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Technology improvement and market structure alteration

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Abstract

In this paper we show that the increasing marginal cost assumption removes the infeasibility of market structure alteration that is present under the constant marginal cost assumption. Specifically, in an infinitely repeated game with increasing marginal cost, we show that technological improvement has the potential to switch the market structure from collusion to Cournot generating additional welfare gains.

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1. Introduction

The issue of collusion has been addressed from various perspectives such as product differentiation (Deneckere, 1983; Wernerfelt, 1989; Chang, 1991; Ross, 1992; Symeodinis, 2002; and Collie, 2006), asymmetric firms (Harrington, 1989), and cheap talks (Miralles, 2010). In the context of homogeneous goods with constant marginal cost, Gibbons (1992), Martin (2001), Shy (1996), and Tirole (1988) shows that the existence of collusion or Cournot competition as the subgame perfect equilibrium (SPE) in an infinitely repeated game is independent of the technology. It only depends on the magnitude of the discount factor. In this paper we show that changing the assumption of constant marginal cost to increasing marginal cost drastically alters the result and has other interesting implications for cost reducing technological improvement.

Collie (2006) and Weibull (2006) consider convex cost to study conditions that lead firms to collude. While Collie (2006) shows that if marginal cost is sufficiently increasing, then for any degree of product substitutability collusion is more easily sustainable in a Cournot set up than in a Bertrand set up, Weibull (2006) generalizes the Bertrand model from linear cost to convex cost functions and hints that firms profits may be increasing in their production costs. The above papers have assumed convex costs but their focus and results significantly differ from ours. Specifically, we show that in an infinitely repeated game, technological improvement increases the critical discount factor, above which collusion is the SPE. Hence, as technology improves and reaches a certain level, the SPE market structure switches from collusion to Cournot competition generating additional welfare gains. So the infeasibility of an alteration of market structure that is present under constant marginal cost is removed by the increasing marginal cost assumption. Thus we show how market structures can evolve with technological changes.

Our paper is also related to the literature on open economic policies and welfare such as Lahiri and Ono (2004), Beladi and Mukherjee (2012), Mukherjee and Sinha (2012), and Marjit and Roychoudhury (2004). This paper has interesting implications for outsourcing or arm's length international contracts that reduce cost of production and is related to the recent body of literature exploring this issue such as Marjit and Mukherjee (2008), Marjit, Beladi and Yang (2012) and Bandyopadhyay, Marjit and Yang(2014).

2. The Model

We consider a two-firm oligopolistic market with a linear inverse demand function of the form $p = a - q$. Firms are symmetric and firm i's cost function is, $c_i(q_i) = \frac{sq_i^2}{2}; i = 1, 2.$ q_i is firm i's output and s is the technology parameter ($s > 0$). A fall in s represents a cost reducing technological improvement. Thus, we retain the same framework as Gibbons (1992) with the exception that the cost structure is changed from constant marginal cost to increasing marginal cost and thus our results contrast with that of Gibbons (1992) as we show that collusion is a function of technology. To analyze the condition under which collusive output is a SPE in an infinitely repeated game, we develop the Cournot oligopoly model and analyze the firms' incentives to collude and or to unilaterally deviate from collusion when the game is played only once.

In the Cournot game, firm i's profit is $\pi_i(q_i, q_j) = (a - q_i - q_j)q_i - \frac{sq_i^2}{2}$ and the reaction function is as follows,

$$q_i = \frac{a-q_j}{s+2} \tag{1}$$

From the reaction function and using the symmetric assumption we get each firm's equilibrium output as $q_i^{nc} = \frac{a}{s+3}$; $i = 1, 2$; where the superscript "nc" represents *non-cooperation*. Thus, the market output and price are,

$$q^{nc} = \frac{2a}{s+3} \text{ and } p^{nc} = \frac{a(s+1)}{s+3} \tag{2}$$

The equilibrium profit of any firm *i* is,

$$\pi_i^{nc} = \frac{a^2(s+2)}{2(s+3)^2}; i = 1, 2. \tag{3}$$

When the two firms collude, they act as a cartel and maximize joint profit. The equilibrium condition is, $MC_1 = MC_2 = MR$. Using $MC_i = sq_i$, $MR = a - 2q = a - 2(q_1 + q_2)$, the symmetric assumption, and the equilibrium condition, we get $sq_i = a - 2(q_1 + q_2) = a - 4q_i$; $i = 1, 2$. Thus, firm i's collusive equilibrium output is $q_i^c = \frac{a}{s+4}$; $i = 1, 2$; where the superscript "c" represents *collusion*. The market output and price are,

