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Quadratic Costs, Innovation and Welfare: The Role of Technology

Abstract

In a Cournot oligopoly set up with constant marginal cost and linear demand, innovation is rewarding. In this paper we work with a Cournot oligopoly framework with increasing marginal cost and linear demand and show that innovation may not be rewarding. We endogenize the success probability of R&D and its response to the intensity of competition and specifically show that if the technology is already advanced and competition intensifies then firms wouldn't innovate. The dynamic interaction we attempt to capture and explain is the one of technology with the possibility of innovation via the intensity of competition. We finally conclude that the intensity of competition and welfare may not have the usual (direct) relationship and suggest 'monitored competition', wherein initially (at initial stages of innovation) competition is encouraged and then (at later stages of innovation) curtailed, to encourage innovation and thus welfare, as a suitable policy measure. Thus, entry should be restricted in order to foster innovation while innovation itself encourages entry.

JEL-Codes: L110, L130, L210.

Keywords: quadratic costs, innovation, welfare, technology.

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1. Introduction

Incentives to innovate have been analyzed form various angles such as product differentiation (horizontal – Bester and Petrakis (1993) and vertical – Bonanno and Haworth (1998)), profit incentives (Yi (1999) and Delbono and Denicolò (1990)). This literature suggests that different measures of competition affect the firms' incentives to innovate in different ways.

Market structures and innovation has occupied the centre-stage in the innovation literature since 1943 (Schumpeter's Capitalism, Socialism, and Democracy). The "Schumpeterian tradeoff" – perfectly competitive firms perform well in the sense of efficient allocation of resources (in the static sense) but poorly in terms of innovation, has been dominant in many contributions (Paolo Sylos-Labini (1969), F. M. Scherer (1980), C. C. von Weizsacker (1980), Richard Nelson and Sidney Winter (1982), and Morton Kamien and Nancy Schwartz (1982)). Thus, the optimal market form seems to be the one having elements of monopoly.

However, later it was shown that perfect competition was more conducive to innovation than monopoly as there are more incentives for a perfectly competitive firms to innovate as against a monopolist (Arrow (1962)). This is so because the monopolist already makes profits before innovation while the perfectly competitive firm just recovers its costs. Belleflamme and Vergari (2011) present a unified framework whereby various sources of competition interact and shape the firm's incentives to innovate. They study the intensity of competition on innovation incentives and argue, in consonance of the existing literature (both, theoretical (Scherer (1967b), Barzel (1968), and Kamien and Schwartz (1972, 1976) as well as empirical (Mansfield (1963), Williamson (1965), and Scherer (1967a)) that in contrast to the diametrically opposite and extreme cases of perfect competition and monopoly, the intermediate market forms may offer higher innovation incentives. However, they (Belleflamme and Vergari (2011)) qualify their findings by stating that different market forms create different incentives for innovation in different industries.

Tandon (1984) extends the Dasgupta and Stiglitz (1980) approach for analysis of the tradeoff between static and dynamic efficiency. Optimal market structure or optimal degree of concentration is the main focus in answering the questions, '*are barriers to entry in addition to those created by R&D desirable?'* He finds the answer to be in the affirmative.

Traditional view suggests that entry of a firm in a market decreases the profit of the incumbent firms. However, introduction of R&D activities may lead to conclusions in contrast to the traditional view. Ishida et al. (2011) show that entry of a firm with a less efficient technology enhances the both the R&D investment and the profit of the incumbent firms (which have a more efficient production technology). Entry in presence of marginal cost differences decreases welfare in Cournot oligopoly set up if the constant marginal cost of the entrant is sufficiently higher than those of the incumbents (Klemperer (1988) and Lahiri and Ono (1988)). Thus this literature again is in contrast to the conventional view that entry enhances welfare, may not hold in Cournot oligopoly set up. There is also a part of the literature focusing on asymmetry due to differences in firm level R&D capabilities. Interested readers may see Gallini (1992), Bester and Petrakis (1993), Mukherjee (2002), Mattoo et al. (2004) and Mukherjee and Pennings (2004 & 2011).

Some studies have also shown that entry of firms may enhance the incumbent firms' profits. Working with a sequential – move model in an asymmetric (marginal cost) Stackelberg set up Mukherjee and Zhao (2009) show that an inefficient follower (entrant) increases the profits of the incumbent firms (two) which, though, are heterogeneous in their efficiencies, but are relatively more efficient compared to the follower (entrant). However, similar results also obtained by Coughlan and Soberman (2005), Chen and Riordan (2007), and Ishibashi and Matsushima (2009), but the difference is that they use simultaneous – move models.

