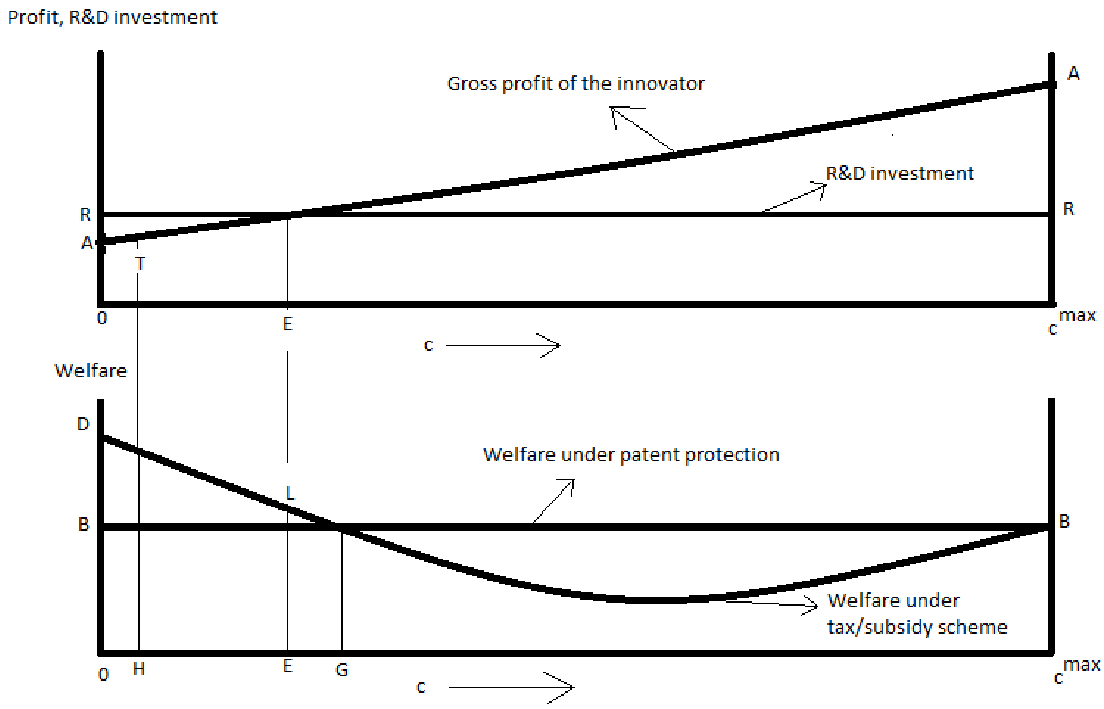

Figure 1

It is easy to check from the profit and welfare expressions derived above that the profit of the innovator falls as *c* is reduced and welfare under the tax/subsidy scheme is convex with respect to *c* and it reaches the minimum value at

$$\hat{c} = \frac{(2n(1-\gamma)+\gamma)^2(3n-2\gamma(n-1))}{(n(1-\gamma)+\gamma)(12n^2+4n\gamma(4-5n)+(n-1)(8n-5)\gamma^2)}, \text{ where } \hat{c} \in [0, c^{max}].$$

The reason that the welfare function is convex follows from Lahiri and Ono (1988) and Klemperer (1990). If *c* falls from $c^{\max}$, it creates three effects. First, it reduces the costs of the imitators, which is beneficial for welfare. Second, it helps to increase the total output, which is also beneficial for welfare. Third, it allows the high-cost imitators to steal market share from the low-cost innovator and therefore, creates production inefficiency by shifting outputs from the low-cost innovator to the high-cost imitators, which tends to reduce welfare. If c is high (low), the third effect dominates (is dominated by the combination of) the first and second effects due to a large (small) production inefficiency effect and a lower c decreases (increases) welfare.

The top panel in Figure 1 shows the gross profit of the innovator, shown by AA, and the R&D investment, shown by RR. The bottom panel in Figure 1 shows the welfare under patent protection with no imitation, shown by BB, and welfare under the tax/subsidy scheme, shown by BD.