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

Any firm i's profit under collusion is,

$$\pi_i^c = \frac{a^2}{2(s+4)}; i = 1, 2. \tag{5}$$

Suppose firm *j* sticks to the collusive output, $q_i^c = q_j^c = \frac{a}{s+4}$; $i, j = 1, 2; i \neq j$, but firm i deviates and chooses its output according to its reaction function given in equation (1). This yields $q_i^d = \frac{a(s+3)}{(s+4)(s+2)}$. The superscript "$d$" denotes *deviation*. The market output and price are,

$$q^d = \frac{a(2s+5)}{(s+4)(s+2)} \text{ and } p^d = \frac{a(s+1)(s+3)}{(s+4)(s+2)} \tag{6}$$

Firm i's profit from *deviation*, and firm j's profit from *not deviating* denoted by "$-d$" are as follows,

$$\pi_i^d = \frac{a^2(s+3)^2}{2(s+4)^2(s+2)} \text{ and } \pi_i^{-d} = \frac{a^2(s^2+5s+6)}{2(s+4)^2(s+2)}; i, j = 1, 2; i \neq j. \tag{7}$$

If firm *j* chooses the non-cooperative Cournot output, then firm i is better off choosing the same rather than choosing the collusive output since $\pi_i^{nc} - \pi_i^{-d} = \frac{a^2(s^2+6s+10)}{2(s+4)^2(s+3)^2(s+2)} > 0$.

Alternatively, if firm *j* chooses the collusive output, then deviation gives firm i a higher payoff because $\pi_i^d - \pi_i^c = \frac{a^2}{2(s+4)^2(s+2)} > 0$. Thus, we have the standard prisoner's dilemma situation where non-cooperation or the Cournot output is the dominant strategy in one shot game.

3. Self-enforcing Collusion

In an infinite repetition of the above game, firm i's strategy set is $\{q_i^{nc}(t),\ q_i^c(t),\ q_i^d(t)\}$ in any period t. We consider the following trigger strategy.

Definition: *Firm i is playing a trigger strategy if for every period* $t = 1,2, \ldots$.

$$q_i(t) = \begin{cases} q_i^c, & if\ q_1(\tau) = q_2(\tau) = q_i^c; i = 1,2;\ \forall\, \tau = 1,2, \ldots, t-1. \\ q_i^{nc}, & otherwise. \end{cases}$$

Consider any representative period t prior to which no firm has deviated. In period t, firm *i* either plays the collusive output $q_i^c(t)$ or deviates and plays $q_i^d(t)$. The present discounted value of the profit stream from the choice of $q_i^c(t)$ is $\Pi_i^c = \frac{\pi_i^c}{1-\delta} = \frac{1}{1-\delta}\left(\frac{a^2}{2(s+4)}\right)$, where δ $(0 < \delta < 1)$ is the discount factor. If firm i chooses $q_i^d(t)$ then in period t it earns $\pi_i^d = \frac{a^2(s+3)^2}{2(s+4)^2(s+2)}$, but in all future periods it will earn $\pi_i^{nc} = \frac{a^2(s+2)}{2(s+3)^2}$, following the definition of trigger strategy. Thus the present discounted value of firm i's profit from deviation is $\Pi_i^d = \pi_i^c + \frac{\delta\pi_i^{nc}}{1-\delta} = \frac{a^2(s+3)^2}{2(s+4)^2(s+2)} + \frac{\delta}{1-\delta}\left(\frac{a^2(s+2)}{2(s+3)^2}\right)$. So the condition for collusion to be a SPE is,

$$\Pi_i^c \geq \Pi_i^d. \tag{8}$$

This leads us to Proposition 1.

Proposition 1.

(i) *Collusion is a SPE if* $\delta \geq \bar{\delta}$ *where* $\bar{\delta} \equiv \frac{\pi_i^d - \pi_i^c}{\pi_i^d - \pi_i^{nc}} = \frac{(s+3)^2}{(s+3)^2 + (s+4)(s+2)}$ *is a function of technology. This is in contrast to the model with constant marginal cost where* $\bar{\delta}$ *is the constant* $\frac{9}{17}$ *(Gibbons, 1992).*

(ii) *A cost reducing technological improvement (a fall in* s*) monotonically increases* $\bar{\delta}$*.*

Proof of Proposition 1.