In general, the linear demand constant marginal cost framework has been extensively used for the behavioral analysis of the firms. For instance, in collusion literature the constant cost framework has been extensively used. In the context of homogeneous goods with constant marginal cost, Gibbons (1992), Martin (2001), Shy (1996), and Tirole (1988) show that in an infinitely repeated game whether collusion or Cournot competition would be the subgame perfect equilibrium (SPE) has nothing to do with (is independent of) technology. The magnitude of the discount factor is the sole determinant of the SPE. However, altering the basic framework just slightly and working with increasing marginal cost instead alters the results drastically and offers novel insights.

Marjit, Misra & Banerjee (2017) analyze the issue of collusion using the altered framework (replacing the constant marginal cost assumption with increasing marginal cost) and contribute drastically different results to the collusion literature. They show that the critical discount factor which determines the SPE outcome is monotonically increasing in technological improvement, as in, technological improvement monotonically increases the critical discount factor, above which collusion is the SPE. They highlight an alteration of the market structure from collusion to Cournot competition as a function of technological improvement and the resultant welfare. They show as to how technology can possibly contribute in evolution of market structures. Under the constant marginal cost framework, as stated above, technology has no role to play in collusion and thus the market structure alteration due to technological changes is ruled out.

It is well known that in the linear demand constant marginal cost setting innovation by the firms will always be rewarding and also that an increase in the number of firms will be welfare enhancing. The purpose of this paper is to show that both the above stated results may not hold. Also, an implicit result in Marjit, Misra & Banerjee (2017) is that a technological improvement enhances the profit of an individual firm in collusion while the same would not be true of Cournot competition; we show this result explicitly in this paper. Using the increasing marginal cost framework, we analyze the incentives for innovation by firms and derive a novel set of results, which potentially could have very interesting welfare/ policy implications.

Our basic model is presented in section 2, innovation incentives are analyzed in section 3, inter-temporal analysis of innovation and entry by firms is presented in section 4 and section 5 finally, has the concluding remarks.

2. The Model

Consider a market with an inverse demand function of the form $p = a - q$. Suppose there are n firms with symmetric cost function of the form $c_i(q_i) = \frac{sq_i^2}{2}; i = 1,2, \dots, n$ and q_i is the output produced by firm i. The parameter s captures the level of technology and we assume that $s > 0$. A fall in s or a lower s represents a cost reducing technological improvement.

Consider an n-firm Cournot oligopoly. Firm i's profit and reaction function are $\pi_i(q_i, q_{-i}) = (a - \sum_{i=1}^{n} q_i)q_i - \frac{sq_i^2}{2}$ and $q_i = \frac{a - \sum_{j \neq i}^{n} q_j}{s+2}$. We use the superscript "o" to denote the equilibrium outcomes under Cournot oligopoly. Due to symmetry, in equilibrium we have $q_1^o = q_2^o = \cdots = q_i^o = \cdots = q_n^o = \frac{a}{n+s+1}$. Thus, the total output and price in equilibrium are,

$$q^o = \frac{na}{n+s+1} \text{ and } p^o = \frac{a(s+1)}{n+s+1} \quad (1)$$

The equilibrium profit of the firm i is,

$$\pi_i^o = \frac{a^2(s+2)}{2(n+s+1)^2} \quad (2)$$

Suppose the n firms collude, act as a cartel and maximize joint profit. This is like a multi-plant monopoly with n plants. The equilibrium condition in this case is that the marginal cost of producing the last unit in each plant should equal one another and also equal the marginal revenue, that is,

$$MC_1 = MC_2 = \cdots = MC_i = \cdots = MC_n = MR \quad (3)$$

Now $MC_i = sq_i$ and $MR = a - 2q = a - 2\sum_{i=1}^{n} q_i$. Then using the equilibrium condition stated in equation (3) we get $sq_i = a - 2\sum_{i=1}^{n} q_i$. Since all firms are symmetric, hence, in equilibrium the output produced in each plant will be the same. Thus, $sq_i = a - 2nq_i$. The solution to this equation gives us the equilibrium output produced by each firm under collusion, which is $q_i^c = \frac{a}{2n+s}$, where the superscript "c" represents collusion. The total output and the market price under collusion are,