Now consider $c \in (0, G)$, say, $c = H$. In this situation, welfare under the tax/subsidy scheme is higher than welfare under patent protection with no imitation. If the authority reduces the patent breadth under patent protection, it will allow imitation and consequently will reduce the marginal cost of the imitators and the profit of the innovator. If a narrower patent breadth under patent protection allows imitation, the curve BD also shows the welfare under patent protection with a narrower patent breadth.

For any cost to the left of E, the investment in R&D is greater than the profit of the innovator in the absence of patent protection. For the patent authority, it is not feasible to reduce the marginal cost of the imitators below E because the innovator will then not have the incentive to innovate. Therefore, the maximum welfare that can be achieved with a narrow patent breadth is lower than the welfare under the tax/subsidy scheme that allows imitators to produce at a marginal cost less than E. Note that in our diagram, the point E lies to left of G. It can also be shown that our conclusion will not change even if the point E lies to the right of G.

In the discussion above, we assumed there is no tax/subsidy scheme under patent protection. Even if the authority uses a tax/subsidy scheme along with patent protection, it is intuitive that as long as there is a positive patent breadth under patent protection, it will create marginal costs for the imitators higher than *c*. Since the imitators face the marginal cost *c* under no patent protection, an added positive patent breadth is likely to increase the marginal costs of the imitators,[13] implying that the tax/subsidy scheme with no patent protection will generate higher welfare compared to patent protection with tax/subsidy.

Now we consider the case of imperfect substitutes with $\pi_1^{CNP} < R < min\{\frac{1}{4}, W^{CNP,t,g}\}$, so that both the patent system and the tax/subsidy scheme can finance innovation. Since the general analysis is difficult for this situation due to the complicated nature of some expressions, we consider an example with $n = 2$ and $\gamma = 0.5$ to show that the qualitative results discussed above for homogeneous goods hold under imperfect substitutes. For these values of n and γ, we get $c < \frac{5}{6} \equiv c^{max}$ and $\frac{1}{4} < W^{CNP,t,g}$, and find $W^{CNP,t} > (<)W^P$ if $c \in [0, .086(approx.))$ ($c \in (.086, \frac{5}{6})$), suggesting that the patent system is preferable (not preferable) to the tax/subsidy scheme if the imitators are sufficiently (not very) cost inefficient.

The above discussion is summarized in the following proposition.

Proposition 1: *(i) If $W^{CNP,t,g} < \frac{1}{4}$ and $R \in (W^{CNP,t,g}, \frac{1}{4})$, the patent system is preferable to the tax/subsidy scheme, since the tax/subsidy cannot finance the innovation.*

(ii) If $\frac{1}{4} < W^{CNP,t,g}$ and $R \in (\frac{1}{4}, W^{CNP,t,g})$, the tax/subsidy scheme is preferable to the patent system, since innovation does not occur under patent protection.

[13] We thank a referee for mentioning this point.

(iii) If $\pi_1^{CNP} < R < min\{\frac{1}{4}, W^{CNP,t,g}\}$ *so that both the patent system and the tax/subsidy scheme can finance innovation, the patent system can be preferable (not preferable) to the tax/subsidy scheme if the imitators are sufficiently (not very) cost inefficient.*

3. The case of Bertrand competition

Now we want to show the implications of Bertrand competition in the product market. First, we focus on the homogeneous goods case. Then we show the implications of product differentiation.

If the products are homogeneous, i.e., if $\gamma = 1$, then the corresponding inverse demand function will be $P = 1 - \sum_{i=1}^{n} x_i$.

If the products are differentiated, i.e., if $\gamma \in [0,1)$, then following the inverse demand function mentioned in Section 2, the corresponding demand function will be

$$x_i = \frac{[k-\gamma- P_i(k + \gamma(n-2)) + \gamma \sum_{j=1}^{n} P_j]}{(k-\gamma)[k + \gamma(n-1)]}, \ i \neq j.$$

Note that for $\gamma = 1$, we get $k = 1$. In this limiting case of $\gamma = 1$, x_i is not well-specified since the inverse demand function features a kink.

