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# Credible collusion in a model of spatial competition*

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**Abstract**

In a spatial model with quantity setting firms, we analyze the possibility of cooperation in a long term relationship, where firms compete in location. It is found that endogeneizing the location decisions makes collusion more difficult.

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# 1 Introduction

The theory of supergames provides a framework to use in evaluating the factors that influence collusion.[1] In this work, we focus on the transportation cost associated with firm location and address the following question: does spatial competition affect collusion stability?

When firm location is exogenous, we have to resort to comparative statics to analyze how changes in transportation cost may affect collusion stability. There exist several works concerned principally in studying this relationship (see, for example, Ross, 1992, and Gross and Holahan, 2003).[2] We focus on a different aspect of the problem: endogenous location. Since the optimal locations of a firm in a monopoly (as a result of, for example, a cooperative agreement) and a competitive frameworks do not necessary coincide, it suggests us to add one degree of freedom in the scenario allowing firms to choose previously which of both situations is preferred. Therefore, our interest is in the effect of endogenous location decisions on a credible agreement in an infinitely repeated game.

To do this, we solve a two-stage model of supergame cooperation with spatial competition in which, in a first-stage, firms simultaneously choose locations and, in the second-stage, we replicate the basic cournot game infinite times. When analyzing the model, we evaluate the possibility of considering firm location as an endogenous variable against to consider it as a given parameter. Thus, we obtain that when firms decide their locations, collusion is more difficult to attain. Consequently, we

[1] See, for example, a survey in Vives (1999, ch. 9).

[2] Ross (1992), in a supergame model of collusion, analyzes the effect of different levels of product differentiation on cartel stability and finds that greater homogeneity can reduce this stability. In a more recent paper, Gross and Holahan (2003) show stability is achieved for a wide range of transportation costs, and that increases of these costs tend to destabilize the collusive agreement.

demonstrate that spatial competition can reduce collusion stability.

The paper is organized as follows. Section 2 presents the model; Section 3 determines the subgame perfect equilibria; and, Section 4 presents the conclusions.

# 2 The model

Let us consider an oligopolistic sector producing a homogeneous good. On the demand side, we assume that consumers for the good are uniformly distributed with density one along the line segment $A = [0, 1]$. At each location $x \in A$, demand function is linear, $p(x) = \alpha - \beta q(x)$. On the supply side, there are two firms, called 1 and 2, selling the good. Let us denote by $x_j$ the location of firm $j = 1, 2$, and let the supply of firm $j$ to location $x$ be $q_j(x)$. Total supply to $x$ is then $q(x) = q_1(x) + q_2(x)$. For simplicity, we assume that there is no setup cost, and that firms do not incur any production cost. Furthermore, we assume that firms transport the good to consumers and that the unit transportation cost from firm $j$ to location $x$ is $\tau_j(x) = \tau |x - x_j|$, for $\tau > 0$. Therefore, the profit function of firm $j$ at location $x$ is

$$\pi_j(x) = (p(x) - \tau_j(x)) q_j(x). \tag{1}$$

We consider a two-stage game in which, in the first-stage (at time zero), the firms simultaneously choose their locations in the market and, in the second-stage, given the locations, we replicate the basic cournot game infinite times, i.e., firms compete repeatedly in quantities over an infinite horizon (period times one and beyond) with complete information and discount the future with discount factor $\delta \in (0, 1)$.[3]

[3]We assume that arbitrage is not feasible. Therefore, quantities set at different locations by the same firm must be strategically independent.

Consider also the following trigger strategy: in period one, firm $j$ charges the monopoly quantity at each location $x$ of $A_j \subseteq A$, where $A = A_1 \cup A_2$ and $A_1 \cap A_2 = \oslash$. Furthermore, firm $j$ charges the monopoly quantity in $A_j$ in the following periods until there is a defection (i.e., either firm invade the rival's market, in which case it sets the cournot (one-shot) quantity forever). Therefore, each firm must anticipate how its choice of location affects not only its demand function but also the stability of a possible cooperation.

In the next section, we will prove that this trigger strategy can sustain cooperation as a subgame-perfect Nash equilibrium of the infinitely repeated two-stage game. In particular, we look for optimal locations at time zero from which firms collude in period times one and beyond.

