DOI https://doi.org/10.30525/978-9934-588-86-0.13

AGGLOMERATION AND DISPERSION OF FIRMS UNDER SPATIAL COMPETITION

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INTRODUCTION

In search of a solution to the Bertrand paradox, Hotelling proposed to take into account the factor of space under the price competition of firms. In Hotelling's linear city model[1], two firms compete on a segment with a unit demand at each point. Firms optimize their prices and location on the segment. Transportation delivery costs of goods are borne by consumers. Hotelling found that in an equilibrium state, firms would be minimally spatially differentiated, since they would be located in the center. This conclusion of the model analysis subsequently became a famous "principle of minimal differentiation".

In further research, the Hotelling model has been developed in the following areas:

– an increase in the number of firms[2, 3];

– an increase in the dimension of space[4, 5];

– the complexity of the type of transport costs function[6, 7];

– consideration of the Cournot competition[8, 9] and Stackelberg competition[10, 11].

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[1] Brenner, S. (2005). Hotelling Games with Three, Four, and More Players. *Journal of Regional Science*, 45(4), 851–864. doi: 10.1111/j.0022-4146.2005.00395.x

[2] Patri, S., Sacco, A. (2017). Sequential Entry in Hotelling Model with Location Costs: A Three-Firm Case. Spatial Interaction Models: Facility Location Using Game Theory, 261–272. doi: 10.1007/978-3-319-52654-6_12

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Anderson and Neven[12] restricted the analysis to $t < b/2$. Rivas[13] extended the analysis to $t \le b$ allowing for different market configurations. The paper identified market patterns where firms compete over the whole market as well as patterns where a firm behaves as a monopoly in a market segment.

In this chapter we are extending the analysis to $t \le 2 \cdot b$ and showing that firms have location decisions, which provide a full cover of markets.

THE LINEAR CITY MODEL

Two firms sell homogeneous goods on the unit segment, at each point of which is consumer market x, $\mathrm{x} \in [0,1]$. The distance of the firms from zero point is equal x_1 and x_2 accordingly, and $\mathrm{x}_1 \le x_2$. Each firm faces linear transportation costs of t to move one good unit per one unit of distance. Consumer arbitrage is assumed to be prohibitively costly.

The linear demand curve on market x:

$$p(x) = b - q_1(\mathrm{x}) - q_2(x),$$

where $\mathrm{p}(\mathrm{x})$ – the price on market x, $q_1(x)$, $q_2(x)$ – the quantities supplied by firms on market x, b – a minimum price, at which there is no demand (reservation price).

Let us assume that firms supply products to all markets (full coverage): $\mathrm{q}_1(x=1) \ge 0$, $\mathrm{q}_1(x<1) > 0$, $\mathrm{q}_2(x=0) \ge 0$, $\mathrm{q}_2(x>0) > 0$. Thus, zero quantities supplied are possible only at the boundaries of a unit segment.

The profits of firms on market x:

$$F_1(\mathrm{x}) = q_1(\mathrm{x}) \cdot \left(b - q_1(x) - q_2(x) - t \cdot |x - x_1|\right) \rightarrow \max_{x_1, q_1(x)},$$

$$F_2(x) = q_2(x) \cdot \left(b - q_1(x) - q_2(x) - t \cdot |x - x_2|\right) \rightarrow \max_{x_2, q_2(x)}.$$

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[9] Torbenko, A. (2013). Model lineinogo goroda s ekzogennoi konkurentciei po Shtakelbergu [The Linear City Model with Exogenous Stackelberg Competition]. *Mat. Teor. Igr Pril.*, 5(2), 64–81.

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[13] Ibid.

The competitive game consists of two stages. In the first stage, the firms simultaneously select their locations. In the second stage, at the given location decisions, the firms simultaneously choose their supplied quantities. The equilibrium of the model is solved by backward induction.

THE COURNOT COMPETITION

According to the backward induction method we begin with the second stage. Let us assume that firms optimize supplied volumes under Cournot competition. Solving the first-order conditions yields the reaction curves of the firms:

$$q_1(x) = \frac{b - q_2(x) - t \cdot |x - x_1|}{2}, \quad q_2(x) = \frac{b - q_1(x) - t \cdot |x - x_2|}{2}.$$

The equilibrium supply volumes of firms to market x:

$$q_1^*(x) = \frac{b - 2 \cdot t \cdot |x - x_1| + t \cdot |x - x_2|}{3}, \tag{1}$$

$$q_2^*(x) = \frac{b - 2 \cdot t \cdot |x - x_2| + t \cdot |x - x_1|}{3}. \tag{2}$$

Let us define the feasible region locations of firms.