$$q^c = \frac{na}{2n+s} \text{ and } p^c = \frac{a(n+s)}{2n+s} \quad (4)$$

Correspondingly, each firm's profit under collusion is,

$$\pi_i^c = \frac{a^2}{2(2n+s)} \quad (5)$$

Comparing the total output under collusion to that under Cournot oligopoly we see that $q^c = \frac{na}{2n+s} < q^o = \frac{na}{n+s+1}$ because $2n > n + 1$. This means that the standard result that the Cournot output exceeds the collusive output holds. A comparison between the profit levels of each firm in the Cournot case (π_i^o) to that in the case of collusion (π_i^c) yields,

$$\pi_i^c - \pi_i^o = \frac{a^2(n-1)^2}{2(2n+s)(n+s+1)^2} > 0 \tag{6}$$

That is, the collusive profit of a firm always dominates its Cournot profit. Hence, for all values of s collusion is always a possibility.

Let us now consider the deviation from collusion. Suppose each of the $n - 1$ firms, with the exception of firm i, plays the naive collusive output level $q_j^c = \frac{a}{2n+s}; j \neq i$. Firm i deviates by choosing its output according to its reaction function, which yields $q_i^d = \frac{a(n+s+1)}{(2n+s)(s+2)}$ where the superscript "d" denotes the outcome under deviation. The price and firm i's profit under defection are $p^d = \frac{a(s+1)(n+s+1)}{(2n+s)(s+2)}$ and $\pi_i^d = \frac{a^2(n+s+1)^2}{2(2n+s)^2(s+2)}$.

Now we have a prisoner's dilemma setting where the equilibrium of the one-shot game is each firm chooses the non-cooperative Cournot oligopoly output. We next proceed with the analysis of self-enforcing collusion.

3 Innovation Incentives

Profit of a colluding firm, is always an increasing function of technological improvement, i.e., a cost reducing technological improvement (a reduction in s), always enhances an individual firm's profit under collusion. However, the same may not hold under Cournot competition.

Proposition 1: *A technological improvement that reduces s:*

(i). unambiguously increases a firm's profit under collusion;

(ii). increases a firm' profit under Cournot oligopoly iff $n \leq s + 3$.

Proof of Proposition 1:

(i). $\frac{d\pi_i^c}{ds} = -\frac{a^2}{2(2n+s)^2} < 0$ which indicates that a reduction in s increases the profit of a firm under collusion.

(ii). $\frac{d\pi_i^o}{ds} = \frac{a^2(n-s-3)}{2(n+s+1)^3}$ which is negative (a reduction in s increases the profit of a firm under Cournot oligopoly) iff $n \leq s + 3$. ***Q.E.D.***

The above proposition shows that under collusion, technological improvement always increases an individual firm's profit. However, when Cournot oligopoly is the market structure with quadratic costs, cost cutting technological improvement would not necessarily always increase an individual firm's profit. In this case a decline in s raises a firm's profit if and only if the number of firms is restricted to $n \leq s + 3$ or technology is as per the following relationship $s \geq n - 3$. If $n \leq 3$ then a cost cutting technological improvement increases an individual firm's profit with certainty. However, a cost cutting technological improvement would not increase an individual firm's profit with certainty if $n > 3$. Thus, in our set up, there would be conditional innovation by the firms, i.e., innovation contingent upon the number of firms in the market, as per the required condition of $n \leq s + 3$. This is very different from a Cournot model with constant marginal cost where cost cutting innovation is always profitable.

For instance, if we consider a discrete analysis, the following schedule coupled with figure 1 illustrates the idea. n is the number of firms in the market and s is the technological condition required for innovation to take place.

