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On the Profitability of Collusion in Location Games^α

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Abstract

In this note we take a first step towards the analysis of collusion in markets with spatial competition, focusing on the case of pure location choices. We find that collusion can only be profitable if a coalition contains more than half of all players. This result holds for location games played in k -dimensional Euclidean space as long as consumers are distributed via atomless density functions. For competition on the unit interval, unit circle, and unit square we also derive sufficient conditions for collusion to be profitable.

1 Introduction

While economic literature has paid considerable attention to collusion in Bertrand and Cournot markets, collusion with different sorts of competition has been largely neglected. In this note we take a first step towards the analysis of collusion in markets with spatial competition, focusing on the case of pure location choices as introduced by Hotelling (1929). Our results are based on an approach which does not rely on any rationality requirements. It assumes that players discussing the formation of a coalition will only go ahead if they can guarantee themselves a payoff better than the payoff expected “behind the veil of ignorance”. For linear and circular cities with a uniform distribution of consumers we find that collusion is profitable if and only if more than half of the players collude. Part of this result can

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be generalized to location games in multi-dimensional spaces with arbitrary density functions: As long as the distribution of consumers is atomless, collusion can only be profitable if more than half of all firms cooperate. For competition on the unit interval, unit circle, and unit square we are also able to derive sufficient conditions for collusion to be profitable. These results are of considerable relevance for the topic of merger in markets with limited price competition.

The remainder of the paper is organized as follows. Section 2 introduces the general setup and notation. Section 3 deals with the simplest one-dimensional cases, i.e., with linear and circular cities with uniform consumer densities. Section 4 deals with the general multi-dimensional case and establishes the main theorem of the paper. Section 5 adds sufficient conditions for collusion to be profitable in games on the unit line, unit circle and unit square. Section 6 concludes.

2 Setup and definitions

Let $\gamma(O; P)$ be a location game on $O \subset \mathbb{R}^k$ with set of players P . Let $p^i \in P$ be player i with $i = 1; 2; \dots; n$. Each player p^i chooses a location $x^i \in O$. Consumers are distributed over O via a Lebesgue measurable density function f with total mass 1. Let $d(o; o')$ be the distance between two points $o, o' \in O$. Each consumer is assumed to buy one unit of an unspecified good from the player closest to her. That is, a consumer at $o \in O$ buys from player i only if $d(o; x^i) = \min_j d(o; x^j)$. If there are more than one closest player then the consumer is assumed to buy from each closest player with the same probability. The price of the good is fixed at 1 and production costs are normalized to zero.

Let $O^i(j) = \{o \in O : d(o; x^i) = \min_{j \in P} d(o; x^j)\}$. Player p^i 's market share and profit is then given by $\pi^i(j) = \frac{1}{r^i} \int_{O^i(j)} f(o) do$ where r^i denotes the number of players located at x^i . By assumption, $\sum_i \pi^i = 1$. By virtue of this fact, we say that a player's expected payoff before the game is actually played ("behind the veil of ignorance") is $\frac{1}{n}$.

Next we define for integer m with $1 \leq m < n$ a set $V(m)$ of reals with $v \in V(m)$ if there is a collusion strategy for a coalition $M \subset P$ of m players that guarantees them a total payoff of at least v . Let $v(m) = \sup V(m)$.

Definition 1 Collusion of a set of m players is profitable if $v(m) > \frac{m}{n}$.

