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Technology, Costs and Innovation Incentives

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Abstract:

In a Cournot oligopoly set up with constant marginal cost and linear demand, innovation is rewarding, i.e., profit enhancing. We show that the same is not true when marginal costs are increasing. When the number firms $n = 1$ or 2 innovation is unconditional and with certainty while for $n > 3$ there exists an innovation – neutral technology line dividing the regions of innovation and technological retrogression (henceforth retrogression). Unlike the constant marginal cost and linear demand set up, we show the possibilities of conditional innovation/retrogression by firms. We finally suggest that the intensity of competition and welfare may not have conventional (direct) relationship.

Key Words: Cost Structures; Innovation; Welfare; Technology.

JEL Codes: L11; L13; L21.

1. Introduction

The main purpose of this paper is to highlight, contrary to the popular belief that innovation by firms may not necessarily and always be rewarding. We specifically show that if the technology is already advanced and competition intensifies then firms would not innovate. The market and cost structures, intensity of competition and the prevailing level of technology come out as crucial factors determining innovation incentives of the firms. We also show that technology and the possibility of innovation, via intensity of competition, have an interesting interaction.

In a Cournot oligopoly set up with constant marginal cost and linear demand, innovation is rewarding. In this paper we demonstrate that the same is not true when marginal costs are

[*] I am greatly indebted to Sugata Marjit for many rounds of discussion on the topic. The usual disclaimer applies.

increasing. We attempt to capture and explain the interaction of technology with the possibility of innovation via the intensity of competition. We finally suggest 'monitored competition', wherein a limited number of firms (contingent upon the level of technology) should be allowed in the market, to encourage innovation and thus enhance welfare, as a suitable policy measure. Thus, entry[1] should be restricted in order to foster innovation while innovation itself encourages entry.

Firms' incentives to innovate can be influenced by different measures of competition such as profit incentives (Yi, 1999; Delbono and Denicolò, 1990) and product differentiation (vertical – Bonanno and Haworth, 1998; and horizontal – Bester and Petrakis, 1993). Since 1943, the central theme in the innovation literature has been market structure and innovation (Schumpeter's Capitalism, Socialism, and Democracy). The "Schumpeterian tradeoff"[2] has been dominant in many contributions (Sylos-Labini, 1969; Scherer, 1980; von Weizsacker, 1980; Nelson and Winter, 1982; Kamien and Schwartz, 1982), suggesting presence of the elements of monopoly in the optimal market form.

However, later, Arrow (1962) showed that perfect competition was more conducive to innovation than monopoly as the firms in the former market form have more incentives to innovate than the one in the latter. This is because the monopolist already makes profits before innovation while the perfectly competitive firm just earns normal profits. A unified framework was presented by Belleflamme and Vergari (2011) 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 that in contrast to the extreme cases of perfect competition and monopoly, the intermediate market forms may offer higher innovation incentives. Their results concur with those of the existing literature (both, theoretical (Scherer, 1967b; Barzel, 1968; Kamien and Schwartz, 1972 and 1976) as well as empirical (Mansfield, 1963; Williamson, 1965; Scherer, 1967a). However, Belleflamme and Vergari (2011) also qualify their findings by stating that different incentives for innovation are created by different market forms in different industries.

For analysis of the trade–off between static and dynamic efficiency Dasgupta and Stiglitz (1980) approach was extended by Tandon (1984) where optimal market structure (or optimal

[1] We work with free entry throughout the paper.

[2] Perfectly competitive firms perform well in the sense of efficient allocation of resources (in the static sense) but poorly in terms of innovation.

degree of concentration) occupies the centre stage. He finds the answer to be in the affirmative for the question: '*are barriers to entry in addition to those created by R&D desirable?'*

Regarding entry of a firm in a market and the equilibrium profit of the incumbent firms, conventional wisdom suggests that the former decreases the latter. However, introduction of R&D activities may lead to contrasting conclusions. Ishida et al. (2011) show that if the entering firm has a less efficient production technology, then the entry enhances both the R&D investment and the profit of the incumbent firms (which have a more efficient production technology). The conventional view that entry enhances welfare, may not hold in Cournot oligopoly set up (Klemperer, 1988; Lahiri and Ono, 1988). They showed that 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. For the literature 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).