n	3	4	5	6	7	8	9	10	11
s	> 0	> 1	> 2	> 3	> 4	> 5	> 6	> 7	> 8

Table 1: Number of firms (n) and the technology (s) required for innovation

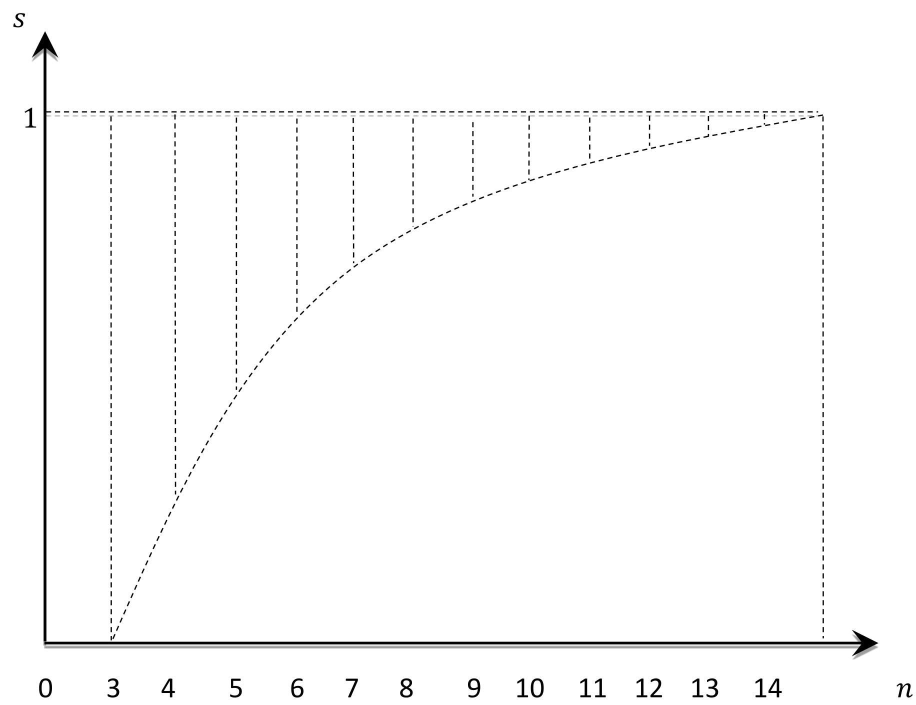

Figure 1: Number of firms (n) and the probability of innovation

In the above graph (figure 1), the dotted vertical line corresponding to every level of n can be interpreted as the probability of innovation by the firms. As can be seen, as n becomes larger and larger, the probability of innovation gets smaller and smaller and ultimately becomes zero.

The above analysis can be generalized for the continuous case as follows. Let S be defined as all possible levels of technology, i.e., the universal set of technology, and indexed as $S \in [0,1]$, 0 being most efficient and 1 being least efficient. Let $s = s(n)$ be the set of technology for which technological innovation would be undertaken by the firms. Our above condition $n \leq s + 3$ or $s \geq n + 3$ ensures that $s' < 0$, i.e., as the number of firms in the market increases, the set of technology for which innovation would take place goes on shrinking. Thus, the probability of innovation can be given as the following fraction, $\frac{s(n)}{S}$.

It can be shown that $\lim_{n \to 0} s(n) = S$ and $\lim_{n \to \infty} s(n) = 0$. Thus, $\lim_{n \to \infty} \frac{s(n)}{S} = 0$, i.e., no probability of innovation. The same may be shown graphically as follows (figure 2),