We assume $c < \frac{1}{2} \equiv c^{max}$ for $\gamma = 1$ to ensure that there is a meaningful threat of competition from the imitators and $c < \frac{(k-\gamma)[2k+\gamma(2n-3)]}{2k^2+2k\gamma(n-2)-\gamma^2(n-1)}$ for $\gamma \in [0,1)$ to ensure positive outputs of the imitators.

We also assume $c(1-c) < R$ for $\gamma = 1$ and $\pi_1^{BNP} < R$ for $\gamma \in [0,1)$, where

$$\pi_1^{BNP} = \frac{[k+\gamma(n-2)][2k^2+\gamma^2(3+c(n-2)(n-1)-2n)+k\gamma(-5+c(n-1)+2n)]^2}{(k-\gamma)[2k+\gamma(n-3)]^2[k+\gamma(n-1)][2k+\gamma(2n-3)]^2}.$$

The superscript *BNP* stands for 'no patent protection under Bertrand competition'. These conditions will ensure that firm 1 will not innovate in the absence of patent protection and tax/subsidy scheme.

3.1. Patent protection

If there is patent protection and only firm 1 (the innovator) produces the output, as in subsection 2.1, we get the equilibrium net profit of firm 1 as $\pi_1^P = \frac{1}{4} - R$, since *k = 1* when *n = 1*. The equilibrium net profit of firm 1 is positive for $R < \frac{1}{4}$. The equilibrium welfare under patent protection is $W^P = \frac{3}{8} - R$ if $R < \frac{1}{4}$.

If there is no patent protection, as shown below, the equilibrium net profit of firm 1 under innovation can be shown to be $[c(1-c) - R]$ for $\gamma = 1$ and $(\pi_1^{BNP} - R)$ for $\gamma \in [0,1)$. We have assumed $c(1-c) < R$ for $\gamma = 1$ and $\pi_1^{BNP,t} < R$ for $\gamma \in [0,1)$, implying that firm 1 will not invent the technology in the absence of patent protection if there is no tax/subsidy scheme, in which case the corresponding welfare will be zero.

3.2. Tax/subsidy scheme

Now consider the tax/subsidy scheme, which will induce the innovator to innovate if the tax revenue can at least cover the cost of R&D.

First, consider the case of homogeneous goods, i.e., $\gamma = 1$. In this case firm 1 will charge *c* for the product and will sell *(1 – c)* units of output. It is easy to see that as *c* increases, the price charged by firm 1 will increase, consistent with the definition of patent breadth. The outputs of the imitators are *0*. The equilibrium gross profit of firm 1 is $\pi_1^{BNP,t}(\gamma = 1) = c(1 - c)$ and the equilibrium profit of each imitator is *0*. The corresponding consumer surplus is $CS^{BNP,t}(\gamma = 1) = \frac{(1-c)^2}{2}$.

The government can raise tax revenue and subsidise the innovator to induce innovation if the sum of total gross industry profit and consumer surplus is higher than the cost of R&D, i.e.,

$$c(1-c)+\frac{(1-c)^2}{2}=\frac{(1-c^2)}{2}>R.$$

The equilibrium net welfare under no patent protection with the tax/subsidy scheme is $W^{BNP,t}(\gamma=1)=\frac{(1-c^2)}{2}-R$, where $W^{BNP,t}$ stands for the equilibrium net welfare under Bertrand competition with no patent protection but tax/subsidy.

Next consider the case of differentiated products, i.e., $\gamma \in [0,1)$. If *n* firms (i.e., the innovator and *(n – 1)* imitators) compete as Bertrand oligopolists, the equilibrium prices charged by the innovator and the *i*th imitator respectively are

$$P_1^{BNP,t}=\frac{[2k^2+\gamma^2(3+c(n-2)(n-1)-2n)+k\gamma(-5+c(n-1)+2n)]}{[2k+\gamma(n-3)][2k+\gamma(2n-3)]}$$

and $$P_i^{BNP,t}=\frac{[2(1+c)k^2+\gamma^2(3+2c(n-2)^2-2n)+k\gamma(-5+4c(n-2)+2n)]}{[2k+\gamma(n-3)][2k+\gamma(2n-3)]},$$

