Economics Bulletin

Volume 31, Issue 4

Knowledge diffusion vs. technological progress: the optimal strength of IPRs protection

Shuai Niu
School of Economics, Australian School of Business, The University of New South Wales

Abstract

By adjusting the strength of IPRs protection, the government can change the extent of knowledge spillovers in R&D. A large spillover rate helps to improve the productivity of the less efficient firms and save on the overall production costs. But, at the same time, it reduces the innovator's incentives to conduct R&D and results in a lower equilibrium innovation level. So, there is an inherent tension between knowledge diffusion and technological progress. In this paper, we formalized this relationship in a two stage asymmetric duopoly model and discussed the optimal IPRs protection policy. The main conclusion is that, to maximize social welfare the strength of IPRs protection should rise as the increase of the innovating firm's R&D efficiency.

I am grateful to associate editor Raymond Deneckere and the anonymous referees for their helpful comments.
Citation: Shuai Niu, (2011) "Knowledge diffusion vs. technological progress: the optimal strength of IPRs protection", *Economics Bulletin*, Vol. 31 No. 4 pp. 2839-2846.
Contact: Shuai Niu - shuai.niu@student.unsw.edu.au.
Submitted: September 14, 2011. **Published:** October 10, 2011.

1. Introduction

An inherent characteristic of the R&D process is the knowledge spillover effects. Due to spillovers, a firm can partly benefit from the other firms' innovation without any payment. A consequence is that, the innovating firm will have less incentives to conduct research compared to the case without spillovers. Since the seminal work of d'Aspremont and Jacquemin (1988), this phenomenon is thoroughly analyzed by researchers. And, to correct the incentive distortion some forms of R&D cooperation are suggested, like the R&D cartelization, the RJV competition, and the RJV cartelization (Kamien, Muller and Zang, 1992). Compared to R&D competition, cooperative research agreement may have two opposite effects on social welfare. On the one hand, it helps to correct the innovating firms' incentives to conduct R&D, but on the other hand, it also impairs the market competition. Based on this, Leahy and Neary (1997) discussed theoretically the appropriate policy stance should be taken towards R&D cooperation. [1]A main conclusion is that, with strategic behavior the payoff from encouraging R&D cooperation is limited and the welfare loss of lax competition policy tends to be high.

Different from the above researchers, in this paper we discuss another policy tool to deal with R&D incentive distortions, the intellectual property rights (IPRs). [2]By IPRs protection, the knowledge spillover rate is made endogenous and is put under the control of the government. To determine the optimal strength of IPRs protection, the focus of this paper is on the tension between technological progress and knowledge diffusion. That is, a large spillover rate helps to strength the less efficient firms and save on the overall production costs, but, at the same time, it reduces the innovator's incentives to conduct R&D and results in a lower equilibrium innovation level. To clearly explain this tradeoff, we adopted a two stage asymmetric duopoly game model. And, the game proceeds as follows: firm one, the innovator, first invests in cost-reducing R&D and then engages in Cournot competition with firm two, the follower, in the final product market. In equilibrium, the social welfare level can be expressed as a function of the spillover rate. The first order derivative of this relationship indicates that, if we change the extent of knowledge spillovers four kinds of effects on social welfare can be identified. And, they are: the knowledge diffusion effect, the production effect, the indirect innovation effect, and the direct innovation effect. By balancing between these effects, we got the optimal IPRs protection policy: to maximize social welfare, the strength of IPRs protection should rise as the increase of the innovating firm's R&D efficiency.

This article is organized as follows. In the next section, we introduce a two stage asymmetric duopoly game and explain how the innovating firm's incentives to conduct R&D will be influenced by knowledge spillovers. In section 3, given the equilibria of the two stage game, we constructed the social welfare function, solved for the socially optimal spillover rate, and then gave the corresponding policy suggestions. The last section summarizes the main results.

[1]For policy practices, the work of Jacquemin (1988), Martin (1997), and Labory (2004) can be referred.

[2]A related research to this paper comes from Kang (2006). In the context of international trade, the author discussed how a government will choose the optimal policy mix of IPR protection and R&D subsidies to maximize the domestic exporting firm's profits. The conclusion is, a government will adopt weak IPRs protection and subsidize the domestic firm's R&D investments. The difference between us is that, in this paper we adopted a domestic duopoly model setting and considered the optimal IPRs policy from the standpoint of social welfare. Under the new criterion, a minimum strength of IPRs protection is not necessarily socially optimal.