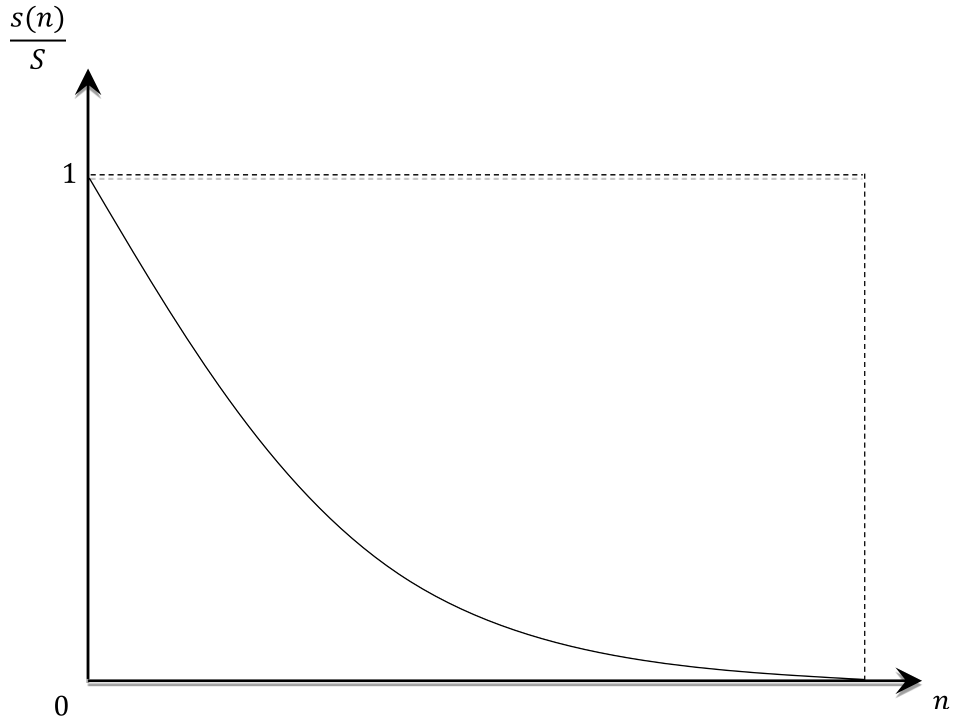

Figure 2: Number of firms (n) and the probability of innovation

Proposition 2: *Number of firms, n, affects the probability of innovation in the following manner,*
(i). As long as there are three or lesser firms is the market, i.e., for $n \leq 3$, firms will take up cost cutting innovation with certainty.
(ii). When there are more than three firms is the market, i.e., for $n > 3$, firms will not take up cost cutting innovation with certainty. Rather, there would be conditional innovation by firms.

Proof of Proposition 2: Please see the above discussion and analysis in sections 3 and figures 1 and 2.

4 Innovation, entry and welfare

It has been established above that if $n \leq 3$ then a cost cutting technological improvement increases an individual firm's profit with certainty. Let us engage in an intertemporal analysis of innovation and entry of firms in the market. Let us work with Cournot duopoly where the firms invest in R&D and thus in innovation in the first time frame and there is entry of firms in the market in the next time frame. A representative firm's profit in Cournot oligopoly with quadratic costs would be as follows,

$$\pi_i^o = \frac{a^2(s+2)}{2(n+s+1)^2}$$

Thus, a representative firm's profit in Cournot duopoly with quadratic costs would be the following,

$$\pi_i^{du} = \frac{a^2(s+2)}{2(s+3)^2}$$

Let the firm indulge in cost cutting innovation. Let the initial technology of the firm be s_0 and after innovation the firm has access to a technological level s_1; where, $s_1 < s_0$. Let the relationship between s_0 and s_1 be as given as below,

$$s_1 = \alpha s_0;\ 0 \leq \alpha \leq 1 \tag{7}$$

where, α can be interpreted as the proportion of the original cost required for production post innovation. Clearly, the more α moves towards zero, the lesser is the post innovation s, and thus, the greater is the technological improvement.

Let Ω be defined as the degree of innovation. Thus, $\Omega = \Omega(\alpha)$; $\Omega' < 0$. The same can be depicted graphically as shown below (figure 3),

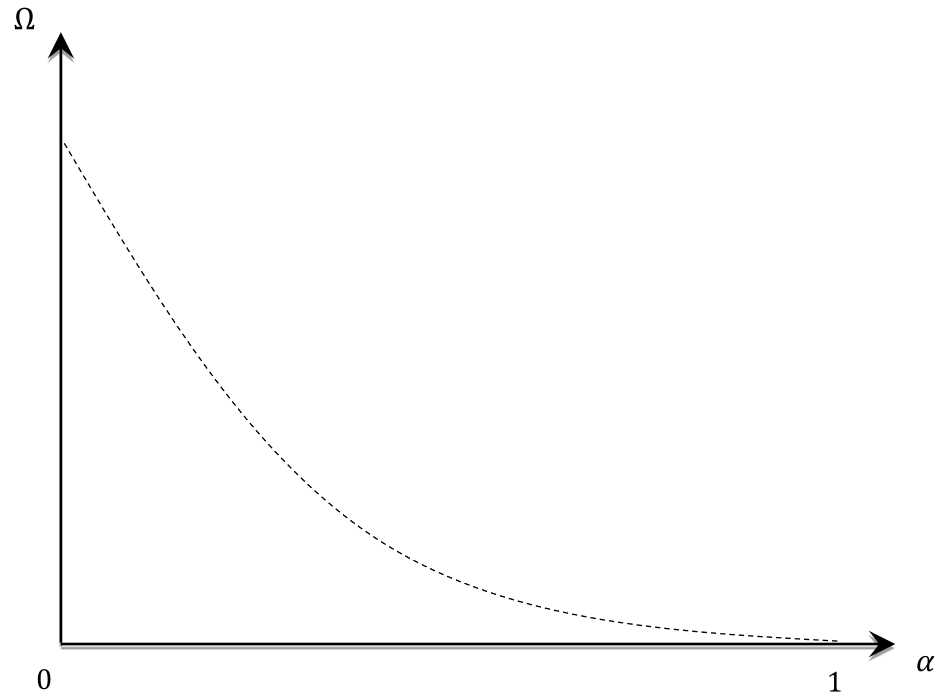

Figure 3: Degree of innovation, $\Omega = \Omega(\alpha)$

Let the representative firm's pre innovation and post innovation profits be given as follows,