i = 2, …, n. The superscript *BNP,t* stands for 'no patent protection with tax/subsidy under Bertrand competition'. It can be shown that $p_1^{BNP,t}$ increases with *c*, consistent with the definition of patent breadth. The corresponding outputs are respectively

$$q_1^{BNP,t}=\frac{[(k+\gamma(n-2))(2k^2+\gamma^2(3+c(n-2)(n-1)-2n)+k\gamma(-5+c(n-1)+2n))]}{(k-\gamma)[2k+\gamma(n-3)][k+\gamma(n-1)][2k+\gamma(2n-3)]}$$

and $$q_i^{BNP,t}=\frac{[(k+\gamma(n-2))(2(1-c)k^2+\gamma^2(3+c(n-1)-2n)+k\gamma(-5-2c(n-2)+2n)]}{(k-\gamma)[2k+\gamma(n-3)][k+\gamma(n-1)][2k+\gamma(2n-3)]},$$

i = 2, …, n.

The gross equilibrium profit of the innovator and the *i*th imitator are respectively

$$\pi_1^{BNP,t}=\frac{(k+\gamma(n-2))[2k^2+\gamma^2(3+c(n-2)(n-1)-2n)+k\gamma(-5+c(n-1)+2n)]^2}{(k-\gamma)[2k+\gamma(n-3)]^2[k+\gamma(n-1)][2k+\gamma(2n-3)]^2}$$

$$=\pi_1^{BNP}$$

and $$\pi_i^{BNP,t}=\frac{(k+\gamma(n-2))[2(1-c)k^2+\gamma^2(3+c(n-1)-2n)+k\gamma(-5-2c(n-2)+2n)]^2}{(k-\gamma)[2k+\gamma(n-3)]^2[k+\gamma(n-1)][2k+\gamma(2n-3)]^2},$$

i = 2, …, n.[14]

The government can raise tax revenue and subsidise the innovator to induce innovation if the sum of total gross industry profit and consumer surplus is higher than the cost of R&D, i.e.,

$$W^{BNP,t,g} = \frac{\begin{array}{l}(k+\gamma(n-2))[2c(k-\gamma)(3k+\gamma(n-4))(n-1)(2k+\gamma(2n-3))^2 \\ -(k-\gamma)(3k+\gamma(n-4))n(2k+\gamma(2n-3))^2 \\ +c^2(n-1)(-12k^4-28k^3\gamma(n-2)+k^2\gamma^2(-89+(89-20n)n) \\ +\gamma^4(n-1)(6+(n-6)n)-2k\gamma^3(n-2)(13+n(2n-13)))]\end{array}}{2(\gamma-k)[2k+\gamma(n-3)]^2[k+\gamma(n-1)][2k+\gamma(2n-3)]^2} > R,$$

where $W^{BNP,t,g}$ shows the gross welfare under Bertrand competition with no patent protection but tax/subsidy. The superscript *g* stands for the gross value. In the absence of the superscript g, it shows the net value.

If the tax/subsidy scheme under no patent protection induces innovation, welfare under the tax/subsidy scheme is $W^{BNP,t} = W^{BNP,t,g} - R$.

3.3. Welfare comparison

Now compare welfare under 'patent protection' and 'no patent protection with tax/subsidy'.

First, consider the case of homogeneous goods, i.e., $\gamma = 1$. We get that $W^{BNP,t}(\gamma = 1) = \frac{(1-c^2)}{2} > W^P = \frac{3}{8}$ for $c \in [0, \frac{1}{2})$, suggesting that the tax/subsidy scheme is preferable to the patent system. This happens since, unlike Cournot competition, here only the innovator produces all outputs under no patent protection, thus creating no production inefficiency as described in the previous section. Hence, the tax/subsidy scheme creates higher welfare compared to patent protection for all feasible values of *c*. This is different from the Cournot case.

[14] For simplicity, we suppose the tax is imposed on the gross profit of the innovator, i.e., excluding the R&D cost. The result will not be affected if instead the tax were imposed on the net profit of the innovator, i.e., including the R&D cost.

