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Inducing R&D investment with price ceilings

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Abstract

Though government intervention is prevalent in the market for research and development (R&D), most literature has focused on the use of subsidies, patents or joint research ventures to obtain the efficient R&D investment. By using a two-stage duopoly model in which firms first choose the level of investment and then output, our paper shows that the introduction of a price ceiling by the regulator will result in the optimal level of R&D. This interesting but counterintuitive result contrasts with the existing literature and advances our understanding about price ceilings.

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1. Introduction

It is well known that the public good nature of research and development (R&D) results in sub-optimal levels of R&D chosen by profit-maximizing firms. Because a single firm cannot appropriate rents from the positive spillovers created from their own R&D investment, it chooses a level that is below what a social planner would choose. In the existing literature, the role of the social planner to address this market failure has traditionally been to subsidize firm R&D, to encourage joint research cooperatives or to grant property rights over the outcomes of R&D (e.g. patents).[1] Using a two-stage duopoly game, this paper shows that a price ceiling can be used to induce the optimal level of R&D investment. However, because of the information burden it imposes, it is not to be interpreted as a policy prescription, but rather as a surprisingly interesting (and counterintuitive) theoretical result.

The two-stage duopoly model with positive R&D spillovers introduced by D'Aspremont and Jacquemin (1988) provides the theoretical framework for the model employed here. The first stage is characterized by firms choosing R&D levels which result in process innovation (lowering of marginal production costs). The second stage is characterized by Cournot competition. It is the case that firms fail to recognize the marginal social benefit created from their investment in R&D when spillovers exist. A price ceiling can be used to raise the marginal private benefit of R&D.[2] Simply, when the firm is faced with a fixed price and quantity, its choice variable simplifies to choosing R&D levels that lower marginal costs. The more a firm produces, the more it is motivated to lower its marginal costs by investing in R&D. Therefore, by making the market more "competitive", firms want to innovate more.

The remainder of the paper is as follows. In Section 2, we employ the standard two-stage duopoly model to show that a profit-maximizing firm chooses a level of R&D that is below what is optimal. Since the use of a R&D subsidy is most prevalent in existing literature, we derive the relevant subsidy that would correct the market failure. In Section 3, we show how a price ceiling on output can be used to induce the optimal R&D investment. In Section 4, we conclude with a brief comparison of mechanisms used to correct the market failure and the limitation of using a price ceiling.

2. The Modeling Framework

Consider a model with two firms producing a homogeneous good.[3] Firms are identical and indexed by i, $i = 1,2$. Firms face an inverse demand function $P = P(Q)$, where $Q = q_1 + q_2$, q_i denotes firm i's output, and $P'(Q) < 0$. Each firm has an initial constant marginal cost c_0, and can reduce c_0 by investing in research and development. Firms independently invest in R&D, but R&D is a public good in that one firm's R&D spending also benefits the other firm. We denote the marginal cost function for each firm as $c_i = c(R)$, where $R = r_1 + r_2$, r_i is firm i's investment in R&D, $c(0) = c_0$, $c'(R) < 0$, and $c''(R) > 0$. The convexity of the cost function reflects diminishing returns to R&D spending: each firm benefits from its own R&D investment and the other firm's R&D investment,

[1] For example, see Tirole (Ch. 10, 1988) for a detailed discussion.

[2] This is in contrast to a subsidy which effectively lowers the marginal cost of R&D.

[3] Our results derived from a two-firm model can be easily extended to an n-firm case.

but at a decreasing rate. The timing of firms' decisions is as follows. In the first stage, each firm makes a decision on how much to invest in R&D independently, and in the second stage they compete on quantity with their costs of production determined in stage one.

Using backward induction, given the R&D investment levels chosen in the first stage, firms engage in Cournot competition in the second stage. Firm i solves the following problem:

$$\underset{q_i}{Max}\ [P(q_1+q_2)-c(r_1+r_2)]\cdot q_i.$$

The first-order condition, $P'(q_1+q_2)\cdot q_i+P(q_1+q_2)-c(r_1+r_2)=0$, implicitly defines the best response function for firm i given r_i determined in the first stage. Assuming a symmetric equilibrium exists, we can express the equilibrium solution as a function of (r_1,r_2) : $q_i^*=q(r_1+r_2)$. It is easy to show $\partial q_i^*/\partial r_i>0$.[4] That is, a greater R&D investment leads to a greater output in the second stage.

