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# A NOTE ON ARÉVALO-TOMÉ AND CHAMORRO-RIVAS: LOCATION AS AN INSTRUMENT FOR SOCIAL WELFARE IMPROVEMENT IN A SPATIAL MODEL OF COURNOT COMPETITION

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*In a recent paper in this journal, Arévalo-Tomé and Chamorro-Rivas claim to have shown that, in a two-stage game where Cournot duopoly firms discriminate over two marketplaces on a line, a social planner can use the firm's location variable as an instrument for reallocating production from the equilibrium spatial pattern to the optimal outcome. This note points out that with linear demand there is no need to use such an instrument for social welfare improvement, because the equilibrium locations are indeed socially optimal. The note also discusses the possibility of using such an instrument for general demand.*

*Keywords: Spatial competition, Cournot, welfare.*

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## 1. Introduction

Bergstrom and Varian (1985a, b) and Salant and Shaffer (1999) demonstrate that output and price in a Cournot industry depend only on the sum of the marginal costs, and not on their distribution across the firms, provided the Cournot equilibrium is interior. Even more interesting is that, contrary to intuition, asymmetry has both social and private advantages.

Arévalo-Tomé and Chamorro-Rivas (A-C hereafter) reinterpret and extend such remarks in Cournot equilibrium to the spatial context with multiple marketplaces. They point out that in a spatial Cournot competition model with two endpoint markets on a line, the sum of

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the duopoly firms' unit transportation costs at each market is constant, if the firms locate symmetrically around the midpoint of the line. This implies that social surplus reaches its maximal when the duopoly firms locate separately at the opposite endpoints of the line. However, in the competitive framework there is aggressiveness shown in the duopoly by moving towards the center so as to obtain a strategic advantage. For a special case of linear market demand, the only location equilibrium is when duopoly firms agglomerate at the center. In a sense, if there exists an interior location equilibrium such as in the linear demand model, then a social planner concerned about social welfare maximization can use location as an instrument for social welfare improvement, which means relocating and increasing the duopoly firms' location differentiation.

The main interest of this note is to show that the equilibrium locations of the duopoly firms in the A-C model satisfy the principle of maximal location differentiation, given linear market demand. This means that the equilibrium welfare is already socially optimal, and thus there is no need for a social planner to use location as an instrument for social welfare improvement.

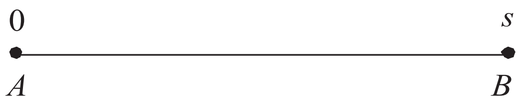
The same result is almost valid for non-linear market demand. Since there exists no interior location equilibrium with duopoly firms separately and symmetrically located around the midpoint of the line, the equilibrium welfare can only be improved if duopoly firms agglomerate at the center. However, the possibility of spatial agglomeration in equilibrium is ruled out by a mild restriction on the third-order derivative of the inverse demand function, which means that maximal location differentiation is the only possible symmetric location equilibrium and, in this sense, the equilibrium welfare cannot be improved any more by a social planner.

It is worth taking a look at a symmetric location equilibrium and the result in this note only applies to the particular case of a duopoly. We should emphasize that it remains an open question to investigate what could happen in the general case of an oligopoly with more than two firms.

## 2. The basic model

We shall first recall the A-C model and notations. It is assumed two firms locate on a line with length $s$ between two different markets denoted by $A$ and $B$, each of which is located at a point such as following Figure 1 shows.

FIGURE 1
Spatial market




At each market $j$, the inverse demand is given by $P_j = P(Q_j)$, where $P_j$ is the market price and $Q_j = q_{1j} + q_{2j}$ is the market's industry output, for $j = A, B$. It is assumed that symmetric constant-return-to-scale technologies and marginal costs are normalized to zero. Suppose firm $i$ pays a transportation cost $tx_i$ ($t(s - x_i)$, respectively) to ship a unit of the homogeneous good from its own location, $x_i$, to market $A$ (market $B$, respectively), for $t > 0$. A two-stage non-cooperative game with location choice at the first stage and Cournot competition at the second stage is now examined.