Entry, as has been shown by some studies, may enhance the incumbent firms' profits. Mukherjee and Zhao (2009 and 2017) consider a sequential–move model in an asymmetric (marginal cost) Stackelberg set up and show that an inefficient follower (entrant) enhances 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, Coughlan and Soberman (2005), Chen and Riordan (2007), and Ishibashi and Matsushima (2009) also have obtained similar results, but they used simultaneous–move models.

Our paper is closely related to the literature on cost and tax paradox – where the equilibrium profit is shown to increase in the unit cost when demand is very convex. Specifically, our paper is directly related to Seade (1985) and Kimmel (1992). Seade (1985) studies and analyses the comparative statics effects of changes in cost conditions in a homogeneous good oligopoly. It is shown that an increase in excise taxation or a similar industry wide cost decreases the output of all firms, increase the price (by more than the shift in the marginal cost) and the profit of each firm. Kimmel (1992), on the other hand, considers cost changes affecting firms in Cournot oligopoly and shows that an increase in the common costs of the industry can benefit some or all firms. It is demonstrated that a firm's benefits/harm depend upon its market size, increase/decrease in the industry costs, number of firms and the elasticity of the demand curve's slope (i.e., the fraction of the cost changes that are passed on).

Other "perverse" comparative statics of Cournot oligopoly is another strand of literature to which the topic under consideration of this paper is related. In this strand, one of the most important study is by Amir and Lambson (2000), which considers Cournot oligopoly with symmetric firms and shows a highly counter-intuitive result – that the equilibrium price increases in the number of firms when costs are very concave. While Amir (2003) considers Cournot markets, scale economies and industry performance and shows that the per firm profit always decreases in the number of firms while the total industry profit may or may not.

In general, the linear demand constant marginal cost framework has been extensively used for the behavioral analysis of the firms. However, altering the basic framework just slightly and working with increasing marginal cost instead alters the results drastically and offers novel insights.[3] Using the linear demand and increasing marginal cost framework, we analyze the incentives for innovation by firms and derive a novel set of results (in line with Seade 1985; Kimmel, 1992; Amir and Lambson, 2000; Amir 2003), which have very interesting welfare/ policy implications.

The rest of the paper is structured as follows. Our basic model is presented in section 2, innovation incentives are analyzed in section 3, free entry and innovation 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 $p = a - q$; a is publicly observable. There are n firms with symmetric cost function of the form $c_i(q_i) = \frac{sq_i^2}{2}; i = 1,2, \ldots, n$ and q_i is the output produced by firm i. The parameter s captures the level of technology and the technology space is given by the interval $[0, S]$, 0 being the most efficient and S being the least. We assume $s > 0$, i.e., $s \in (0, S]$. A fall (rise) in s represents a cost reducing (increasing)

[3] See Marjit, Misra & Banerjee (2017), which analyses the role of technology in collusion.

technological improvement (deterioration). We assume costless innovation, i.e., firms can costlessly locate anywhere in the technology space, i.e., $s \in [0, S]$.[4]

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 $q_1^o = q_i^o = \cdots = q_j^o = \cdots = q_n^o = \frac{a}{n+s+1}$. Thus, the total output and price in equilibrium are,

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

The equilibrium profit of the firm i is,

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

3. Innovation Incentives

A colluding firm's profit in equilibrium always increases in event of a technological improvement, i.e., a reduction in s. However, the same may not hold under Cournot competition as stated in Proposition 1.

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

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

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

Proof: (i). Equilibrium profit of each firm under collusion is $\pi_i^c = \frac{a^2}{2(2n+s)}$ and $\frac{\partial \pi_i^c}{\partial s} = -\frac{a^2}{2(2n+s)^2} < 0$ which indicates that a reduction in s, i.e., cost cutting innovation, increases the profit of a firm under collusion.

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

[4] Alternatively, one may think of freely available technology in the stated interval, its limits being interpreted as above and the firms choose to locate anywhere in the technology space. The firm's location choice itself is costless, however, it has an impact on the equilibrium profit of the firm as demonstrated by Proposition 1.