# 3 Solving the model

Firstly, we solve the second-stage of the game. In each single period (period times one and beyond), firms choose simultaneously the quantities of good to supply to location $x$, assuming firms locations are $x_1$ and $x_2$, respectively. From maximizing the profit function (1), we compute these optimal (one-shot) quantities at the following three possible situations: monopoly ($M$), invasion ($I$) and cournot competition ($C$). The monopoly quantity is then $q_j^M(x) = (\alpha - \tau_j(x))/2\beta$, for each $x \in A_j$. If at any single period firm $j$ invades the rival's market, $A_{-j}$, (where the subscript $-j$ denotes the rival firm), firm $j$ will set the profit-maximizing quantity $q_j^I(x) = (\alpha - 2\tau_j(x) + \tau_{-j}(x))/4\beta$, for each $x \in A_{-j}$.[4] Finally, the cournot quantity is given by $q_j^C(x) = (\alpha - 2\tau_j(x) + \tau_{-j}(x))/3\beta$, for each $x \in A$. Without loss

[4]The optimal quantity $q_j^I(x)$ is obtained by maximizing the profit function (1) subject to that firm $-j$ sets the monopoly quantity $q_{-j}^M(x)$, for $x \in A_{-j}$.

of generality let $\alpha$ be $2\tau$.[5] Consequently, the optimal (one-shot) profit of firm $j$ at location $x$ is $\pi_j^i(x) = \beta\left(q_j^i(x)\right)^2$, where $i = M, I, C$.[6] In order to keep the symmetry of the model, we consider the situation in which firms agree to divide market $A$ when they collude into two identical segments, $A_1 = [0, 1/2]$ and $A_2 = [1/2, 1]$.

Next we compute the total (one-shot) monopoly profit of firm $j$ by summing up its monopoly profit at each location in $A_j$: $\hat{\pi}_j^M(x_1, x_2) = \int_{A_j} \pi_j^M(x)\,dx$; the total (one-shot) optimal profit obtained from invading the rival market, summing up the total monopoly profit in $A_j$ and the optimal profit from invading each location in $A_{-j}$: $\hat{\pi}_j^I(x_1, x_2) = \hat{\pi}_j^M(x_1, x_2) + \int_{A_{-j}} \pi_j^I(x)\,dx$; and, the total (one-shot) cournot profit, summing up the cournot profit at each location in $A$: $\hat{\pi}_j^C(x_1, x_2) = \int_A \pi_j^C(x)\,dx$.

Consequently, firm $j$'s profit in the second-stage of the game will depend on whether there is collusion or not. In the first case, firm $j$'s profit will be the present value of forbearance in all periods, $\Pi_j^{\text{col}}(x_1, x_2) = \frac{1}{1-\delta}\hat{\pi}_j^M(x_1, x_2)$, otherwise it will be the present value of invading its rival's market in period $T$ and setting cournot quantities in all subsequent periods, $\Pi_j^{\text{inv}}(x_1, x_2) = \frac{1-\delta^T}{1-\delta}\hat{\pi}_j^M(x_1, x_2) + \delta^T\hat{\pi}_j^I(x_1, x_2) + \frac{\delta^{T+1}}{1-\delta}\hat{\pi}_j^C(x_1, x_2)$. In appendix A we demonstrate that firm $j$ invades the rival's market in the first period and, consequently, $\Pi_j^{\text{inv}}(x_1, x_2) = \hat{\pi}_j^I(x_1, x_2) + \frac{\delta}{1-\delta}\hat{\pi}_j^C(x_1, x_2)$.

The incentive compatibility condition for firm $j$ to sustain cooperation in the second-stage of the game requires that the difference between mutual forbearance

[5] This generality is slightly overstated. The condition would be $\alpha \geq 2\tau$. If $\alpha < 2\tau$, it is possible that the equilibrium cournot quantities would not exist. Transportation cost ($\tau$) would be so high relative to market demand ($\alpha$) so that some consumers, in the edged of the market, would not be supplied. This condition is demonstrated in Anderson and Neven (1991).

[6] Note that, in each single period, $q_j^C(x) = \frac{3}{4}q_j^I(x)$, and note also that, under de assumption $\alpha = 2\tau$, $q_j^M(x) > q_j^I(x)$. Consequently, $\pi_j^M(x) > \pi_j^I(x) > \pi_j^C(x)$.

and invasion is positive. We then define $\Delta_j(x_1, x_2) = \Pi_j^{\mathrm{col}}(x_1, x_2) - \Pi_j^{\mathrm{inv}}(x_1, x_2)$.