2. The Basic Model

There are two firms in the market, firm 1 and firm 2, producing homogenous goods, and among them only firm 1 has the ability to conduct cost-reducing R&D. However, due to the existence of spillovers, firm two can partly benefit from firm one's innovation even though it cannot do research itself. In this section, we want to explain how firm one's incentives to invest in R&D will be influenced by the extent of knowledge spillovers. To that, a two stage game is introduced. In the first stage, firm one chooses innovation level, under which the two firms' cost structures will be determined, and then engages in quantity competition with firm two in the second stage game.

Suppose the representative consumer's utility function is of the form:

$$U(q_1, q_2) = \alpha(q_1 + q_2) - \frac{1}{2}(q_1 + q_2)^2 \tag{1}$$

where α is a constant, q_1 and q_2 are the quantities of products bought from firm 1 and 2, respectively. Then, the optimal consumption behavior will lead to the following inverse demand curve

$$p = \alpha - q_1 - q_2 \tag{2}$$

Based on this, the two firms' profits plus of research costs will be

$$\pi_1(q_1, q_2) = (\alpha - c_1 - q_1 - q_2)q_1 \quad \text{and} \quad \pi_2(q_1, q_2) = (\alpha - c_2 - q_1 - q_2)q_2 \tag{3}$$

where c_1 and c_2 are firm one and firm two's constant marginal production costs, respectively.

The game can be solved backwardly. In the second stage game, firm one and firm two choose the output level non-cooperatively to maximize their own profits, i.e.

$$Max_{q_1} \pi_1(q_1, q_2) \quad \text{and} \quad Max_{q_2} \pi_2(q_1, q_2) \tag{4}$$

By the first order conditions, we can get the equilibrium outputs

$$q_1(c_1, c_2) = \frac{\alpha - 2c_1 + c_2}{3} \quad \text{and} \quad q_2(c_1, c_2) = \frac{\alpha - 2c_2 + c_1}{3} \tag{5}$$

In the first stage game, firm 1 determines the optimal innovation level. For cost-reducing innovation, to reduce the marginal production cost by x we assume firm one will incur costs

$$c(x) = kx^2 \tag{6}$$

where k is a positive constant measuring firm one's R&D efficiency. As the rise of k, the research efficiency will decline. Due to the existence of knowledge spillovers, firm one's innovation also helps to reduce firm two's production cost. Suppose the spillover rate is θ, then given a certain innovation level, x, the two firms' production costs will be

$$c_1 = c_0 - x \quad \text{and} \quad c_2 = c_0 - \theta x \tag{7}$$

where c_0 is the initial production cost without innovation. Substitute Eq. (7) into Eq. (5), the equilibrium output levels of the second stage game can be expressed as

$$q_1(x, \theta) = \frac{\alpha - c_0 + (2 - \theta)x}{3} \quad \text{and} \quad q_2(x, \theta) = \frac{\alpha - c_0 + (2\theta - 1)x}{3} \tag{8}$$

Then, in the first stage game firm one's problem can be expressed as

$$Max_x \Pi_1(x) = \pi_1\Big[q_1(x,\theta), q_2(x,\theta)\Big] - kx^2 \tag{9}$$

The first order condition of the above maximization problem is [3]

$$\frac{\partial \pi_1}{\partial q_2}\frac{\partial q_2}{\partial x} - 2kx = -\frac{1}{3}\frac{\partial \pi_1}{\partial q_2} + \frac{2\theta}{3}\frac{\partial \pi_1}{\partial q_2} - 2kx = 0 \tag{10}$$

Based on this, we can get the equilibrium innovation level [4]

$$x(\theta) = \frac{2-\theta}{9k-(2-\theta)^2}(\alpha - c_0) \tag{11}$$

It can be seen from Eq. (10), compared to the case without spillovers a new item appears in firm one's first order condition, i.e. $\frac{2\theta}{3}\frac{\partial \pi_1}{\partial q_2}$. As this item is always non-positive and the second order condition of problem (9) requires $\frac{\partial^2 \Pi_1(x)}{\partial x^2} \le 0$, we can conclude that the introduction of knowledge spillovers will reduce the equilibrium innovation level. Katz (1986) pointed out the reason: under oligopoly model setting, knowledge spillovers strength the competitors and make the innovator suffer from its own innovation, which will dampen the innovator's incentives to do research. Differentiate Eq. (10) with respect to θ, we can get

$$\frac{\partial x(\theta)}{\partial \theta} = -\frac{9k+(2-\theta)^2}{[9k-(2-\theta)^2]^2}(\alpha - c_0) < 0 \tag{12}$$

That means, firm one's incentives to conduct R&D will continue to decline as the rise of the spillover rate.