## 3. Analysis

With straightforward derivation, the Cournot equilibrium of firm $i$ for $i \in \{1, 2\}$ at the second stage of the game at each market can be solved as:

$$q_{iA}^* = \frac{tx_i - P(Q_A^*)}{P'(Q_A^*)}. \qquad [1]$$

$$q_{iB}^* = \frac{t(s - x_i) - P(Q_B^*)}{P'(Q_B^*)}. \qquad [2]$$

Before solving the first stage of the game, the authors (A-C) show that social welfare (global consumer surplus plus global producer profits) is increasing with the duopoly firms' location differentiation, $x_2 - x_1$, and reaches its maximal when the duopoly firms locate separately at the opposite endpoints of the line, $x_1 = 0, x_2 = s$, provided a social planner can regulate only on the firms' locations, but not their quantities.

Turning to the location stage, A-C then ask two questions. First, whether or not the global equilibrium welfare is also optimal from the viewpoint of social welfare. Second, if it is not, then whether or not the welfare improvement can be achieved while maintaining the symmetry of the model and without discriminating between the firms.

In order to get a closed-form solution of the equilibrium location and then answer the above questions, the authors give a specific functional form for market demand. They propose that duopoly firms concentrate at the midpoint between both marketplaces ($x_1^* = s/2, x_2^* = s/2$), which is the only equilibrium location, given linear market demand such that $P(Q_j) = \alpha - \beta Q_j$. They prove such a claim in Proposition 2 of their paper through the following first-order condition of firm $i$ (in a more general framework with $n$ firms).

$$\frac{\partial \pi_i}{\partial x_i} = \frac{2nt}{(n+1)} \left[ \frac{nt(2x_i - s) + \sum_{k \neq i} t(s - 2x_k)}{\beta(n+1)} \right] = 0. \qquad [3]$$

In this interior equilibrium configuration, global welfare is not maximized. It is thus concluded that the firms' location can be used as an instrument for a social planner for welfare improvement by dispersing firms and locating them close to the markets, while preserving a symmetric location.

However, from the second-order condition of equation [3], it follows that this value of $x_i$ is a global minimum instead of global maximum.

$$\frac{\partial^2 \pi_i}{\partial x_i^2} = \frac{4n^2 t^2}{\beta(n+1)^2} > 0. \qquad [4]$$

The profit function of firm $i$ is continuous and convex rather than concave in its own location $x_i$. This means that, given the opponents' location choices, firm $i$ must either set $x_i = 0$ or set $x_i = s$. Turning to the duopoly case, there exist three possible solutions: $(x_1, x_2) = (0,0), (0,s)$, and $(s,s)$. The following equation [5] indicates that, for a fixed $x_2 = s(x_1 = 0$, respectively), the location best response of firm 1 (firm 2, respectively) is given by $x_1 = 0(x_2 = s$, respectively), and thus duopoly firms have no incentives to deviate from maximum location differentiation.

$$\pi_1(0,s) - \pi_1(s,s) = \pi_2(0,s) - \pi_2(0,0) = \frac{4s^2t^2}{9\beta} > 0. \qquad [5]$$

It is concluded that the location equilibrium is actually given by $(x_1^* = 0, x_2^* = s)$ instead of $(x_1^* = s/2, x_2^* = s/2)$ as the authors claim.

PROPOSITION 1. For a linear demand at each market such that $P(Q_j) = \alpha - \beta Q_j$, for $j = A, B$, there exists a unique location equilibrium showing maximal location differentiation such that $(x_1^* = 0, x_2^* = s)$.

Since the duopoly firms will locate at the opposite endpoints of the line, the equilibrium welfare is actually maximized and cannot be improved any more by a social planner.

We next further investigate the possibility for government intervention by relocating the firms for a general market demand. For reason of simplicity and avoiding any equity problem, we concentrate only on a symmetric location equilibrium (i.e. $x_2^* = s - x_1^*$) as assumed by A-C in their paper. The result is demonstrated in the following proposition.

PROPOSITION 2. If there exists a symmetric location equilibrium (i.e. $x_2^* = s - x_1^*$), then the equilibrium locations show maximal differentiation such that $x_1^* = 0, x_2^* = s$. That is, for a general demand at each market $P(Q_j)$, for $j = A, B$.

1) There exists no interior location equilibrium with duopoly firms symmetrically located around the center, outside the central location (i.e. $(x_1^*, x_2^* = s - x_1^*)\, \forall x_1^* \in (0, s/2)$).