The above proposition shows that under collusion, a technological improvement always increases an individual firm's equilibrium profit, while it may not necessarily and always be true for firms in Cournot oligopoly with quadratic costs. Here, a decline in s raises a firm's profit if and only if the number of firms is restricted to $n < s + 3$ or technology is as per the following condition $s > n - 3$. Thus, for $n < 3$ a cost cutting technological improvement, unconditionally (and with certainty), increases an individual firm's equilibrium profit and for $n > 3$ it does so conditionally, hence conditional innovation by firms as per $n < s + 3$. This result is very different from a Cournot model with constant marginal cost where cost cutting innovation is always profitable.

We now proceed to analyze the innovation incentives faced by the firms. For $n = 1$ or 2 innovation is unconditionally and certainly undertaken by firms (indicated by region A in figure 1 below) as the same is rewarding irrespective of the level of s. $\forall n > 3$, clearly, given n, $s(n) = n - 3$ is profit maximizing and hence innovation – neutral technology line (from investment perspective); also note that $s' > 0$. A/ny arbitrary $n_o > 3$ corresponds to a specific s_o on the innovation – neutral technology line, such that $\forall s \in (s_o, S]$ innovation is rewarding (i.e., profit enhancing) and $\forall s \in (0, s_o]$ retrogression is rewarding. Thus, $\forall n > 3$ the innovation – neutral technology line clearly indicates the region of conditional innovation (retrogression), i.e., $B(C)$, as shown below in figure 1.

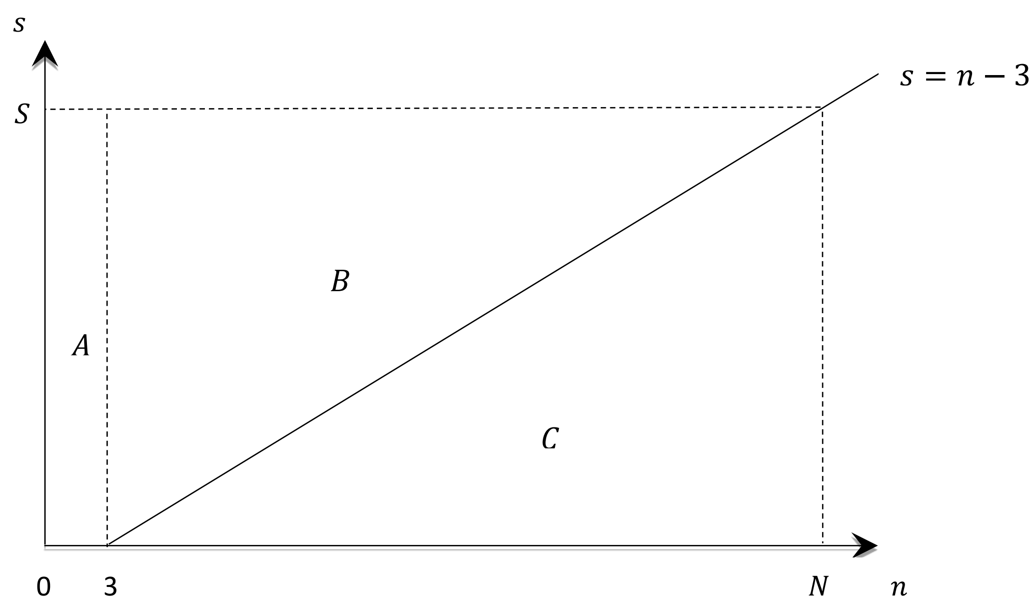

Figure 1: n, s and un/conditional innovation/retrogression

Proposition 2: *For* $n = 1$ *or* 2 A *is the region of unconditional innovation and* $\forall n > 3$, *the innovation – neutral technology line,* $s(n) = n - 3$, *clearly indicates and separates the regions of conditional innovation (retrogression),* $B(C)$.