Now consider the case of imperfect substitutes, i.e., $\gamma \in [0,1)$. As under Cournot competition, $\frac{1}{4}$ is less than or greater than $W^{BNP,t,g}$, depending on γ, *n* and *c*. For example, if $\gamma = 0$, we have $\frac{1}{4} < (>) W^{BNP,t,g}$ for $c < (>)(1 - \frac{\sqrt{3-5n+2n^2}}{\sqrt{3}(n-1)})$. Hence, if the combinations of γ, *n* and *c* are such that $W^{BNP,t,g} < \frac{1}{4}$ and $R \in (W^{BNP,t,g}, \frac{1}{4})$, the tax/subsidy scheme under no patent protection cannot create enough total surplus in the economy to finance innovation. This happens due to the product inefficiency effect created under no patent protection. Hence, patent protection is desirable in this situation.

On the other hand, if $\frac{1}{4} < W^{BNP,t,g}$ and $R \in (\frac{1}{4}, W^{BNP,t,g})$, innovation does not occur under patent protection but increased competition in the absence of patent protection helps to create higher welfare compared to the monopoly profit of the innovator, and this extra surplus can be taxed to finance innovation under no patent protection. Hence, the tax/subsidy scheme is desirable in this situation.

Now consider the situation where R is less than both $\frac{1}{4}$ and $W^{BNP,t,g}$ so that the innovation can be financed under either patent protection or no patent protection with the tax/subsidy scheme. Due to the complicated expression, like the Cournot case, we will consider an example to show that the patent system may be preferable than the tax/subsidy scheme in this situation.

Consider *n* = *2* and $\gamma = .5$. For these values of n and γ, we get $c < \frac{14}{17} \equiv c^{max}$ and $\frac{1}{4} < W^{BNP,t,g}$, and find $W^{BNP,t} > (<) W^P$ if $c \in [0, 0.12(approx.))$ ($c \in (.12, \frac{14}{17})$), suggesting that the patent system is preferable (resp., not preferable) to the tax/subsidy scheme if the imitators are sufficiently (resp., not very) cost inefficient. Hence, if the products are imperfect substitutes, the results under Bertrand competition are similar to those under Cournot competition, and the reasons for the results under Bertrand competition are similar to those under Cournot competition.

The following proposition summarizes the result under Bertrand competition.

Proposition 2: *(i) If* $W^{BNP,t,g} < \frac{1}{4}$ *and* $R \in (W^{BNP,t,g}, \frac{1}{4})$*, the patent system is preferable to the tax/subsidy scheme, since the tax/subsidy cannot finance the innovation.*

(ii) If $\frac{1}{4} < W^{BNP,t,g}$ *and* $R \in (\frac{1}{4}, W^{BNP,t,g})$*, the tax/subsidy scheme is preferable to the patent system, since innovation does not occur under patent protection.*

(iii) Consider $\gamma = 1$ *and* $R \in (c(1-c), \frac{1}{4})$*. The tax/subsidy scheme is preferable to the patent system.*

(iv) Consider $\gamma \in [0,1)$*, and* $\pi_1^{BNP} < R < min\{\frac{1}{4}, W^{BNP,t,g}\}$ *so that either the patent system or the tax/subsidy scheme can finance innovation. In this situation, the patent system can be preferable (resp., not preferable) to the tax/subsidy scheme if the imitators are sufficiently (resp., not very) cost inefficient.*

4. Conclusion

The patent system is used quite commonly to encourage innovative activity. However, there is also an undesirable effect of the patent system known as the “static inefficiency” problem. This arises because the patent system grants monopoly rights to the patent holders, which, in turn, restricts outputs to increase profits. It is generally believed that patent protection is not required if the patent authorities and the innovators have similar information (Scotchmer, 1999).

We show that if there is no informational asymmetry between the firms and the government but optimal taxation is not possible, there is still a case for patent protection. Patent protection is preferable to a tax/subsidy scheme with no patent protection if the marginal costs of the imitators are sufficiently higher than those of the innovator. Otherwise, the tax/subsidy scheme is preferable. These results hold under Cournot and Bertrand competition with differentiated products, but not for the case of Bertrand competition with homogeneous products. The trade-off created by the distortions from monopoly pricing under patents and production inefficiency under the tax/subsidy scheme is the reason for our results. Thus, our results show the implications of production inefficiency and provide a new perspective to the literature on patents and rewards by showing that the cost difference between the innovator and the imitators may be relevant in determining the choice.