2) Suppose the third-order derivative of an inverse demand function is non-positive ($P''' \left(Q_j^*\right) > 0$ for $j = A, B$), or positive ($P''' \left(Q_j^*\right) > 0$ for $j = A, B$) which is at least not too large. Duopoly firms then agglomerating at the midpoint between both marketplaces $(x_1^* = s/2, x_2^* = s/2)$ would never be an equilibrium location.

PROOF: See Appendices A1 and A2.

Note first that for any interior symmetric location equilibrium (i.e. $(x_1^*, x_2^* = s - x_1^*)$, for $x_1^* \in (0, s/2]$), the first-order derivative of a firm's profit function with respect to its own location evaluated at $(x_1^*, x_2^*)$ must be zero (i.e. $\partial \pi_i (x_1^*, x_2^*) / \partial x_i = 0$, for $i \in \{1, 2\}$ and $x_2^* = s - x_1^*$). In Appendix A1, it is shown that $\partial \pi_1 (x_1, x_2) / \partial x_1 < 0$, $\forall x_1 \in [0, s/2)$, $x_2 = s - x_1$, and $\partial \pi_1 (x_1, x_2) / \partial x_1 = 0$ for $x_1 = s/2$ and $x_2 = s/2$ at the location stage of this game. In other words, the first-order condition of an interior symmetric location equilibrium would never hold unless firms agglomerate at the midpoint $(x_1^* = s/2, x_2^* = s/2)$, which guarantees the above Proposition 2 (1).

Since the location choice of each firm is bounded, a corner solution shown as the maximal location differentiation ($x_1^* = 0, x_2^* = s$) and an interior solution shown as the spatial agglomeration at the midpoint ($x_1^* = s/2, x_2^* = s/2$) are therefore the only two possible location equilibria. For the special case of a linear demand, we have shown that a firm's profit function is convex in its own location, and thus the candidate location equilibrium satisfying the first-order condition ($x_1 = s/2, x_2 = s/2$) is invalid. We next check the second-order condition, $\partial^2\pi_i/\partial x_i^2$, for general demand. Since it depends on the third-order derivative of an inverse demand function, we need a further assumption on market demand.

Appendix A2 demonstrates that a firm's profit function is locally convex rather than locally concave in ($x_1 = s/2, x_2 = s/2$) if the third-order derivative of an inverse demand function is non-positive ($P''' \left(Q_j^*\right) \leq 0$ for $j = A, B$), or positive ($P''' \left(Q_j^*\right) > 0$ for $j = A, B$) which is at least not too large, meaning that spatial agglomeration would never be a location equilibrium. In this case, maximal differentiation ($x_1 = 0, x_2 = s$) is the only possible symmetric location equilibrium. Therefore, it would also seem that equilibrium welfare cannot be improved any more by a social planner for the non-linear case, although it should be noted that we do not extend our analysis to prove that the maximal differentiation solution is indeed an equilibrium.

## Appendix A1. Proof of Proposition 2 (1)

Recall that when marginal production costs are constant and arbitrage is non-binding, quantities set at different markets by the same firm are strategically independent. According to the first-order conditions, the equilibrium quantities of market $A$ at the second stage of this game, ($q_{1A}^*(x_1, x_2), q_{2A}^*(x_1, x_2)$), satisfy the following system of equations:

$$\begin{aligned} P'\left(q_{1A}^* + q_{2A}^*\right) q_{1A}^* + P\left(q_{1A}^* + q_{2A}^*\right) - tx_1 = 0, \\ P'\left(q_{1A}^* + q_{2A}^*\right) q_{2A}^* + P\left(q_{1A}^* + q_{2A}^*\right) - tx_2 = 0. \end{aligned} \quad \text{[A1.1]}$$

Assume the Jacobian determinant $J_{F^A} = \det\left[\partial F_i^A/\partial q_{jA}\right]$ for $i, j = 1, 2$ is positive,[1] where $F_i^A$ denotes the left-hand side of the $i$-th equation of the above system. The implicit function theorem thus indicates

[1] The Jacobian determinant $J_{F^A} > 0$ ensures that the Cournot reaction functions are well behaved and have a slope less than one in absolute value, and therefore there exists a unique Cournot equilibrium, such as A-C assume in their paper.