3 The one-dimensional case with uniform distributions

3.1 Linear cities

Let us first consider the standard textbook case of a "linear city" in which $O = [0; 1]$ and in which consumers are uniformly distributed. How can a coalition of m players guarantee itself a "high" payoff? Suppose $m > n/2$, i.e., suppose that more than half of all firms are in the coalition. In that case the coalition can minimize the payoff obtainable to a firm outside the coalition by "evenly spreading out." If f is uniform, the firms in the coalition can guarantee themselves a payoff of $\frac{3m_i n}{2m}$ by locating themselves at $(k; 3k; 5k; \dots; 1 - k)$ with $k = \frac{1}{2m}$. To see this, note that in this case a firm outside the coalition is indifferent between all possible locations as each location yields a payoff of $\frac{1}{2m}$. Furthermore, the worst thing that can happen to the coalition is that the firms outside locate in different intervals, say, one between k and $3k$, one between $3k$ and $5k$ and so on. If they do, the coalition earns $1 - \frac{n_i m}{2m} = \frac{3m_i n}{2m}$. And as this is larger than $\frac{m}{n}$ for $m > \frac{n}{2}$ collusion turns out to be profitable. Thus $m > \frac{n}{2}$ is sufficient for collusion to be profitable in linear cities with a uniform distribution of consumers. That it is also necessary in this case is stated in

Proposition 1 In linear cities with a uniform distribution of consumers collusion pays if and only if $m > \frac{n}{2}$.

Proof The argument above shows that $m > \frac{n}{2} \Rightarrow v(m) > \frac{m}{n}$. Next observe that, by definition,

$$v(m) + v(n - m) = 1. \quad (1)$$

Hence, $m = \frac{n}{2} \Rightarrow m = n - m \Rightarrow v(m) = \frac{1}{2} = \frac{m}{n}$, i.e., collusion is not profitable if exactly half of all firms cooperate. The proof is completed by showing that collusion is also not profitable if $m < \frac{n}{2}$: If $1 - m < \frac{n}{2}$, then $\frac{n}{2} < n - m \Rightarrow n - 1$ so that by the first part of the proof $v(n - m) > \frac{n - m}{n}$. Therefore, by (1) $v(m) < 1 - \frac{n - m}{n} = \frac{m}{n}$.

3.2 Circular cities

A further popular space to study location games on is a circle. In contrast to the line a set of m colluding firms can divide a circle into at most m arcs as opposed to $m + 1$ segments on the line. Nevertheless, one obtains the identical condition for collusion to be profitable.

Proposition 2 In circular cities with a uniform distribution of consumers collusion pays if and only if $m > \frac{n}{2}$.

Proof Position the colluding firms such that there are m arcs with mass $\frac{1}{m}$ each. If $m \geq \frac{n}{2}$ the maximum total payoff the non-colluding firms can obtain is $\frac{n-m}{2m}$, i.e., by using this strategy the colluding firms can ensure a payoff of $\frac{3m-n}{2m}$ which is greater than $\frac{m}{n}$ if $m > \frac{n}{2}$. Using (1) again completes the proof. \square

4 The multi-dimensional case

The following result is the main result of the paper. It generalizes one of the two insights gained above, namely that collusion in location games can only be profitable if more than half of all firms cooperate. This result holds for arbitrary bounded open subsets of \mathbb{R}^k and for arbitrary bounded atomless density functions.

Theorem 1 Suppose consumers are distributed over a bounded open subset $O \subset \mathbb{R}^k$ via a bounded Lebesgue measurable density function f of total mass 1. For the n -player location game $\gamma(O; P)$ it is not profitable for an m -player coalition to collude if $m \leq \frac{n}{2}$.

Proof Suppose the m colluding players p^1, p^2, \dots, p^m locate at $x^1, x^2, \dots, x^m \in O$, not necessarily distinct.