(i) $\Pi_i^c \geq \Pi_i^d \Rightarrow \frac{\pi_i^c}{1-\delta} \geq \pi_i^d + \frac{\delta\pi_i^{nc}}{1-\delta} \Rightarrow \delta \geq \frac{\pi_i^d - \pi_i^c}{\pi_i^d - \pi_i^{nc}} \equiv \bar{\delta}$. Now, $\pi_i^d - \pi_i^c = \frac{a^2}{2(s+2)(s+4)^2}$ and $\pi_i^d - \pi_i^{nc} = \frac{a^2\{(s+3)^2 + (s+4)(s+2)\}}{2(s+4)^2(s+3)^2(s+2)}$. So, $\bar{\delta}$ is a function of s.

(ii) The inverse of $\bar{\delta}$ is $\frac{1}{\bar{\delta}} = 1 + \frac{(s+4)(s+2)}{(s+3)^2}$. Now $\frac{d}{ds}\left(\frac{1}{\bar{\delta}}\right) = \frac{2}{(s+3)^3} > 0$ which implies that $\frac{d\bar{\delta}}{ds} < 0$, that is, $\bar{\delta}$ is inversely related to s. *Q.E.D.*

Proposition 1(ii) leads us to Proposition 2, which is diagrammatically represented in Figure 1.

Proposition 2.

For a given δ*, there exists a unique* $\hat{s}$ *which satisfies* $\bar{\delta}(\hat{s}) = \delta$*, such that for* $s \geq \hat{s}$ *collusion is the SPE and for* $s < \hat{s}$ *Cournot competition is the SPE; and* $\forall\, s \in (0, +\infty), \bar{\delta}(s) \in \left(\frac{9}{17}, \frac{1}{2}\right)$.

Proof of Proposition 2.

Since $\bar{\delta}$ is monotonically decreasing in s, hence for any given δ, there exists a unique s, say $\hat{s}$, such that $\bar{\delta}(\hat{s}) = \delta$. If $s \geq \hat{s}$ then $\delta \geq \bar{\delta}$ and collusion is the SPE, otherwise Cournot competition is the SPE; and, $\bar{\delta}(s) = 1$ if $s = -2$ and for values of $s > -2$, $\bar{\delta}(s) < 1$, specifically for $s = 0$, $\bar{\delta}(s) = \frac{9}{17}$ and $lim_{s \to +\infty} \bar{\delta}(s) = \frac{1}{2}$. Thus, $\forall\, s \in (0, +\infty), \bar{\delta}(s) \in \left(\frac{9}{17}, \frac{1}{2}\right)$. *Q.E.D.*

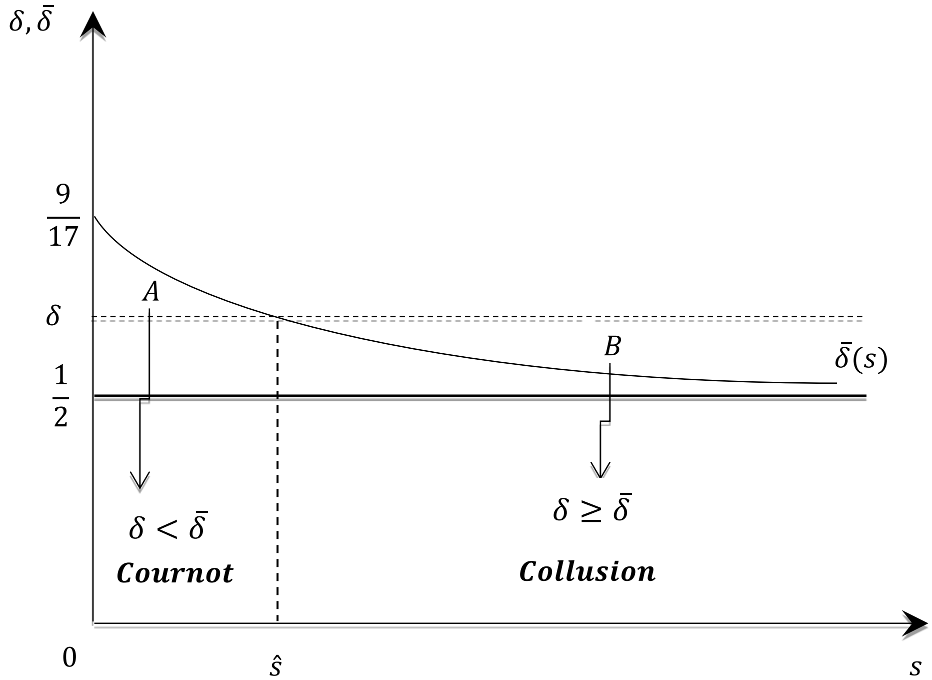

Figure 1: Relationship between s and $\bar{\delta}$, and resultant market structure(s).