that the functions $q_{1A}^*$ and $q_{2A}^*$ have partial derivatives with respect to the locations $x_1$ and $x_2$. The partial derivatives with respect to $x_1$ can be calculated as:

$$\begin{aligned}\frac{dq_{1A}^*}{dx_1} &= -\frac{1}{J_{F^A}}\det\begin{bmatrix} \partial F_1^A/\partial x_1 & \partial F_1^A/\partial q_{2A} \\ \partial F_2^A/\partial x_1 & \partial F_2^A/\partial q_{2A}\end{bmatrix} \\ &= \frac{t[2P'(Q_A^*)+P''(Q_A^*)q_{2A}^*]}{P'(Q_A^*)[3P'(Q_A^*)+P''(Q_A^*)Q_A^*]},\end{aligned}$$

$$\begin{aligned}\frac{dq_{2A}^*}{dx_1} &= -\frac{1}{J_{F^A}}\det\begin{bmatrix} \partial F_1^A/\partial q_{1A} & \partial F_1^A/\partial x_1 \\ \partial F_2^A/\partial q_{1A} & \partial F_2^A/\partial x_1\end{bmatrix} \\ &= \frac{-t[P'(Q_A^*)+P''(Q_A^*)q_{2A}^*]}{P'(Q_A^*)[3P'(Q_A^*)+P''(Q_A^*)Q_A^*]}.\end{aligned} \qquad [A1.2]$$

By a similar argument, the Jacobian determinant $J_{F^B} = \det\left[\partial F_i^B/\partial q_{jB}\right] > 0$ for $i, j = 1, 2$, where $F_i^B$ denotes the left-hand side of the $i$-th equation of the following system.

$$\begin{aligned}P'(q_{1B}^*+q_{2B}^*)q_{1B}^* + P(q_{1B}^*+q_{2B}^*) - t(s-x_1) &= 0,\\ P'(q_{1B}^*+q_{2B}^*)q_{2B}^* + P(q_{1B}^*+q_{2B}^*) - t(s-x_2) &= 0.\end{aligned} \qquad [A1.3]$$

The partial derivatives of the equilibrium quantities of market $B$, $(q_{1B}^*(x_1,x_2), q_{2B}^*(x_1,x_2))$, with respect to $x_1$ can also be calculated as:

$$\begin{aligned}\frac{dq_{1B}^*}{dx_1} &= -\frac{1}{J_{F^B}}\det\begin{bmatrix} \partial F_1^B/\partial x_1 & \partial F_1^B/\partial q_{2B} \\ \partial F_2^B/\partial x_1 & \partial F_2^B/\partial q_{2B}\end{bmatrix} \\ &= \frac{-t[2P'(Q_B^*)+P''(Q_B^*)q_{2B}^*]}{P'(Q_B^*)[3P'(Q_B^*)+P''(Q_B^*)Q_B^*]},\end{aligned}$$

$$\begin{aligned}\frac{dq_{2B}^*}{dx_1} &= -\frac{1}{J_{F^B}}\det\begin{bmatrix} \partial F_1^B/\partial q_{1B} & \partial F_1^B/\partial x_1 \\ \partial F_2^B/\partial q_{1B} & \partial F_2^B/\partial x_1\end{bmatrix} \\ &= \frac{t[P'(Q_B^*)+P''(Q_B^*)q_{2B}^*]}{P'(Q_B^*)[3P'(Q_B^*)+P''(Q_B^*)Q_B^*]}.\end{aligned} \qquad [A1.4]$$

Turning to the first stage of this game, each firm chooses a location to maximize its global profit. Let us concentrate on firm 1. A similar reasoning can be held for the second firm. The global profit of firm 1 of the location subgame can be written as:

$$\begin{aligned}\pi_1 &= [P(Q_A^*) - tx_1] \cdot q_{1A}^* + [P(Q_B^*) - t(s - x_1)] \cdot q_{1B}^* \\ &= \pi_{1A}(q_{1A}^*(x_1, x_2), q_{2A}^*(x_1, x_2), x_1, x_2) + \pi_{1B}(q_{1B}^*(x_1, x_2), \\ &\quad q_{2B}^*(x_1, x_2), x_1, x_2). \qquad [A1.5]\end{aligned}$$