$$\pi_i^{du} = \frac{a^2(s_0 + 2)}{2(s_0 + 3)^2}$$

and

$$\pi_i^{R\&D} = \frac{a^2(s_1 + 2)}{2(s_1 + 3)^2}$$

Let Δ be defined as the post innovation and pre innovation profit differential of the firm. Thus,

$$\Delta = \pi_i^{R\&D} - \pi_i^{du}$$

$$\Rightarrow \Delta = \frac{a^2(s_1 + 2)}{2(s_1 + 3)^2} - \frac{a^2(s_0 + 2)}{2(s_0 + 3)^2}$$

$$\Rightarrow \Delta = \frac{a^2(\alpha s_0 + 2)}{2(\alpha s_0 + 3)^2} - \frac{a^2(s_0 + 2)}{2(s_0 + 3)^2}$$

Finally,

$$\Delta = \frac{a^2\{\alpha s_0^3(1-\alpha) + 3s_0(1-\alpha) + 2s_0^2(1-\alpha^2)\}}{2(\alpha s_0 + 3)^2(s_0 + 3)^2} \geq 0$$

Thus, in the first time frame the firm invests in R&D and experiences enhanced profits. This increased profit attracts other firms and thus there would be entry of firms in the market. Firms would enter the market till the Δ is exhausted or reduced to zero.

Thus,

$$\Delta = \Delta(n);\ \Delta' < 0 \tag{8}$$

As the number of firms becomes sufficiently large in the market, let's say N, the Δ is exhausted or reduced to zero.

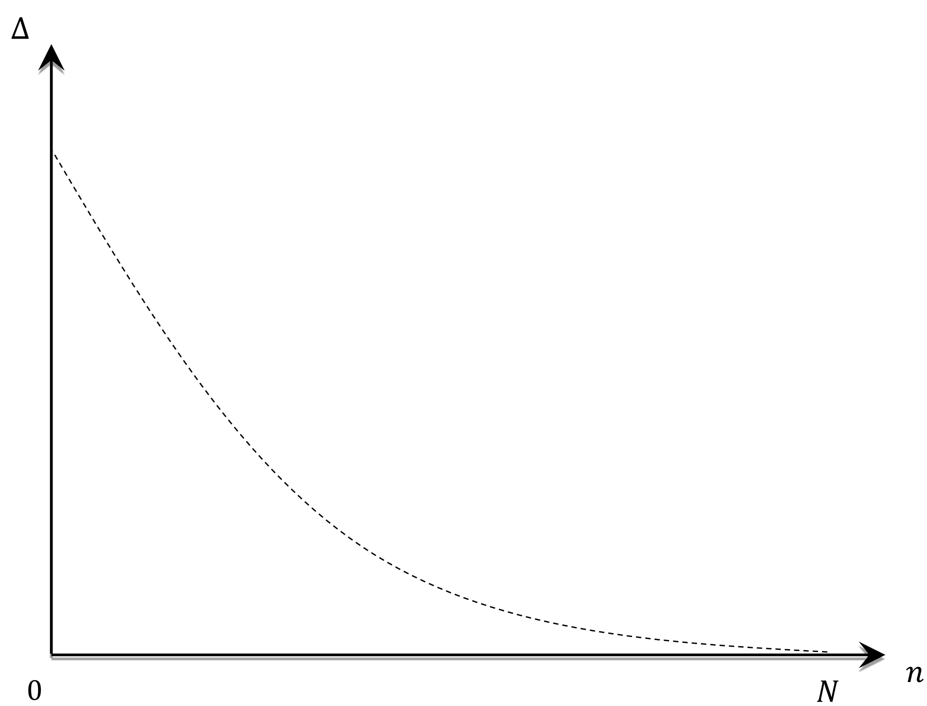

Figure 4: Innovation profit, $\Delta = \Delta(n)$

As has been stated and proved above, that iff $n \leq 3$ then a cost cutting technological improvement increases an individual firm's profit with certainty. An important implication of this result is that restricting entry may be a better policy to encourage innovation in a Cournot oligopolistic market structure with quadratic costs.