In the first stage, firm i chooses R&D investment by solving the following:

$$\underset{r_i}{Max}\ [P(2q(r_1+r_2))-c(r_1+r_2)]\cdot q(r_1+r_2)-r_i.$$

From the first order condition, we obtain:

$$[2P'(2q(R^{NC}))q'(R^{NC})-c'(R^{NC})]q(R^{NC})+[P(2q(R^{NC}))-c(R^{NC})]q'(R^{NC})=1, \tag{1}$$

where $R^{NC}=r_1^{NC}+r_2^{NC}$ denotes the non-cooperative industry R&D investment level.

Assume the demand and cost functions are well behaved such that the second order condition is strictly negative at all ranges we consider. Equation (1) implicitly determines the industry R&D level, R^{NC}, and the best response R&D investment for each firm at the symmetric equilibrium.[5] However, it is not optimal. Firm i only takes into account of its own benefit and ignores the spillover effect of its R&D expenditures on the other firm.

Suppose an industry regulator exists and chooses R&D levels in the first stage that maximizes the combined profits of two firms without changing the nature of competition in stage two. This is analogous to the setting of cooperation in R&D but not in output market as in D'Aspremont and Jacquemin (1988). Thus, the problem in stage two is unchanged, and the regulator solves the following maximization problem in stage one:

$$\underset{r_1,r_2}{Max}\sum_i\{[P(2q(r_1+r_2))-c(r_1+r_2)]\cdot q(r_1+r_2)-r_i\}.$$

The first order condition shows:

$$[2P'(2q(R^*))q'(R^*)-c'(R^*)]q(R^*)+[P(2q(R^*))-c(R^*)]q'(R^*)=\frac{1}{2}, \tag{2}$$

where $R^*=r_1^*+r_2^*$ is the optimal industry R&D level and r_i^* is the desired R&D for each firm from the perspective of the industry regulator.

Comparing equation (2) with equation (1) allows us to infer whether underinvestment in R&D occurs in the non-cooperative setting. Let us denote the left hand side of the first-order conditions

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[4] $\frac{\partial q_i^*}{\partial r_i}=\frac{c'(\cdot)}{SOC}>0$, where SOC denotes the second order condition that is assumed to hold.

[5] There are potentially many equilibrium outcomes, but we only look at the symmetric one.

in stage one as $f(R)$, then equations (1) and (2) can be rewritten as $f(R^{NC}) = 1$ and $f(R^*) = 1/2$, respectively. From our earlier assumption, with well behaved demand and cost functions, $f'(R) < 0$. Recognize that f is a decreasing function implying $R_i^{NC} < R_i^*$, that is, the non-cooperative industry R&D investment is below the optimal industry level and both firms produce less than their optimal.[6] This is consistent with the literature on R&D investment with spillovers. Without government intervention, positive R&D externalities are not considered by firms when making an innovation decision.

The most common tool to correct the market failure is R&D subsidies. Effectively, a subsidy lowers the marginal cost of R&D spending (the RHS of the first-order condition in equation (1)). For example, suppose the industry regulator sets a subsidy of s dollars per dollar of R&D investment spent by the firm. The objective function in stage one is altered such that firm i chooses r_i to solve:

$$\underset{r_i}{Max}\ [P(2q(r_1+r_2)) - c(r_1+r_2)] \cdot q(r_1+r_2) - (1-s)r_i.$$

Using the same notation as before, the first order condition becomes $f(R) = 1-s$. Equating this first order condition with the optimal condition (equation (2)) gives the level of optimal subsidy, $s^* = 1/2$. To induce the optimal level of R&D, the government must cover half of each firm's expenditure.

3. Price Ceiling

Equation (1) indicates that a firm will choose the R&D spending level which makes the marginal benefit to innovate (cost savings on production) equal to the marginal cost of R&D, given the other firm's choice. Note that the cost savings arising from each dollar of R&D spending is associated with the production level the firm chooses. Thus, in this stage of the game, a higher level of output implies a greater marginal benefit of innovation. The more each firm produces, the more each firm wants its production cost to be lower. To induce the two firms to spend more on innovation activities, a price ceiling can be employed to force the firms to produce more.