Next, we solve the first-stage of the game. At time zero, each firm noncooperatively and simultaneously chooses a location based on the outcome of the previous quantity-setting subgame. Our interest is in demonstrating the existence of optimal locations for the firms from which cooperation is sustained in the second-stage of the game. To do this, first, we characterize subgame perfect equilibriums with collusion and, second, we derive necessary and sufficient conditions for a solution to be of this kind.

**Proposition 1** *Every subgame perfect equilibrium in which firms collude has as optimal locations $x_1 = 1/4$ and $x_2 = 3/4$.*

***Proof.*** *Consider, without loss of generality, a subgame perfect equilibrium in which firms collude and the optimal locations are $x_1^* \neq 1/4$ and $x_2^*$. Since firms collude, we obtain that firm 1's profit is $\Pi_1^{\mathrm{col}}(x_1^*, x_2^*)$. Furthermore, by using that $x_1^*$ is the optimal location for firm 1, we get that $\Pi_1^{\mathrm{col}}(x_1^*, x_2^*) > \max\left\{\Pi_1^{\mathrm{col}}(1/4, x_2^*), \Pi_1^{inv}(1/4, x_2^*)\right\}$. Consequently, $\Pi_1^{\mathrm{col}}(x_1^*, x_2^*) > \Pi_1^{\mathrm{col}}(1/4, x_2^*)$. On the other hand, if we maximize the total (one-shot) monopoly profit of firm 1 with respect to $x_1$, we obtain that the optimal location for firm 1 is at $x_1 = 1/4$,[7] implying that $\Pi_1^{\mathrm{col}}(x_1^*, x_2^*) < \Pi_1^{\mathrm{col}}(1/4, x_2^*)$. Thus, since both inequalities stand in contradiction to each other, the proposition is proved.* ■

Next, we proceed with the analysis of the necessary and sufficient conditions for the existence of a subgame perfect equilibrium with collusive agreement. A known

[7] The idea behind this result is really the Anderson and Neven (1991) result. In a static framework, the authors show that firms locate where transportation costs are minimized. Hence, in a situation in which firm $j$ monopolizes market $A_j$, for $j = 1, 2$, the optimal location for firm $j$ is at the center of $A_j$.

result in the literature of supergames (see, for example, Friedman, 1971) is that firms maintain an agreement to abstain indefinitely from invasion of one another's market, through the threat of a trigger strategy, when the discount factor $\delta$ is above some critical value. Given that both firms locate at $x_1$ and $x_2$, respectively, this critical value, denoted by $\delta_{(x_1,x_2)}$, is obtained by setting $\Delta_j(x_1,x_2)$ equal to zero. In particular, for the optimal location candidates $x_1 = 1/4$ and $x_2 = 3/4$, the critical value is $\delta_{(1/4,3/4)} \simeq 0.34$.[8] Consequently, a necessary condition for the existence of a subgame perfect equilibrium with collusive agreement is that the discount factor $\delta$ of the model is over $\delta_{(1/4,3/4)}$.

However, this condition is necessary, but not sufficient. It could be the case in which locations $x_1 = 1/4$ and $x_2 = 3/4$ do not constitute a Nash equilibrium of the first-stage of the game. In fact, next we will demonstrate that the sufficient condition depends on a new critical discount factor $\bar{\delta} > \delta_{(1/4,3/4)}$ and, therefore, solely for $\delta > \bar{\delta}$, collusion and location at $x_1 = 1/4$ and $x_2 = 3/4$ will effectively be a subgame perfect equilibrium.

To do this, we analyze the reaction function of firm 1.[9] Thus, we fix the location of firm 2 at $x_2 = 3/4$ and prove that firm 1 maximizes profits at $x_1 = 1/4$. For each $\delta > \delta_{(1/4,3/4)}$, we can define two sets of locations depending on the value of $\delta_{(x_1,3/4)}$ (see Figure 1). The first set (denoted by $A_\delta^{\text{col}} \subseteq A$) is constituted by those locations from which collusion is stable (i.e., $x_1 \in A$ such that $\delta_{(x_1,3/4)} < \delta$)[10] and within the second set (denoted by $A_\delta^{\text{inv}} \subseteq A$) there are those locations from which collusion is non-stable (i.e., $x_1 \in A$ such that $\delta_{(x_1,3/4)} > \delta$). Consequently, the firm $j$'s profit is $\Pi_1^{\text{col}}(x_1, 3/4)$ when $x_1 \in A_\delta^{\text{col}}$, and $\Pi_1^{\text{inv}}(x_1, 3/4)$ when $x_1 \in A_\delta^{\text{inv}}$, where

[8] By computing $\Delta_j(1/4, 3/4)$, we obtain $\frac{(585-1709\delta)t^2}{13824\beta(\delta-1)} = 0$. Thus, solving for $\delta$, the critical value is obtained, $\delta_{(1/4,3/4)} = \frac{585}{1709}$.