3. Socially Optimal Spillover Rate

As analyzed in the last section, knowledge spillovers reduce firm one's incentives to conduct R&D and is detrimental to technological progress. But, from the standpoint of social welfare it also helps to raise firm two's production efficiency through knowledge diffusion. So, a minimum spillover rate is not necessarily the socially best choice. To maximize social welfare, we should balance between technological progress and knowledge diffusion. Suppose by adjusting the strength of IPRs protection, the government can achieve any spillover rate $\theta \in [0,1]$. In this section, our aim is to find the optimal spillover rate under which the social welfare will be maximized.

Based on the representative consumer's utility function and the cost structures of the two firms, the social welfare function can be constructed as follows

$$W = (\alpha - c_0 + x)q_1 + (\alpha - c_0 + \theta x)q_2 - \frac{1}{2}(q_1+q_2)^2 - kx^2 \tag{13}$$

with $x = x(\theta)$, $q_1 = q_1(x,\theta)$, and $q_2 = q_2(x,\theta)$. Totally differentiate Eq. (13) with respect to θ, we get

$$\frac{dW}{d\theta} = \frac{\partial W}{\partial \theta} + [\frac{\partial W}{\partial q_1}\frac{\partial q_1}{\partial \theta} + \frac{\partial W}{\partial q_2}\frac{\partial q_2}{\partial \theta}] + [\frac{\partial W}{\partial q_1}\frac{\partial q_1}{\partial x} + \frac{\partial W}{\partial q_2}\frac{\partial q_2}{\partial x}]\frac{\partial x}{\partial \theta} + \frac{\partial W}{\partial x}\frac{\partial x}{\partial \theta} \tag{14}$$

It can be seen that, if we change the spillover rate, four kinds of effects can be identified. And, they are:

[3] In the second stage game, we already know $\frac{\partial \pi_1}{\partial q_1} = 0$.

[4] To make sure the equilibrium innovation level is non-negative, i.e. $x(\theta) \ge 0$, and $q_1(x,\theta) \ge 0$, $q_2(x,\theta) \ge 0$, $\frac{\partial^2 \Pi_1(x)}{\partial x^2} \le 0$ at $x = x(\theta)$, for any $\theta \in [0,1]$, in what follows we assume $k \ge \frac{2}{3}$.

- the knowledge diffusion effect: $\frac{\partial W}{\partial \theta}$, noted as KDE
- the production effect: $\frac{\partial W}{\partial q_1}\frac{\partial q_1}{\partial \theta} + \frac{\partial W}{\partial q_2}\frac{\partial q_2}{\partial \theta}$, noted as PE
- the indirect innovation effect: $[\frac{\partial W}{\partial q_1}\frac{\partial q_1}{\partial x} + \frac{\partial W}{\partial q_2}\frac{\partial q_2}{\partial x}]\frac{\partial x}{\partial \theta}$, noted as IIE
- the direct innovation effect: $\frac{\partial W}{\partial x}\frac{\partial x}{\partial \theta}$, noted as DIE

Next, we want to briefly explain each of the four effects and specify their impacts on social welfare. Firstly, the knowledge diffusion effect, [5]

$$\text{KDE} \geq 0 \tag{15}$$

Knowledge spillovers from the innovator will strength firm two and raise its productivity. Then, for a given output level the overall production costs will decline as the rise of the spillover rate. Therefore, the social welfare will improve due to this effect.