Case 1. $n \leq m \leq 2m$. Then for each i , $1 \leq i \leq m$, let p^{m+2i-1} and p^{m+2i} locate at x^{m+2i-1} and x^{m+2i} , two points ϵ units apart on a line through x^i , with x^i between x^{m+2i-1} and x^{m+2i} and ϵ chosen as follows: Let B be a k -dimensional ball containing O and let A be the $k-1$ -dimensional volume of the $k-1$ -dimensional disk formed by intersecting B with a hyperplane through its center. Choose ϵ such that $\epsilon < \frac{1}{nA \sup f}$ and such that ϵ is small enough to guarantee $x^{m+2i-1}, x^{m+2i} \in O$ for $1 \leq i \leq m$. Let the rest of the non-colluding players, $p^{3m+1}, p^{3m+2}, \dots, p^n$ locate anywhere in O . Since the consumers won by p^i , $1 \leq i \leq m$, lie between two hyperplanes ϵ units apart, v^i is at most $\epsilon A \sup f < \frac{1}{n}$. Hence, $v(m) < \frac{m}{n}$.

Case 2. $m < n \leq m < 2m$. For $1 \leq i \leq m$, define the provisional market set $O_{\text{prov}}^i = O^i(j^0)$ with $j^0 = j(O; M)$, i.e., O_{prov}^i contains the points in O that are nearer to x^i than to any other $x^j \neq x^i$ with both $i, j \leq m$. Accordingly, define the provisional payoff $v_{\text{prov}}^i =$

$\frac{1}{4}^i(j^0)$. W.l.o.g. assume that the sequence $\frac{1}{4}_{\text{prov}}^1; \frac{1}{4}_{\text{prov}}^2; \dots; \frac{1}{4}_{\text{prov}}^m$ is non-decreasing. Now locate $3m - n$ of the non-colluding players at $x^1; x^2; \dots; x^{3m-n}$ and use the remaining $2n - 4m$ players to bracket $x^{3m-n+1}; x^{3m-n+2}; \dots; x^m$ as in case 1, but do not yet choose ϵ . Notice that (i) $3m - n > 0$; (ii) $2n - 4m > 0$; (iii) $(3m - n) + (2n - 4m) = n - m$; and (iv) $(3m - n) + (2n - 4m) = 2 = m$. Since the sequence $\frac{1}{4}_{\text{prov}}^1; \frac{1}{4}_{\text{prov}}^2; \dots; \frac{1}{4}_{\text{prov}}^m$ is non-decreasing, the sum of the provisional payoffs $\frac{1}{4}_{\text{prov}}^1 + \frac{1}{4}_{\text{prov}}^2 + \dots + \frac{1}{4}_{\text{prov}}^{3m-n}$ is at most $\frac{3m-n}{m}$. Therefore, the total payoff to the colluding players $\sum_{i=1}^m \frac{1}{4}^i$ is at most $\frac{3m-n}{2m} + \epsilon(n - 2m)$ a.s.p.f. Now notice that $\frac{3m-n}{2m} < \frac{m}{n}$. Hence, it is possible to choose ϵ such that $\frac{m}{n} - \sum_{i=1}^m \frac{1}{4}^i > 0$. Collusion is not profitable.

Case 3. $m = n - m$. Nonprofitability follows from (1) as in the proof of Proposition 1. \square

Thus, we know that collusion in location games (on bounded open subsets of \mathbb{R}^k in which consumers are distributed via atomless density functions) can only be profitable if more than half of all firms join a coalition.

Remark 1 Note that neither the closed interval $[0; 1]$ nor a circle is an open subset of a Euclidean space. However, the conclusion of the theorem holds for location games on these sets, since the techniques of the proof apply. More particularly, it is possible to bracket colluding players as in the proofs. In fact, a colluding player at 0 or 1 in $[0; 1]$ can be bracketed by a single non-colluding player.

Remark 2 The theorem concerns location games defined using Euclidean distances, i.e., straight line distances. Implicitly, this means that consumers may travel along routes that do not belong to O . However, the theorem applies, for example, to a circle (or rather the conclusion of the theorem holds—see Remark 1) even when the distance between two points is the length of the arc joining them, since for a circle in \mathbb{R}^2 a consumer's nearest player is the same whether distance is defined as Euclidean distance or as arc length.

The theorem disallows atoms of consumers. The following example demonstrates the necessity of this assumption.