Here, $q_{iA}^*$ and $q_{iB}^*$ for $i \in \{1, 2\}$ are shown in equations [1] and [2]. Differentiating firm 1's global profit function (from equation [A1.5]) with respect to $x_1$ yields:

$$\begin{aligned}\frac{\partial \pi_1}{\partial x_1} &= \left( \frac{\partial \pi_{1A}}{\partial q_{1A}} \cdot \frac{dq_{1A}^*}{dx_1} + \frac{\partial \pi_{1A}}{\partial q_{2A}} \cdot \frac{dq_{2A}^*}{dx_1} + \frac{\partial \pi_{1A}}{\partial x_1} \right) \\ &\quad + \left( \frac{\partial \pi_{1B}}{\partial q_{1B}} \cdot \frac{dq_{1B}^*}{dx_1} + \frac{\partial \pi_{1B}}{\partial q_{2B}} \cdot \frac{dq_{2B}^*}{dx_1} + \frac{\partial \pi_{1B}}{\partial x_1} \right) \\ &= \left( [P'(Q_A^*) q_{1A}^*] \cdot \frac{dq_{2A}^*}{dx_1} - tq_{1A}^* \right) \\ &\quad + \left( [P'(Q_B^*) q_{1B}^*] \cdot \frac{dq_{2B}^*}{dx_1} + tq_{1B}^* \right). \qquad [A1.6]\end{aligned}$$

It is worth seeing that the second-order condition of a Cournot equilibrium implies equation [A1.7]. The condition ensuring a downward sloping reaction function (Assumption 2 in the original A-C model) implies equation [A1.8].

$$\frac{\partial^2 \pi_{1A}^*}{\partial (q_{1A})^2} + \frac{\partial^2 \pi_{2A}^*}{\partial (q_{2A})^2} = \frac{4[P'(Q_A^*)]^2 + P''(Q_A^*)[t(x_1 + x_2) - 2P(Q_A^*)]}{P'(Q_A^*)} < 0. \qquad [A1.7]$$

$$\frac{\partial^2 \pi_{1A}^*}{\partial (q_{1A})^2} + \frac{\partial^2 \pi_{2A}^*}{\partial q_{1A} \partial q_{2A}} = \frac{3[P'(Q_A^*)]^2 + P''(Q_A^*)[t(x_1 + x_2) - 2P(Q_A^*)]}{P'(Q_A^*)} < 0. \qquad [A1.8]$$

Substituting equations [A1.2] and [A1.4] into equation [A1.6] and evaluating the resulting expression at $x_2 = s - x_1$ and $Q_A^* = Q_B^* = Q^*$, we yield:

$$\frac{\partial \pi_1(x_1, x_2)}{\partial x_1} = \underbrace{\frac{-t^2(2x_1 - s)}{P'(Q^*)}}_{-} \cdot \underbrace{\frac{4[P'(Q^*)]^2 + P''(Q^*)[ts - 2P(Q^*)]}{3[P'(Q^*)]^2 + P''(Q^*)[ts - 2P(Q^*)]}}_{+}. \qquad [A1.9]$$

It is straightforward that equations [A1.7] and [A1.8] imply that the second term of equation [A1.9] is positive. Thus, from equation [A1.9], $\partial\pi_1(x_1, x_2)/\partial x_1 < 0, \quad \forall x_1 \in [0, s/2)$ and $x_2 = s - x_1$. This means that there can be no interior pure strategy equilibrium with firms symmetrically located around the center, outside the central location, since the first-order condition for an interior solution never holds unless duopoly firms agglomerate at the center. Q.E.D.

**Appendix A2. Proof of Proposition 2 (2)**

From equation [A1.9], $\partial\pi_1(x_1, x_2)/\partial x_1 = 0$ only if $x_1 = s/2$ and $x_2 = s/2$. We next check the second-order condition $\partial^2\pi_i/\partial x_i^2$ for such a solution. Differentiating the first-order derivative of firm 1's global profit function (from equation [A1.6]) with respect to $x_1$ and taking into account equations [A1.2] and [A1.4] yield:

$$\frac{\partial^2\pi_1}{\partial x_1^2} = \frac{\partial^2\pi_{1A}}{\partial x_1^2} + \frac{\partial^2\pi_{1B}}{\partial x_1^2}, \text{ for}$$