In Figure 1, the condition $\delta < \bar{\delta}$ is satisfied in region A, which is above the line δ and below the curve $\bar{\delta}(s)$, and Cournot competition is the SPE market structure. The condition $\delta \geq \bar{\delta}$ is satisfied in region B, which is above the curve $\bar{\delta}(s)$ and below the line δ, and collusion is the SPE market structure.

4. Technological Improvement and Welfare

A major implication of Proposition 2 is that a cost reducing technological improvement has the potential to alter the market structure as summarized in Proposition 3.

Proposition 3.

Consider a technological improvement that reduces s *from* s_1 *to* s_2*, that is,* $s_2 < s_1$.

(i) *If $s_1 \geq \hat{s}$ and $s_2 \geq \hat{s}$, then collusion continues to be the SPE.*
(ii) *If $s_1 \geq \hat{s}$ and $s_2 < \hat{s}$, then the SPE market structure switches from collusion to Cournot competition.*
(iii) *If $s_1 < \hat{s}$, then any innovation retains Cournot competition as the SPE.*

Proof of Proposition 3.

(i) If $s \geq \hat{s}$, then collusion is the SPE (Proposition 2). Any cost reducing technological improvement that retains this inequality preserves collusion as the SPE.

(ii) If $s_1 \geq \hat{s}$ and $s_2 < \hat{s}$ then there is a switch from $\delta \geq \bar{\delta}$ to $\delta < \bar{\delta}$. Consequently, SPE switches from collusion to Cournot competition (Proposition 2).

(iii) If $s_1 < \hat{s}$ and $s_2 < \hat{s}$ then $\delta < \bar{\delta}$ continues to hold and Cournot competition continues to be the SPE. *Q.E.D.*

These results are significantly different from the constant marginal cost scenario where the self-enforcing collusion condition, $\delta \geq \bar{\delta} \equiv \frac{9}{17}$, is independent of the technology. Thus, as per conventional wisdom, technological improvement(s) cannot lead to any change in market structure. This infeasibility of alteration of market structure is removed by the increasing marginal cost assumption. Proposition 3 shows that there exists a critical level of technology at which the SPE market structure switches from collusion to Cournot competition. That is, technological improvement has important implications on the type of market structure that can evolve. Further, a market structure switch has important welfare implications as summarized in Proposition 4.

Proposition 4.

A cost reducing technological improvement increases overall output and consumer surplus. If the technological improvement results in a switch in the market structure from collusion to Cournot competition then there is a discontinuous rise in consumer surplus.

Proof of Proposition 4.

Suppose that the technological improvement preserves $s \geq \hat{s}$. Then collusion remains as the SPE. Now q^c is inversely related to s because $q^c = \frac{2a}{s+4}$. Thus, at $\hat{s}, q^c$ and consequently, the consumer surplus under collusion attain their *highest* value. The increase in consumer surplus is purely due to a lower marginal cost.

Next consider technological improvement that preserves $s < \hat{s}$ such that Cournot competition continues to be the SPE. q^{nc} is inversely related to s because $q^{nc} = \frac{2a}{s+3}$. Thus, q^{nc} and the consumer surplus under Cournot competition attain their *lowest* value in the neighbourhood of $\hat{s}$. The increase in consumer surplus due to technological improvement is purely because of a fall in the marginal cost.

Finally, consider a technological improvement that switches the SPE market structure from collusion to Cournot competition, that is, technological improvement alters the inequality $s \geq \hat{s}$ to $s < \hat{s}$.

At $\hat{s}$, $q^{nc}(\hat{s}) - q^{c}(\hat{s}) = \frac{2a}{(\hat{s}+4)(\hat{s}+3)} > 0$, which implies a discontinuous rise in output and consumer surplus when the market structure alters. That is, there are additional welfare gains from the change in the market structure apart from the gains due to a lower marginal cost. *Q.E.D.*

The additional welfare gain to the consumers when the market structure alters is not plausible under the CRS structure because switching of market structures is not feasible in that set up.

5. Conclusion

In this paper we show that the infeasibility of market structure alteration that is present under constant marginal cost is removed under increasing marginal cost. The discount factor above which collusion is sustained as an SPE is increasing in technological improvement. Thus, a critical technology level exists at which the market structure switches from collusion to Cournot competition generating some additional welfare gains. We thus show how market structures evolve with technological improvements.

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