Secondly, the production effect, [6]

$$\text{PE} \geq 0 \quad \text{iff} \quad 3k - 2(1-\theta)(2-\theta) \geq 0 \tag{16}$$

Given a certain innovation level, the rise of θ will narrow the production cost gap between the two firms. Under strategic interactions, this will motivate firm one to reduce output and firm two to increase output. As now a larger proportion of the overall outputs will be produced by the less efficient firm, the social welfare tends to decline. However, if the rise of firm two's output is sufficiently larger than the decline of firm one's output, social welfare can still be increased because of the overall output expansion. So, the sigh of the production effect is ambiguous and it will depend on the relative strength of the output reallocation effect and the output expansion effect. When firm one is not very productive in R&D or the spillover rate is high, i.e. $3k - 2(1-\theta)(2-\theta) \geq 0$, the latter dominates and the sigh of the production effect is positive.

Thirdly, the indirect innovation effect, [7]

$$\text{IIE} \leq 0 \tag{17}$$

If we increase the spillover rate, the equilibrium innovation level will decline. Under a lower innovation level, both firms will reduce their outputs. As for the duopoly case the equilibrium output level is always lower than social optimal, the further decline of overall outputs will reduce social welfare. So, the sigh of the indirect innovation effect is negative.

Finally, the direct innovation effect, [8]

$$\text{DIE} \geq 0 \quad \text{iff} \quad (5\theta - 1)k - \theta(1-\theta)(2-\theta) \leq 0 \tag{18}$$

As DIE $= \frac{\partial W}{\partial x}\frac{\partial x}{\partial \theta}$ and we already know $\frac{\partial x}{\partial \theta} < 0$, to specify the sign of DIE, we only have to determine the sigh of $\frac{\partial W}{\partial x}$. From the standpoint of social welfare, given any

[5] $\text{KDE} = xq_2$

[6] $\text{PE} = \frac{[3k-2(1-\theta)(2-\theta)](\alpha-c_0)}{9k-(2-\theta)^2}x$.

[7] $\text{IIE} = \frac{(1+\theta)(\alpha-c_0)+(2-\theta)^2x+(2\theta-1)^2x}{9}\frac{\partial x}{\partial \theta}$

[8] $\text{DIE} = \frac{[(5\theta-1)k-\theta(1-\theta)(2-\theta)](\alpha-c_0)}{9k-(2-\theta)^2}\frac{\partial x}{\partial \theta}$

output level to achieve the minimum production costs the first best innovation level will always satisfy $\frac{\partial W}{\partial x} = 0$. But, in the two stage game, as pointed out by Brander and Spencer (1983), when R&D take place before the production stage, the innovating firm will use it for strategic purposes rather than simply to minimize costs. The consequences of the strategic use of R&D is that: when the spillover rate is small the equilibrium innovation level is higher than social optimal, whereas for large spillovers the equilibrium innovation level is lower than social optimal. So, if the initial θ is small, raising it will reduce equilibrium innovation level and increase social welfare, whereas if the initial rate is large, further increase of spillovers is welfare reducing.

When the spillover rate changes, the relative importance of the above four effects will vary under different parameter settings. As an example, in figure 1 we give the comparison results for the parameter range $k \times \theta = [\frac{2}{3}, \frac{5}{3}] \times [0, 1]$. [9]

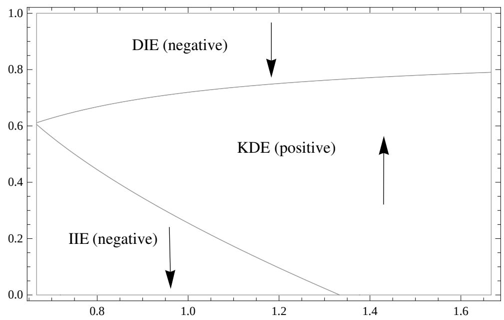

Figure 1: The relative importance of the four effects caused by spillover change [10]

It can be seen that, when firm one's R&D efficiency is high and the spillover rate is small, the indirect innovation effect dominates, when firm one's innovation efficiency is low and the spillover rate is not very large, the knowledge diffusion effect dominates, and for large spillovers the direct innovation effect plays a dominant role and its sign is negative regardless of firm one's R&D efficiency. As for the production effect, it never plays a dominant role in the above parameter range. Based on the relative strength of the four effects specified in the three different parameter regions, it can be anticipated that the optimal spillover rate should be a declining function of firm one's R&D efficiency. And, the exact result is given by figure 2.