We considered R&D investment that is higher than the innovator's gross profit under no patent protection. If R&D investment is lower than the innovator's gross profit under no patent protection, it is immediate that the government does not need to give the patent protection or to use a tax/subsidy scheme to induce innovation. However, the authority may still want to decide whether to grant patent protection, since the market structure and the welfare implications will be affected by patent protection. While patent protection will create a monopoly, the market structure will be an oligopoly under no patent protection. Hence, the welfare comparison will be similar to our analysis where innovation occurs under both patent protection and the tax/subsidy scheme.

We focused on the welfare comparison and showed when the government will prefer patent protection or the tax/subsidy scheme. However, it is worth mentioning that increased competition under the tax/subsidy scheme always makes the consumers better off under the tax/subsidy scheme compared to patent protection, so long as the former induces innovation.

References

Abramowicz, M., 2019, ‘Prize and reward alternatives to intellectual property’, in B. Depoorter, P. Menell and D. Schwartz (Eds.), *Research handbook on the economics of intellectual property law*, Vol 1, Theory Vol 2: Analytical methods, Ch 13: 350-375, Edward Elgar, Cheltenham, UK.

Arrow, K.J., 1962, ‘Economic welfare and the allocation of resources for inventions’, In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Ed. by R.R. Nelson, Princeton, NJ: Princeton University Press.

Bagchi, A. and A Mukherjee, 2014, ‘Technology licensing in a differentiated oligopoly’, *International Review of Economics and Finance*, 29: 455-465.

Chari, V.V., M. Golosov and A. Tsyvinski, 2012, ‘Prizes and patents: using market signals to provide incentives for innovations’, *Journal of Economic Theory*, 147: 781-801.

Clarke, R. and D. Collie, 2003, ‘Product differentiation and the gains from trade under Bertrand duopoly’, *Canadian Journal of Economics*, 36: 658-73.

Cornelli, F. and M. Schankerman, 1999, ‘Optimal patent renewals’, *Rand Journal of Economics,* 30: 197–213.

Coşgel, M. M., 2006, ‘Taxes, efficiency, and redistribution: discriminatory taxation of villages in Ottoman Palestine, Southern Syria, and Transjordan in the sixteenth century’, *Explorations in Economic History*, 43: 332–356.

Dasgupta, P. and J. Stiglitz, 1980, ‘Uncertainty, industrial structure, and the speed of R&D’, *Bell Journal of Economics*, 11: 1-28.

Faulí-Oller, R. and J. Sandonís, 2002, ‘Welfare reducing licensing’, *Games and Economic Behavior*, 41: 192-205.

Faulí-Oller, R. and J. Sandonís, 2003, ‘To merge or to license: implications for competition policy’, *International Journal of Industrial Organization*, 21: 655-672.

Galasso, A., 2020, 'Rewards versus intellectual property rights when commitment is limited', *Journal of Economic Behavior and Organization*, 169: 397-411.

Galasso, A., M. Mitchell and G. Virag, 2016, 'Market outcomes and dynamic patent buyouts', *International Journal of Industrial Organization*, 48: 207-243.

Galasso, A., M. Mitchell and G. Virag, 2018, 'A theory of grand innovation prizes', *Research Policy*, 47: 343-362.

Gallini, N., 1992, 'Patent policy and costly imitation, *Rand Journal of Economics*, 23: 52-63.

Gandal, N. and S. Scotchmer, 1993, 'Coordinating research through research joint ventures', *Journal of Public Economics*, 51: 173–193.

Gilbert, R., and C. Shapiro, 1990, 'Optimal patent length and breadth', *Rand Journal of Economics*, 21: 106-112.

Heady, C., 1993, 'Optimal taxation as a guide to tax policy: a survey', *Fiscal Studies*, 14: 15-41.

Hopenhayn, H., G. Llobet and M. Mitchell, 2006, 'Rewarding sequential innovators: prizes, patents, and buyouts', *Journal of Political Economy*, 114: 1041-1068.