[9] By symmetry, the same applies for firm 2.

[10] Note that since we are considering that $\delta > \delta_{(1/4,3/4)}$, location $x_1 = 1/4 \in A_\delta^{\text{col}}$.

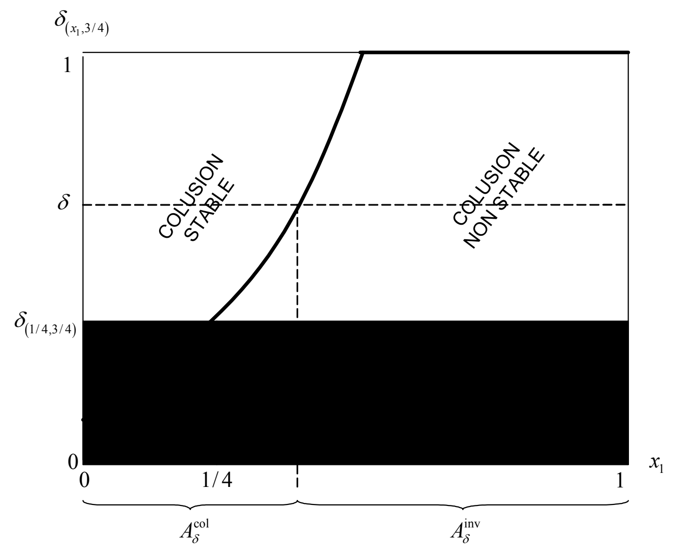


Figure 1: Dependence of collusion on the discount factor and firm location.

$A = A_\delta^{\mathrm{col}} \cup A_\delta^{\mathrm{inv}}$ and $A_\delta^{\mathrm{col}} \cap A_\delta^{\mathrm{inv}} = \emptyset$.

It is quite straightforward, following the same argument that proves proposition 1, that firm 1 maximizes profits at $x_1 = 1/4$ within $A_\delta^{\mathrm{col}}$. Therefore, we now focus in $A_\delta^{\mathrm{inv}}$. In the following propositions, first, we compute the maximum in $A_\delta^{\mathrm{inv}}$ and, second, we analyze under which conditions the maximum profit attained in $A_\delta^{\mathrm{inv}}$ is not over the profit at $x_1 = 1/4$.

**Proposition 2** *Given that $x_2 = 3/4$ and $x_1 \in A_\delta^{inv}$, firm 1's optimal location is at $x_{1,\delta} = \left(27 + \delta - \sqrt{729 - 243\delta - 38\delta^2}\right)/16\delta$.*

The proof of this lemma comes from the maximization of $\Pi_1^{\mathrm{inv}}(x_1, 3/4)$ with respect to $x_1$.

**Proposition 3** *Given that $x_2 = 3/4$. $\exists \bar{\delta}$ such that if $\delta \geq \bar{\delta}$ then the payoff from cooperation at $x_1 = 1/4$ is greater than the payoff from defection at $x_1 = x_{1,\delta}$, otherwise the contrary holds.*

This proposition is proved by setting $\Pi_1^{\text{col}}(1/4, 3/4) - \Pi_1^{\text{inv}}(x_{1,\delta}, 3/4)$ equal to zero and solving for $\delta$. The critical value is then $\bar{\delta} = 0.430789 > \delta_{(1/4,3/4)}$.[11]

Finally, we estate the following theorem that shows the necessary and sufficient condition for the existence of a subgame perfect equilibrium with collusion.