Proof: See above discussion and figure 1. ***Q.E.D.***

However, $\forall n > 3$, innovation/retrogression is conditional and depends upon both the actual level of prevailing technology, say s^a and n. As stated earlier, for any arbitrary n, say n_i there is a corresponding technology level on the innovation – neutral technology line, s_i, which, as indicated above, is the optimal level of technology for firms and there is no incentive for a firm to deviate from this level. However, given $n = n_i$, s_i^a can be anywhere in the range from 0 to S, i.e., $s_i^a \in (0, S]$. The actual location of s_i^a determines whether innovation or retrogression is undertaken by firms. Innovation is undertaken by firms iff $s_i^a \in (s_i, S]$; hence A can also be thought of as the region of conditional innovation. Similarly, for $s_i^a \in [0, s_i)$ region B can be interpreted with respect to retrogression.

Proposition 3: For $n = 1$ or 2 *cost cutting innovation is taken up by firms unconditionally and with certainty and* $\forall n > 3$ *there is conditional innovation/retrogression.*

Proof: See above discussion and figure 1. ***Q.E.D.***

For $n > 3$ and s^a, an increase in the number of firms impacts the spaces of conditional innovation/retrogression. For instance, $\forall s^a \in (s_o, S]$ as n increases the space of conditional innovation, $(S - s_o)$, shrinks and ultimately converges to zero while $\forall s^a \in (0, s_o]$ the space of conditional retrogression expands. However, conditional innovation and retrogression are mutually exclusive, and given an arbitrary $n_o > 3$ depend upon s_0^a. $\forall s_0^a \in (s_o, S]$, innovation is undertaken while retrogression is undertaken $\forall s_0^a \notin (s_o, S]$. Thus, given an n_o the location of $s_0^a \in (0, S]$ dictates one of the said outcomes (of innovation or retrogression).

Proposition 4: $\forall n_o > 3$ and $s_o = n_o - 3$,

(i). *innovation and retrogression are mutually exclusive.*

(ii). *in general,* $s_i^a = s_i$ *leads to stagnation, i.e., neither innovation nor retrogression is undertaken by the firms.*

(iii). *as* n *increases, the potential space of conditional innovation shrinks and ultimately converges to zero.*

(iv). For $s_i^a = \bar{\bar{s}}_i > s_o$, *cost cutting innovation is undertaken* $\forall n_i \in (3, \bar{\bar{n}}_i)$; $\bar{\bar{n}}_i > n_o$, *while retrogression is undertaken* $\forall n_i \in (\bar{\bar{n}}_i, N]$.

(v). For $s_i^a = \bar{s}_i < s_o$, *cost cutting innovation is undertaken* $\forall n_i \in (3, \bar{n}_i)$; $\bar{n}_i < n_o$, *while retrogression is undertaken* $\forall n_i \in (\bar{n}_i, N]$.