Let the entry require incurrence of a fixed cost, F, $(F > 0)$, by the firm. As stated above, entry continues till the $\Delta > 0$. Let us denote entry by E. Then we can reasonably assume that a firm's decision to enter is a function of the magnitude of fixed cost and also that an enhancement in the fixed cost reduces entry, i.e., $E = E(F);\ E' < 0$. Clearly, with the incurrence of fixed costs by the firms, lesser number of firms would enter as against a situation of no fixed costs.

Let us suppose that there is sequential entry by the firms. Thus, for the marginal firm would get zero economic profit net of its fixed costs. The same can be shown as below (figure 5),

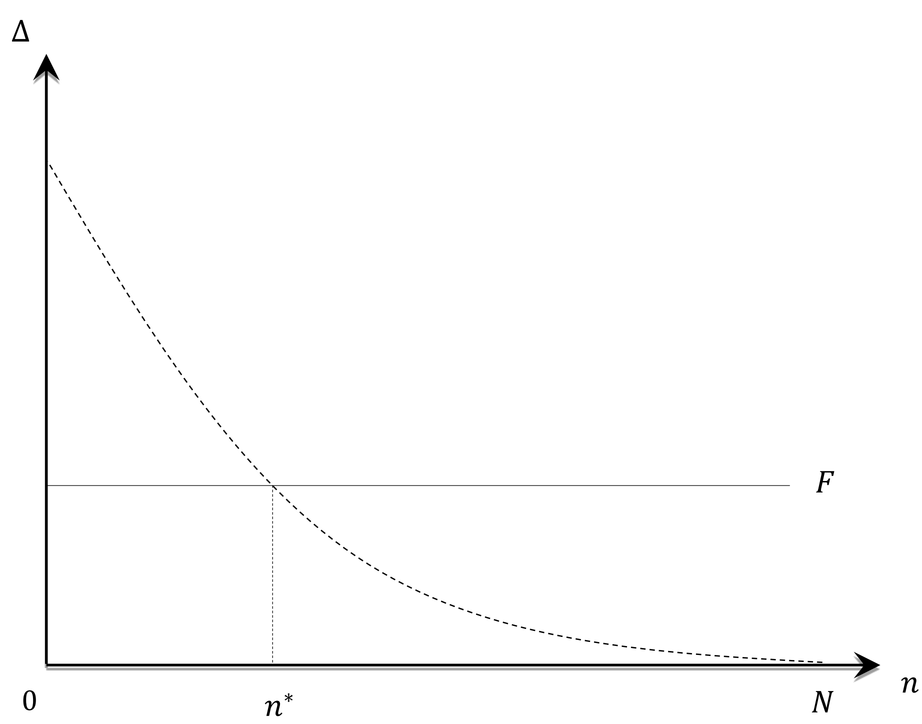

Figure 5: Innovation profit ($\Delta = \Delta(n)$), Fixed costs and Entry

In the above diagram (figure 5) n^* represents the optimal number of firms in this market.

Let the number of firms in the market be decided by a competitive process. Then, entry must be allowed till there is incentive to innovate by the firms, i.e., $n < s + 3$. If $n^* < n = s + 3$, the policy should be aimed at reducing the fixed costs (may be through subsidies) in order to encourage entry till $n^* = n = s + 3$ and if $n^* > n = s + 3$, the policy must be aimed at increasing the fixed costs (may be through taxes) to discourage entry till $n^* = n = s + 3$.

5 Conclusion

It is straightforward that a (Cournot) oligopolistically competitive firm facing constant marginal cost and linear demand, would undertake innovation as it is rewarding. However, with just a slight alteration of the framework, replacing constant marginal cost with increasing marginal cost, we show that innovation may not be rewarding. We show that if the technology is already advanced and competition intensifies then firms wouldn't innovate. We attempt to capture and explain is the interaction of technology with the possibility of innovation via the intensity of competition. We finally conclude that the intensity of competition and welfare may not have the usual (direct) relationship. We suggest 'monitored competition', as a suitable policy measure wherein initially (at initial stages of innovation) competition is encouraged and then (at later stages of innovation) curtailed, to encourage innovation and thus welfare. Thus, entry should be restricted in order to foster innovation while innovation itself encourages entry.

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