**Theorem 4** *Collusion and location at $x_1 = 1/4$ and $x_2 = 3/4$ constitute a subgame perfect equilibrium if and only if $\delta > \bar{\delta}$.*

Proof comes directly from propositions 1, 2 and 3. Comparing the values of $\delta_{(1/4,3/4)}$ and $\bar{\delta}$, we find that for $\delta \in \left(\delta_{(1/4,3/4)}, \bar{\delta}\right)$ and considering $x_1 = 1/4$ and $x_2 = 3/4$, firms would collude in a market situation with exogenous firm locations, but this would not be a solution in a spatial competition context because to come closer and to invade the rival's market is the best reply for either firm.

# 4 Conclusions

In a model of cournot competition with infinite horizon, we analyze the effect of firm location decisions on the existence and stability of a possible tacit agreement. The results obtained are the following: (1) collusion is possible and implies the location of each firm in the middle of its monopolized market, searching for the minimization of transportation costs and, (2) to achieve a collusive agreement when locations are endogenous is more difficult than when locations are exogenous. In our model, we find some spatial configurations in which, contrarily to what would happen in a model with exogenous locations, collusive agreements are not stable in time. The intuition behind this result is as follows. When firms choose their

[11] Note that effectively $x_{1,\bar{\delta}} = 0.375176 \in A_{\bar{\delta}}^{\text{inv}}$ since $\Delta_1\left(x_{1,\bar{\delta}}, 3/4\right) = -0.024\tau^2/\beta < 0$.

optimal location, their main objective (profit maximization) depends much less on the market conditions that guarantee the agreement stability between firms (i.e., the value of the discount factor). As we showed in the results, in our model of spatial cournot competition, the competition is not very strong and profit maximization yields firms to choose market locations where transportation cost is minimized. Therefore, if the discount factor is not high enough, to come closer and to invade the rival's market is the best reply for either firm. Consequently, in a more general framework, our results imply that spatial competition could difficult the stability of a collusive agreement.

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# A Appendix

Suppose that $x_1$ and $x_2$ are such that firm $j$ invades the rival's market. Therefore, we will verify that to invade at a period $T$ beyond the first period is less profitable than to invade at the first period,

$$\frac{1-\delta^{T}}{1-\delta}\hat{\pi}_{j}^{M}\left(x_{1},x_{2}\right)+\delta^{T}\hat{\pi}_{j}^{I}\left(x_{1},x_{2}\right)+\frac{\delta^{T+1}}{1-\delta}\hat{\pi}_{j}^{C}\left(x_{1},x_{2}\right)<\hat{\pi}_{j}^{I}\left(x_{1},x_{2}\right)+\frac{\delta}{1-\delta}\hat{\pi}_{j}^{C}\left(x_{1},x_{2}\right). \tag{2}$$

In order to make notation easier, from now on we will drop the reference to firm location. Therefore,

$$\frac{1}{1-\delta}\hat{\pi}_{j}^{M}<\frac{1-\delta^{T}}{1-\delta}\hat{\pi}_{j}^{M}+\delta^{T}\hat{\pi}_{j}^{I}+\frac{\delta^{T+1}}{1-\delta}\hat{\pi}_{j}^{C}, \tag{3}$$

so that,

$$\frac{\delta^{T}}{1-\delta}\hat{\pi}_{j}^{M}<\delta^{T}\hat{\pi}_{j}^{I}+\frac{\delta^{T+1}}{1-\delta}\hat{\pi}_{j}^{C}. \tag{4}$$

Since $\delta\in(0,1)$, we can simplify previous equation and obtain

$$\frac{1}{1-\delta}\hat{\pi}_{j}^{M}<\hat{\pi}_{j}^{I}+\frac{\delta}{1-\delta}\hat{\pi}_{j}^{C}. \tag{5}$$

Next, multiply both sides of the inequality by $\left(1-\delta^{T}\right)$,

$$\left(1-\delta^{T}\right)\left(\frac{1}{1-\delta}\hat{\pi}_{j}^{M}\right)<\left(1-\delta^{T}\right)\left(\hat{\pi}_{j}^{I}+\frac{\delta}{1-\delta}\hat{\pi}_{j}^{C}\right), \tag{6}$$

so that,

$$\left(1-\delta^{T}\right)\left(\frac{1}{1-\delta}\hat{\pi}_{j}^{M}\right)+\delta^{T}\left(\hat{\pi}_{j}^{I}+\frac{\delta}{1-\delta}\hat{\pi}_{j}^{C}\right)<\hat{\pi}_{j}^{I}+\frac{\delta}{1-\delta}\hat{\pi}_{j}^{C}. \tag{7}$$

This completes de proof.

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