Proof: See above discussion and figure 2. ***Q.E.D.***

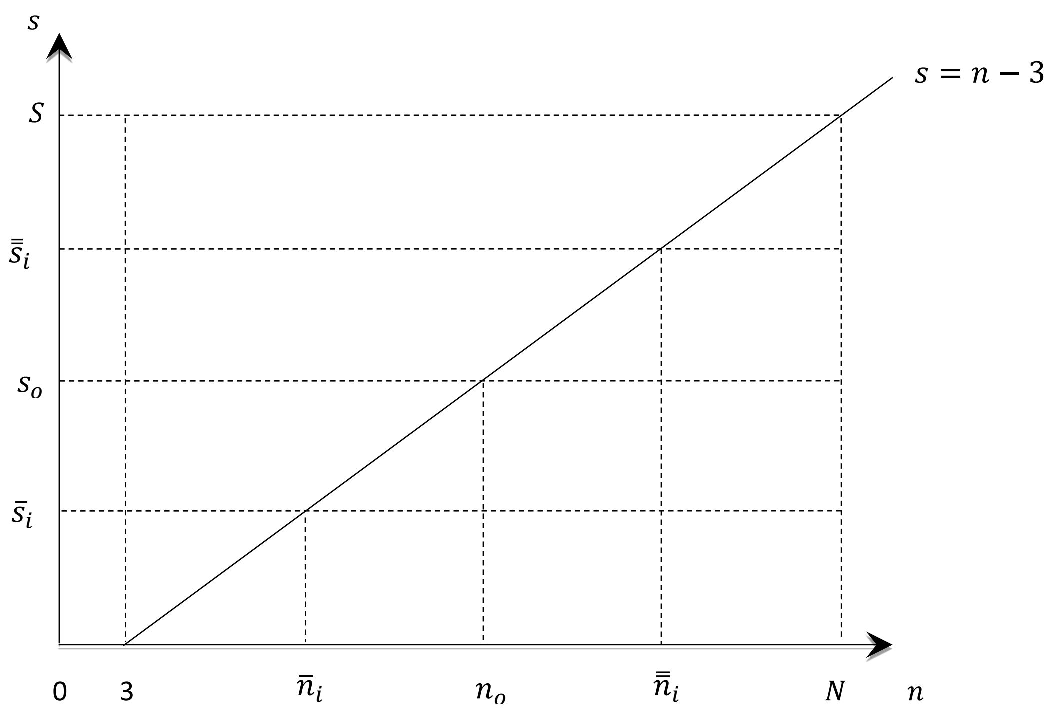

Figure 2: n, s and conditional innovation/retrogression

The above propositions and discussion regarding s and $n_o > 3$ also convey some information with respect to the magnitude of innovation and retrogression. We know that an arbitrary $n_o > 3$ corresponds to a specific s_o on the innovation – neutral technology line. Consider n_1, the actual number of firms, such that $3 < n_1 \leq n_o$. As per proposition 4, given n_1, for $s_1^a \in (s_1, S]$, innovation would be undertaken by the firms. However, the actual magnitude of potential innovation may be given by $\alpha_1 = (s_1^a - s_0)$, as it is rewarding until $s_1^a = s_0$, hence it would be undertaken until attainment of this equality. Given a specific n, once this equality is attained, further innovation is not rewarding. It can be generalized for any $3 < n_i \leq n_o$ and corresponding $s_i^a \in (s_i, S]$ and be given as $\alpha_i = (s_i^a - s_i)$. It is also straight forward that in the given situation innovation would be undertaken with certainty. It is straight forward to see that $\alpha_i = \alpha_i(n_i, s_i^a)$ and $\frac{\partial \alpha_i}{\partial n_i} < 0$ while $\frac{\partial \alpha_i}{\partial s_i^a} > 0$. Similarly, we may think of the magnitude of potential retrogression, given by δ_i. Clearly, for $\delta_i > 0$, s_i^a must $\in (0, s_i)$. $\delta_i = (s_i - s_i^a)$. $\delta_i = \delta_i(n_i, s_i^a)$ and and $\frac{\partial \delta_i}{\partial n_i} > 0$ while $\frac{\partial \delta_i}{\partial s_i^a} < 0$. $\alpha_i(n_i, s_i^a) \in [0, (s_i^a - s_i)]$ while $\delta_i(n_i, s_i^a) \in [0, (s_i - s_i^a)]$. Thus, no matter where s_i^a is located in the interval $(0, S]$, ultimately, through innovation or retrogression, it would converge to the innovation – neutral technology line, i.e., $s_i = n_i - 3$.

Proposition 5: *Given $n_o > 3$, $s_a \in (0, S)$ and $s_o = n - 3$,*

(i). $3 < n_i \leq n_o$ and corresponding $s_i^a \in (s_i, S]$, the magnitude of innovation is $\alpha_i = (s_i^a - s_i)$.

(ii). $\alpha_i = \alpha_i(n_i)$ and $\alpha_i' < 0$.

(iii). $3 < n_i \leq n_o$ and corresponding $s_i^a \in (0, s_i]$, the magnitude of retrogression is $\delta_i = (s_i - s_i^a)$.

(iv). $\delta_i = \delta_i(n_i)$ and $\delta_i' > 0$.

(v). irrespective of its initial location in the interval $(0, S)$, ultimately, s_i^a converges to the innovation – neutral technology line, i.e., $s_i = n_i - 3$. Thus, the innovation – neutral technology line, i.e., $s_i = n_i - 3$ is the equilibrium outcome.

Proof: See the above discussion and figure 2. ***Q.E.D.***

4. Free Entry and Innovation

We now proceed to analyze the relationship between free entry and innovation. While innovation enhances profits which in turn attract firms in the market, the market however, can absorb only a specific number of firms without hampering the innovation incentives. It is worth noting, as we show, that the intensity of competition and welfare do not necessarily have the popular and usually accepted (direct) relationship. Larger number of firms not only leads to stagnation, i.e., absence of innovation, but can potentially encourage retrogression. Thus, from policy perspective, it is required that free entry must be regulated in order to nurture the innovation incentives.