Example Consider the 5-player location game on $[0; 1]$ with two consumers, one at $\frac{1}{4}$ and one at $\frac{2}{3}$. Suppose p^1 and p^2 collude by locating at $\frac{1}{4}$

and $\frac{2}{3}$ respectively. Their worst total payoff occurs when p^3 and p^4 locate at $\frac{1}{4}$ and p^5 locates at $\frac{2}{3}$. The total payoff of p^1 and p^2 is then $\frac{1}{3} + \frac{1}{2} = \frac{5}{6}$ which is greater than the veil of ignorance expected payoff of $2(\frac{2}{5}) = \frac{4}{5}$. Collusion is profitable with $m = 2$ even though $m < \frac{n}{2}$. As in the proof of Proposition 1, where it is shown that the complement of a profitable coalition is unprofitable, collusion is unprofitable for $m = 3$, even though in that case $m > \frac{n}{2}$.

5 Sufficient conditions for unit interval, unit circle, and unit square

The main theorem above showed that $m > \frac{n}{2}$ is necessary for collusion to be successful. In the following we will establish sufficient conditions for collusion to be profitable in a location game played on the unit interval, the unit circle, and the unit square.

Proposition 3 In linear cities, collusion pays if $m > \frac{n}{2}$ and $\frac{\sup f}{\inf f} < \frac{2m}{n}$.

Proof W.l.o.g. let x^1, x^2, \dots, x^m be the set of locations occupied by the coalition chosen so that

$$\int_{x^1}^{x^2} f(o) do = \int_{x^2}^{x^3} f(o) do = \int_{x^3}^{x^4} f(o) do = \dots = \int_{x^m}^1 f(o) do = \frac{1}{2m}.$$

If a non-colluding player locates to the left of x^1 or to the right of x^m , his payoff is at most $\frac{1}{2m} < \frac{1}{n}$. If a non-colluding player locates between x^i and x^{i+1} , his payoff is $\int_c^d f(o) do$ where $x^i < c < d < x^{i+1}$ and $d - c = \frac{1}{2}(x^{i+1} - x^i)$. Then

$$\begin{aligned} \int_c^d f(o) do &\leq (d - c) \sup f \\ &= \frac{x^{i+1} - x^i}{2} \sup f \\ &\leq \frac{1}{2} \int_{x^i}^{x^{i+1}} \sup f \\ &\leq \frac{1}{2m} \frac{\sup f}{\inf f} \\ &= \frac{1}{n}. \end{aligned}$$

If a non-colluding player locates at x^i , $1 \leq i \leq m$, then he shares the market set O^i with p^i . By the argument above, the portion of O^i to the left of x^i has consumer mass less than $\frac{1}{n}$, as does the portion of O^i to the right of x^i . Therefore, the payoff to each non-colluding player is less than $(\frac{1}{n} + \frac{1}{n})g = \frac{2}{n}g$. Since in all these cases the payoff to a non-colluding player is less than $\frac{1}{n}g$, the total payoff to the coalition is more than $1 - \frac{m}{n} = \frac{n-m}{n}$. Collusion is profitable.

The sufficient condition in Proposition 3 is stronger than necessary. For instance, we used as an assumption on f only that $\frac{\sup_{f(x): x^1 < x < x^{l+1}} f(x)}{\inf_{f(x): x^1 < x < x^{l+1}} f(x)} < \frac{2m}{n}$. This allows any amount of variation to the left of x^1 and to the right of x^m and, if m is large, between x^1 and x^m .¹

Proposition 4 In circular cities, collusion pays if $m > \frac{n}{2}$ and $\frac{\sup f}{\inf f} < \frac{2m}{n}$.

Proof Analogous to the proofs of Propositions 2 and 3.

Finally, we look at location games played on the unit square with uniform consumer density.