Klemperer, P., 1988, 'Welfare effects of entry into markets with switching costs', *Journal of Industrial Economics*, 37: 159-65.

Klemperer, P., 1990, 'How broad should the scope of patent protection be?', *Rand Journal of Economics*, 21: 113-30.

Kremer, G., 1998, 'Patent buyouts: a mechanism for encouraging innovation', *Quarterly Journal of Economics*, 113: 1137-1167.

Lahiri, S. and Y. Ono, 1988, 'Helping minor firms reduces welfare', *Economic Journal*, 98: 1199-1202.

Lancaster, K.J., 1966, 'A new approach to consumer theory', *Journal of Political Economy*, 74: 132-157.

Langinier, C. and G, Moschini, 2002, 'The Economics of Patents', in *Intellectual Property Rights and Patenting in Animal Breeding and Genetics*, Ed. by S. Newman and M. Rothschild, CAB International, 31-50.

Leffler, K. and C. Leffler. 2004. Efficiency trade-offs in patent litigation settlements: Analysis gone astray. *USFL Rev.*, 39, p.33.

Leahy, D. and P. Neary. 2009. Multilateral subsidy games. *Economic Theory*, 41, 41-66.

Loury, G.C., 1979, 'Market structure and innovation', *Quarterly Journal of Economics*, 93: 395–410.

Minehart, D. and S. Scotchmer, 1999, 'Ex Post regret and the decentralized sharing of information', *Games and Economic Behavior*, 17: 114–131.

Mukherjee, A., 2017, 'Patent protection and R&D with endogenous market structure', *Journal of Industrial Economics*, LXV, 220-234.

Mukherjee, A. and S. Mukherjee, 2005, 'Foreign competition with licensing', *Manchester School*, 73: 653-663.

Muto, S., 1993, 'On licensing policies in Bertrand competition', *Games and Economic Behavior*, 5: 257-267.

Nordhaus, W.D., 1969, *Inventions, growth and welfare: a theoretical treatment of technological change.* Cambridge, MA: MIT Press.

O'Donoghue, T., S. Scotchmer and J.-F. Thisse, 1998, 'Patent breadth, patent life, and the pace of technological progress', *Journal of Economics and Management Strategy*, 7: 1–32.

O'Donoghue, T. and J. Zweimuller. 2004. Patents in a model of endogenous growth. *Journal of Economic Growth*, 9: 81-123.

Ordover, J. A. 1991. A patent system for both diffusion and exclusion. *Journal of Economic Perspectives*, 5: 43-60.

Penin, J., 2005, 'Patents versus ex post rewards: a new look', *Research Policy*, 34: 641-656.

Rockett, K., 1990, ‘The quality of licensed technology’, *International Journal of Industrial Organization*, 8: 559-574.

Roin, B.N., 2014, ‘Intellectual property versus prizes: reframing the debate’, *The University of Chicago Law Review*, 81: 999-1078.

Scherer, F.M., 1972, ‘Nordhaus’ theory of optimal patent life: a geometric reinterpretation’, *American Economic Review*, 62: 422-427.

Scotchmer, S. 1991. On the optimality of the patent renewal system. *Rand Journal of Economics*, 30: 181-196.

Shavell, S. and T.V. Ypersele, 2001, ‘Rewards versus intellectual property rights’, *Journal of Law and Economics*, XLIV: 525-4547.

Shubik, M. and R. Levitan, 1980, ‘*Market Structure and Behaviour’*, Harvard University Press, Cambridge, MA.

Spulber, D.F., 2015, ‘Public prizes versus market prices: should contests replace patents?’, *Journal of the Patent and Trademark Office Society*, 97: 690-735.

Weyl, E.G. and J. Tirole, 2012, ‘Market power screens willingness-to-pay’, *Quarterly Journal of Economics*, 127: 1971-2003.

Wright, B., 1983, ‘The economics of invention incentives: patents, prizes and research contracts’, *American Economic Review,* 73: 691–707.

Yang, L., Y. Tsai and A. Mukherjee, 2016, ‘Intellectual property rights and the quality of transferred technology in developing countries’, *Review of Development Economics*, 20: 239-249.