We have highlighted above that innovation and retrogression are dependent upon both, n and s^a. Given s^a, magnitudes of innovation and retrogression can be analyzed. From proposition 5 we know that $3 < n_i \leq n_o$ and corresponding $s_i^a \in (s_i, S]$, the magnitude of innovation is $\alpha_i = (s_i^a - s_i)$. Given this specific s_i^a, an increase in n generally decreases the magnitude of innovation and ultimately reducing it to zero and may also leads to retrogression. Consider $3 < n_i \leq n_o$ and $s_i^a = s_o$. When $n = n_i$, $\alpha_i(n_i, s_i^a) = (s_o - s_i) > 0$; $\lim_{n_i \to 3} \alpha_i(n_i, s_i^a) = s_o > 0$, $\lim_{n_i \to n_0} \alpha_i(n_i, s_i^a) = (s_i^a - s_0) = 0$ while $\lim_{n_i \to n_h > n_o} \alpha_i(n_i, s_i^a) = (s_o - s_h) < 0$, conveying retrogression. Similarly, for the magnitude for retrogression. Consider $3 < n_i \leq n_o$ and $s_i^a = s_l$ corresponding to $n_l < n_i$. When $n = n_i$, $\delta_i(n_i, s_i^a) = (s_l - s_i) < 0$; $\lim_{n_i \to n_0} \delta_i(n_i, s_i^a) = (s_l - s_0) < 0$; $\lim_{n_i \to n_l} \delta_i(n_i, s_i^a) = (s_i^a - s_l) = 0$ while $\lim_{n_i \to n_{vl} < n_l} \delta_i(n_i, s_i^a) = (s_l - s_{vl}) > 0$, conveying innovation. Specifically, when the technology is already advanced, increased intensity of competition would discourage innovation and encourage retrogression. Thus, generally, given an s_0, $\forall n_i > n_o$ innovation is not undertaken by the firms, rather retrogression is. Thus, given an s_0, for encouraging innovation, entry must be restricted and ensured that $3 < n_i < n_o$.

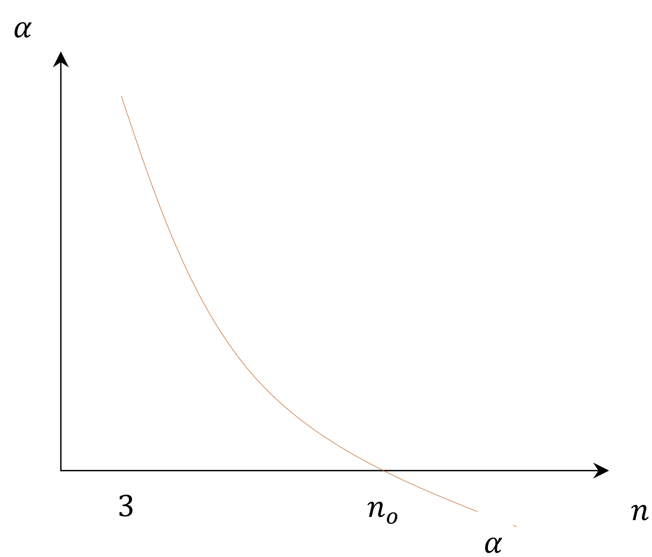

Figure 3: Relationship between α and n

Proposition 6: *Given* $s_i^a = s_i = s_0$ *and the corresponding* $n_i = n_o$, *for innovation to be undertaken entry must be restricted such that* $3 < n < n_i = n_o$, *as the firms engage in retrogression* $\forall n > n_i = n_o$.

Proof: See the above discussion and figures 2 and 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, as in profit enhancing. However, with increasing marginal cost, we show that innovation may not be rewarding. Also, 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 free entry should be restricted in order to foster innovation while innovation itself encourages entry.

Declaration of competing interest

We hereby declare that none of the authors has any conflict of interest with any entity/organization.

Data availability

No data was used for the research described in the article.

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