Let the price ceiling be P^c. As long as P^c is higher than the marginal cost after innovation, the two firms will produce according to the demand curve. In the symmetric equilibrium, these two firms evenly split the market, and each firm produces $q_i = P^{-1}(P^c)/2$. Equating the marginal benefit from one dollar of spending on R&D to the marginal cost, we have

$$-c'(r_1+r_2) \cdot q_i = 1, \text{ or, } P^{-1}(P^c) = -\frac{2}{c'(R)},$$

which defines the relationship between the level of R&D spending the firms will choose and the price ceiling the government imposes: $R = R(P^c)$. It is easy to show that the market R&D investment level is decreasing in the price ceiling: $R'(P^c) < 0$ for $P^c \geq c(R)$. This means imposing a lower price ceiling causes firms to spend more on R&D as long as they will make a profit. To induce firms to choose the optimal level of R&D investment, the industry regulator simply sets $R(P^{c^*}) = R^*$. Solving the equation, we get $P^{c^*} = P(-2/c'(R^*))$, which proves the following result.

[6] This is usually the case even with incomplete spillovers.

Proposition 1. *Firms invest in cost-reducing R&D activities at the optimal level under the price ceiling* $P^{c^*} = P(-2/c'(R^*))$ *in the symmetric equilibrium, as long as the following holds:*

$$P\left(-\frac{2}{c'(R^*)}\right) \geq c(R^*) - R^* \cdot \frac{c'(R^*)}{2}. \tag{3}$$

The condition we need (expression (3)) for a price ceiling to work is a participation constraint which simply says a firm's profit is nonnegative. The revenue from selling products should be at least as large as the sum of production cost and R&D spending. As long as the market is large enough to satisfy this condition, the optimal level of R&D, as we outlined in section 2, can be achieved.

Generally, price regulation is often overlooked as a tool to achieve socially desired outcomes. In that light, our result that an appropriate price ceiling induces the optimal level of R&D investment is quite surprising. In a setting of positive R&D spillovers, the effective role of price ceiling arises from the particular assumption that R&D reduces marginal costs. Under these circumstances, the benefit from investing in R&D is associated with the firm's production level. Consequently, making a firm invest more in R&D can be accomplished by making a firm produce more. The price ceiling forces firms to choose higher production levels, and thus benefit more from additional R&D spending.

4. Conclusive Discussion

In a market where R&D investment can spillover to other firms, the standard free-riding problem exists and underinvestment in R&D occurs. R&D subsidies, joint research cooperatives and patents have been used in economic theory (and in public policy) to allow firms to internalize the positive externality. In the case of subsidies, the marginal cost of R&D is reduced; for cooperatives and patents, the marginal private benefit of R&D is raised. In the preceding analysis, we showed that, in theory, a price ceiling for Cournot duopolists could be used to raise the marginal private benefit of R&D as well. Although the use of a price ceiling is less practical from a policy standpoint, the analysis still provides a surprising mechanism that achieves the optimal level of R&D.

Still, even these aforementioned mechanisms have their issues worth mentioning. Subsidies place financial burdens on the government which may result in large welfare losses when lump-sum taxation is not used. And if a subsidy is given retroactively to the firm, moral hazard problems exist if monitoring of R&D is too costly (Romano 1991). Assigning patents to the outputs of R&D (such as a new production technology) can have significant welfare effects as well if they create excess market power (Romano 1991). Research joint ventures may increase the probability that the participating firms collude on the output market (Leahy and Neary 1997).

Theoretically, a price ceiling would not have these particular issues. However, finding a proper price ceiling requires the regulator having perfect information about the firms' cost structure relating to R&D spending and information on market demand as well. This places extra burdens on the regulator. As a result, the policy implication of this paper is rather limited. With that said, our finding that a price ceiling induces Cournot competitors to innovate contributes to the existing R&D literature. While price ceilings are often seen as distorting the market and creating efficiency losses, we find a circumstance where it can enhance efficiency.

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