From previous studies[14, 15] we know that the equilibrium in this model is symmetrical about the center:

$$x_1^e + x_2^e = 1,\ x_1^e \le 1/2,\ x_2^e \ge 1/2. \tag{3}$$

In the center of line segment the firms minimize a total distance of traffic, therefore full coverage of markets is possible with the highest transport tariff. Substituting into (1) values $x_1 = 1/2$, $x_2 = 1/2$, $x = 1$ or into (2) values $x_1 = 1/2$, $x_2 = 1/2$, $x = 0$, we find that at any locations of firms the coverage of all markets is possible only at $t \le 2 \cdot b$.

From (1) it follows that for firm 1 the minimum volume of deliveries is reaching on market $x = 1$. Therefore a condition of coverage of markets for firm 1:

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[14] Chamorro-Rivas, J. M. (2000). Spatial Dispersion in Cournot Competition. *Spanish Economic Review*, 2, 145–152.

[15] Hamilton, J. H., Thisse, J.-F. Weskamp, A. (1989). Spatial discrimination, Bertrand vs. Cournot in a model of location choice. *Regional Science and Urban Economics*, 19, 87–102.

$$q_1^*(x=1)=0 \quad \Leftrightarrow \quad b-2\cdot t\cdot(1-x_1)+t\cdot(1-x_2)=0. \tag{4}$$

For firm 2 the minimum volume of deliveries is reaching on market $x=0$. Therefore a condition of coverage of markets for firm 2:

$$q_2^*(x=0)=0 \quad \Leftrightarrow \quad b-2\cdot t\cdot x_2+t\cdot x_1=0. \tag{5}$$

Solving the system of equations (4)–(5) yields

$$x_1^{\mathrm{cov}}=\frac{1}{2}-\frac{2\cdot b-t}{6\cdot t}, \tag{6}$$

$$x_2^{\mathrm{cov}}=\frac{1}{2}+\frac{2\cdot b-t}{6\cdot t}. \tag{7}$$

Thus, the feasible region locations are (Fig.1):

$$\begin{cases} 0\le x_1\le 1/2 \quad \mathit{for} \quad 0<t\le b/2, \\ x_1^{\mathrm{cov}}\le x_1\le 1/2 \quad \mathit{for} \quad 0<t\le b/2, \\ 1/2\le x_2\le 1 \quad \mathit{for} \quad 0<t\le b/2, \\ 1/2\le x_2\le x_2^{\mathrm{cov}} \quad \mathit{for} \quad b/2<t\le 2\cdot b. \end{cases} \tag{8}$$

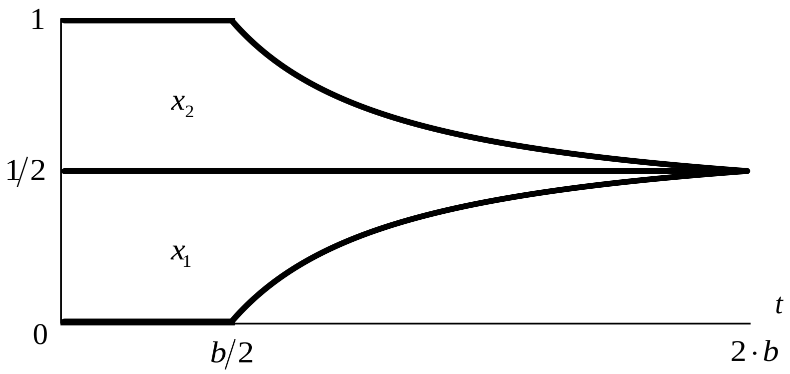

Fig. 1. The feasible region locations

The equilibrium profits of firms on market x:

$$\begin{aligned} F_1^*(x)&=\frac{\left(b-2\cdot t\cdot|x-x_1|+t\cdot|x-x_2|\right)^2}{9}=\left(q_1^*(x)\right)^2, \\ F_2^*(x)&=\frac{\left(b-2\cdot t\cdot|x-x_2|+t\cdot|x-x_1|\right)^2}{9}=\left(q_2^*(x)\right)^2. \end{aligned} \tag{9}$$

In the first stage each firm selects a profit-maximizing location at a given location of the rival.