$$\frac{\partial^2\pi_{1j}}{\partial x_1^2} = \frac{t^2\left[-24(P_j')^3 + \eta_1(P_j')^2 + \eta_2 P_j' + \eta_3\right]}{P_j'(P_j''Q_j + 3P_j')^3}, \qquad \text{[A2.1]}$$

where $\eta_1 = 2P_j''(-16Q_j + 11q_{1j}) + P_j'''q_{1j}(3q_{1j} - 2Q_j), \eta_2 = 2(P_j'')^2 (-5q_{1j}^2 - 7Q_j^2 + 11q_{1j}Q_j), \eta_3 = -2(P_j'')^3 Q_j(q_{1j} - Q_j)^2$, and $j = A, B$. In order to clarify notation, we have denoted $P_j' = P'(Q_j^*)$,$P_j'' = P''(Q_j^*)$, $P_j''' = P'''(Q_j^*)$,$q_{1j} = q_{1j}^*$, and $Q_j = Q_j^*$. Note first that $\eta_1 = \eta_2 = \eta_3 = 0$ $(P_j'' = P_j''' = 0)$ for the special case of a linear demand such that $P(Q_j) = \alpha - \beta Q_j$, and the second-order derivative of global profit can be rewritten as (from equation [A2.1]):

$$\frac{\partial^2\pi_1}{\partial x_1^2} = \frac{\partial^2\pi_{1A}}{\partial x_1^2} + \frac{\partial^2\pi_{1B}}{\partial x_1^2} = \frac{8t^2}{9\beta} + \frac{8t^2}{9\beta} = \frac{16t^2}{9\beta} > 0, \qquad \text{[A2.2]}$$

which was computed directly in equation [4] for $n = 2$.

It is worth seeing that $x_1 = x_2 = s/2$ implies $q_{1A}^* = q_{1B}^* = q_{2A}^* = q_{2B}^* = q$, $Q_A^* = Q_B^* = Q = 2q$, $P_A' = P_B' = P'$, $P_A'' = P_B'' = P''$, and $P_A''' = P_B''' = P'''$. Therefore, from equation [A2.1], the second-order derivative of global profit when duopoly firms agglomerate at the center can be calculated as:

$$\frac{\partial^2 \pi_1}{\partial x_1^2} = \frac{-2t^2 \left\{ \overbrace{2(P' + P''q)}^{-} \overbrace{\left[ 2(P'')^2 q^2 + 9P'(P' + P''q) + 3(P')^2 \right]}^{+} + \overbrace{P'''(P')^2 q^2}^{?} \right\}}{\underbrace{P'(3P' + 2P''q)^3}_{+}}. \quad \text{[A2.3]}$$

The second-order condition of a Cournot equilibrium, $\partial^2\pi_{1A}^*/\partial(q_{1A})^2 = 2P'+P''q < 0$, and the condition ensuring a downward sloping reaction function, $\partial^2\pi_{1A}^*/\partial q_{1A}\partial q_{2A} = P' + P''q < 0$, imply that the denominator of equation [A2.3] is positive and the sign of $\partial^2\pi_1(x_1, x_2)/\partial x_1^2$ when $x_1 = x_2 = s/2$ depends on the sign of $P'''$. If $P''' \leq 0$, or $P''' > 0$ is at least not too large, then this expression is positive ($\partial^2\pi_1(x_1, x_2)/\partial x_1^2 > 0$ when $x_1 = x_2 = s/2$), which indicates that, for a given $x_2 = s/2$, firm 1's profit function is locally convex rather than locally concave in $x_1 = s/2$. Therefore, spatial agglomeration is never a location equilibrium. Q.E.D.

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## Resumen

*En un artículo reciente de esta revista, Arévalo-Tomé y Chamorro-Rivas sostienen haber demostrado que, en un juego en dos etapas donde dos empresas que compiten a la Cournot deciden su localización a lo largo de una línea, un planificador social podría utilizar la localización de la empresa como un instrumento para reasignar la producción del equilibrio del modelo espacial al resultado óptimo. Esta nota muestra que con una demanda lineal no sería necesario utilizar este instrumento para mejorar el bienestar social porque las localizaciones elegidas por las empresas son socialmente óptimas. Además se analiza la posibilidad de utilizar la localización de las empresas como un instrumento del planificador en el caso de una demanda más general.*

*Palabras clave: Competencia espacial, Cournot, bienestar.*

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