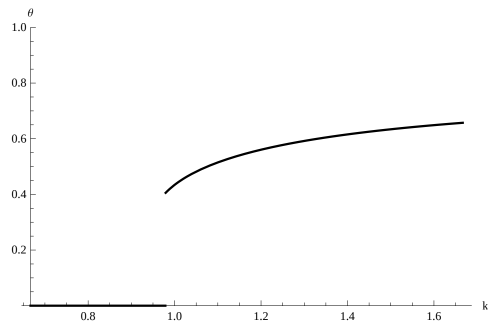

Figure 2: Optimal strength of IPRs protection

The rationale behind figure 2 is very straightforward. When firm one's innovation efficiency is very high, the indirect innovation effect dominates. In this case, to maximize

[9]We use Mathematica to get the results in figure 1 and figure 2, the calculation code can be provided upon request.

[10]The arrows point to the directions in which the spillover rate should be changed to increase social welfare.

social welfare we should maintain a strict IPRs protection. As the rise of k, the importance of knowledge diffusion effect increases, and now it is better to relax the IPRs protection strength and let the follower firm enjoy some benefits of firm one's innovation. Of course, due to the counteractive influence of the direct innovation effect the spillover rate cannot be raised unboundedly. However, as the continue decline of firm one's innovation efficiency the relative importance of direct innovation effect will decline, and now to raise social welfare we can further increase the spillovers. In all, the socially optimal spillover rate should be a decreasing function of firm one's R&D efficiency. Graphically, the optimal θ will rise as the increase of k. [11]For policy concern, the government should increase the strength of IPRs protection as the rise of the innovating firm's R&D efficiency.

4. Conclusion

By adjusting the strength of IPRs protection, the government can change the extent of knowledge spillovers in R&D. A large spillover rate helps to strength the less efficient firms and save on the overall production costs. But, at the same time, it reduces the innovator's incentives to conduct R&D and results in a lower equilibrium innovation level. So, there is an inherent tension between knowledge diffusion and technological progress. In this paper, we formalized this relationship in an economic model, tried to find the socially optimal spillover rate, and then specified the optimal IPRs protection strength.

Specifically, a two stage asymmetric duopoly game is introduced in this paper. For this game, the equilibrium social welfare can be expressed as a function of the spillover rate. The first derivative of this function indicates that: if we change the extent of knowledge spillovers four kinds of effects on social welfare can be identified, the knowledge diffusion effect, the production effect, the indirect innovation effect, and the direct innovation effect. Under different parameter settings, the relative importance of the four effects will change. By balancing between these effects, we demonstrated that: the socially optimal strength of IPRs protection should be an increasing function of the innovating firm's R&D efficiency.

[11]Due to the multidimensional effects of spillovers on social welfare, the optimal spillover rate displays a discontinuous characteristic at $k \approx 0.98$. At this point, the maximum welfare can be realized at either $\theta = 0$ or $\theta \approx 0.41$.

References

Brander, J. A. and B. J. Spencer (1983) "Strategic Commitment with R&D: The Symmetric Case" *The Bell Journal of Economics* 14, 225-235.

D'Aspremont, C. and A. Jacquemin (1988) "Cooperative and Noncooperative R&D in Duopoly with Spillovers" *The American Economic Review* 78, 1133-1137.

Jacquemin, A. (1988) "Cooperative agreements in R&D and European antitrust policy" *European Economic Review* 32, 551-560.

Kamien, M. I., E. Muller and I. Zang (1992) "Research Joint Ventures and R&D Cartels" *The American Economic Review* 82, 1293-1306.

Kang, M. (2006) "Trade Policy mix: IPR Protection and R&D Subsidies
Mlanges de politiques commerciales: protection des droits de proprit intellectuelle et subventions la R&D" *Canadian Journal of Economics/Revue canadienne d'conomique* 39, 744-757.

Katz, M. L. (1986) "An Analysis of Cooperative Research and Development" *The RAND Journal of Economics* 17, 527-543.

Labory, S. (2004) "EU Policies for Innovation and Knowledge Diffusion" in *Patrizio Bianchi and Sandrine Labory, The Economic Importance of Intangible Assets* Hampshire, UK: Ashgate Publishing Ltd., 49-72.

Leahy, D. and J. P. Neary (1997) "Public Policy Towards R&D in Oligopolistic Industries" *The American Economic Review* 87, 642-662.

Martin, S. (1997) "Public Policies Towards Cooperation in Research and Development" in *Competition Policy in the Global Economy* London and New York: Routledge.