So, let us start with firm 1. The total profit of firm 1 in all markets:

$$\mathrm{F}_1 = \int_0^1 \mathrm{F}_1^*(\mathrm{x})\,dx = \int_0^{\mathrm{x}_1} \mathrm{F}_1^*(\mathrm{x})\,dx + \int_{\mathrm{x}_1}^{\mathrm{x}_2} \mathrm{F}_1^*(\mathrm{x})\,dx + \int_{\mathrm{x}_2}^{1} \mathrm{F}_1^*(\mathrm{x})\,dx,$$

$$\begin{aligned} 9\cdot \mathrm{F}_1 = &\int_0^{\mathrm{x}_1} \left(b + 2\cdot t\cdot(x - x_1) - t\cdot(x - x_2)\right)^2 dx + \\ &+\int_{\mathrm{x}_1}^{\mathrm{x}_2} \left(b - 2\cdot t\cdot(x - x_1) - t\cdot(x - x_2)\right)^2 dx + \\ &+\int_{\mathrm{x}_2}^{1} \left(b - 2\cdot t\cdot(x - x_1) + t\cdot(x - x_2)\right)^2 dx. \end{aligned} \tag{10}$$

After integrating and identical transformations (10), we obtain:

$$\begin{aligned} 81\cdot \mathrm{t}\cdot \mathrm{F}_1 = &\,4\cdot\left(b - t\cdot(x_1 - x_2)\right)^3 + 2\cdot\left(b + 2\cdot t\cdot(x_1 - x_2)\right)^3 - \\ &-3\cdot\left(b - t\cdot(2\cdot x_1 - x_2)\right)^3 - 3\cdot\left(b + t\cdot(2\cdot x_1 - x_2 - 1)\right)^3. \end{aligned}$$

The optimal location is defined by the necessary condition:

$$\frac{9}{4\cdot \mathrm{t}}\cdot\frac{\partial \mathrm{F}_1}{\partial x_1} = \mathrm{t}\cdot(x_1 - x_2)^2 + 2\cdot b\cdot(x_1 - x_2) - (2\cdot b - t)\cdot(2\cdot x_1 - x_2 - 1/2) = 0. \tag{11}$$

The sufficient condition for the existence of profit maximum for firm 1:

$$\frac{9}{8\cdot \mathrm{t}}\cdot\frac{\partial^2 \mathrm{F}_1}{\partial x_1^2} = -\,\mathrm{t}\cdot(\mathrm{x}_2 - \mathrm{x}_1) - (b - t) < 0.$$

The necessary condition for the existence of the equilibrium location for firm 1 is the nonnegativity of the discriminant of square equation (11):

$$\mathrm{D}_1 = 4\cdot(b - t)^2 + 4\cdot t\cdot(2\cdot b - t)\cdot(x_2 - 1/2) \geq 0. \tag{12}$$

It is easy to make sure that $\mathrm{D}_1 > 0$ at $\mathrm{x}_2 \geq 1/2$. Therefore, due to condition (3), in the equilibrium state discriminant (12) is always nonnegative.

The roots of square equation (11) are:

$$\left(x_1^*\right)_1 = x_2 + \frac{b-t}{t} - \frac{\sqrt{D_1}}{2\cdot t}, \quad \left(x_1^*\right)_2 = x_2 + \frac{b-t}{t} + \frac{\sqrt{D_1}}{2\cdot t}.$$

Root $\left(x_1^*\right)_2$ does not satisfy the basic conditions of the model and therefore is not further analyzed. The total profit of firm 2 in all markets:

$$F_2 = \int_0^1 F_2^*(x)\,dx = \int_0^{x_1} F_2^*(x)\,dx + \int_{x_1}^{x_2} F_2^*(x)\,dx + \int_{x_2}^{1} F_2^*(x)\,dx.$$

$$\begin{aligned} 9\cdot F_2 = &\int_0^{x_1}\left(b + 2\cdot t\cdot\left(x - x_2\right) - t\cdot\left(x - x_1\right)\right)^2 dx + \\ &+\int_{x_1}^{x_2}\left(b + 2\cdot t\cdot\left(x - x_2\right) + t\cdot\left(x - x_1\right)\right)^2 dx + \\ &+\int_{x_2}^{1}\left(b - 2\cdot t\cdot\left(x - x_2\right) + t\cdot\left(x - x_1\right)\right)^2 dx. \end{aligned} \tag{13}$$