Proposition 5 For the n -player location game on the square $[0; 1] \times [0; 1]$ with consumers distributed uniformly, collusion is profitable if there is a positive integer h with $(2h + 1)^2 \leq m < n < (2h + 1)^2$.

Proof Suppose m, n and h satisfy the hypotheses of the theorem. Consider the set C of points in $[0; 1] \times [0; 1]$ of the form $(\frac{i-1}{2h+1}, \frac{j-1}{2h+1})$ where i and j are integers, $1 \leq i, j \leq 2h + 1$, and i and j are not both even. There are exactly $(2h + 1)^2 \leq m$ points in C . Locate the m colluding players so that there is at least one of them at each point of C (recall that $m \geq (2h + 1)^2$). In the course of proving that an infinite square lattice is a Nash equilibrium for the location game in the plane with consumers distributed uniformly, Knoblauch (1998) proved that in the

¹Moreover, the players located at x^1 and x^m could move further into the interior as the mass on the fringes has only to be smaller than $\frac{1}{n}$. Using this, one can increase the allowed variation between x^1 and x^m from $\frac{2m}{n}$ to $\frac{2(m-1)}{n-2} \geq \frac{2m}{n}$. To see this, simply observe that the colluding players can position themselves so that the remaining mass between x^1 and x^m , $1 \leq \frac{2}{n}$, is equally distributed over $m-1$ intervals. The proof then goes through with $\frac{\sup_{f(x): x^1 < x < x^{l+1}} f(x)}{\inf_{f(x): x^1 < x < x^{l+1}} f(x)} < \frac{2(m-1)}{n-2}$. Therefore, $\frac{\sup_{f(x): x^1 < x < x^m} f(x)}{\inf_{f(x): x^1 < x < x^m} f(x)}$ can be as large as $\frac{2(m-1)}{n-2}$.

location game on $[0; 1] \in [0; 1]$, any player with at least one opponent at each point of C earns a payoff of at most $\frac{1}{(2h+1)^2}$ so that the non-colluding players' total payoff is at most $\frac{n-m}{(2h+1)^2} < \frac{n-m}{n}$. Hence, $v(m) > \frac{m}{n}$.

For large n , the theorem says, roughly, that collusion is profitable if $m > \frac{3n}{4}$. This interpretation follows from the fact that for large n there is an integer h such that $n < (2h+1)^2$, $\frac{(2h+1)^2}{n} \leq 1$, and $\frac{(2h+1)^2 - h^2}{n} \leq \frac{3}{4}$. For example, if $n = 1,000,000$ choose $h = 500$. Then $(2h+1)^2 = 1,002,001$ and $(2h+1)^2 - h^2 = 752,001$. The theorem says collusion is profitable if $\frac{m}{1,000,000} > 0.752001$.

6 Discussion

We find that collusion in location games only pays if the set of colluders is larger than the set of non-colluding competitors. Bilateral collusion, for example, can only pay if there are no more than three competitors. This result is based on an approach which does not rely on any rationality requirements. It assumes that players discussing the formation of a coalition will only go ahead if they can guarantee themselves a payoff better than the payoff expected "behind the veil of ignorance".

The results may have implications for the topic of mergers in markets with (pure) spatial competition as an example of which competition among big book retailers (where price competition is extremely limited) may serve. As merger in the traditional sense (see Salant, Switzer, and Reynolds 1983) where firms simply "disappear" never pays in such location games, merger can only be profitable if the merging units are kept as separate units which are governed by a central headquarter. This is identical to the case of collusion analysed above. However, the analysis reveals that with this kind of competition only "mega mergers" are likely to occur.²

²Concerning the market for books such a mega merger has recently occurred in the UK where Waterstone's took over Dillon's. And, interestingly, the new Waterstone's branches in London are pretty much "spread out." In particular, Waterstone's two flagship stores are not at Charing Cross Road, the traditional spot for large book stores but rather "to the left and to the right" of the competitors' big stores, namely at Picadilly and UCL.

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