After integrating and identical transformations (13), we obtain:

$$\begin{aligned} 81\cdot t\cdot F_2 = 4\cdot\left(b + t\cdot\left(x_2 - x_1\right)\right)^3 + 2\cdot\left(b - 2\cdot t\cdot\left(x_2 - x_1\right)\right)^3 - \\ -3\cdot\left(b - t\cdot\left(2\cdot x_2 - x_1\right)\right)^3 - 3\cdot\left(b + t\cdot\left(2\cdot x_2 - x_1 - 1\right)\right)^3. \end{aligned}$$

The optimal location is defined by the necessary condition:

$$\begin{aligned} \frac{9}{4\cdot t}\cdot\frac{\partial F_2}{\partial x_2} = 2\cdot b\cdot\left(x_2 - x_1\right) - t\cdot\left(x_2 - x_1\right)^2 - \\ -\left(2\cdot b - t\right)\cdot\left(2\cdot x_2 - x_1 - 1/2\right) = 0. \end{aligned} \tag{14}$$

The sufficient condition for the existence of profit maximum for firm 2:

$$\frac{9}{8\cdot t}\cdot\frac{\partial^2 F_2}{\partial x_2^2} = -t\cdot\left(x_2 - x_1\right) - \left(b - t\right) < 0.$$

The necessary condition for the existence of the equilibrium location for firm 2 is the nonnegativity of the discriminant of square equation (14):

$$D_2 = 4\cdot\left(b - t\right)^2 + 4\cdot t\cdot\left(2\cdot b - t\right)\cdot\left(1/2 - x_1\right) \ge 0. \tag{15}$$

It is easy to make sure that $D_2 > 0$ at $x_1 \le 1/2$. Therefore, due to condition (3), in the equilibrium state, discriminant (15) is always nonnegative. The roots of square equation (14) are:

$$\left(x_2^*\right)_1 = x_1 - \frac{b-t}{t} + \frac{\sqrt{D_2}}{2 \cdot t}, \quad \left(x_2^*\right)_2 = x_1 - \frac{b-t}{t} - \frac{\sqrt{D_2}}{2 \cdot t}.$$

Root $\left(x_2^*\right)_2$ does not satisfy the basic conditions of the model and therefore is not further analyzed. Thus, we received the reaction curves of firms:

$$x_1 = x_2 + \frac{b-t}{t} - \frac{\sqrt{(b-t)^2 + t \cdot (2 \cdot b - t) \cdot (x_2 - 1/2)}}{t}, \tag{16}$$

$$x_2 = x_1 - \frac{b-t}{t} + \frac{\sqrt{(b-t)^2 + t \cdot (2 \cdot b - t) \cdot (1/2 - x_1)}}{t}. \tag{17}$$

Substituting (16) into (17), we are obtaining symmetry condition (3). Using symmetry condition (3), we find solutions of system (16)-(17):

$$x_1^{agg} = x_2^{agg} = 1/2, \tag{18}$$

$$x_1^{dis} = 1/2 - \frac{3 \cdot t - 2 \cdot b}{4 \cdot t}, \tag{19}$$

$$x_2^{dis} = 1/2 + \frac{3 \cdot t - 2 \cdot b}{4 \cdot t}. \tag{20}$$

So, we have obtained two equilibrium location strategies for firms: central agglomeration and symmetric dispersion. For $t = 2 \cdot b/3$, solutions (18) and (19)-(20) coincide. From the location condition, $x_1 \le x_2$, it follows that firms can apply the dispersion strategy only when $t \ge 2 \cdot b/3$.

THE ANALYSIS OF THE STABILITY OF EQUILIBRIUM

Let us analyze a stability of solutions (18)–(20). For this we consider a two-dimensional map:

$$\begin{aligned} x_1(n+1) &= x_2(n) + \frac{b-t}{t} - \frac{\sqrt{(b-t)^2 + t \cdot (2 \cdot b - t) \cdot (x_2(n) - 1/2)}}{t}, \\ x_2(n+1) &= x_1(n) - \frac{b-t}{t} + \frac{\sqrt{(b-t)^2 + t \cdot (2 \cdot b - t) \cdot (1/2 - x_1(n))}}{t}, \end{aligned} \tag{21}$$

where n is a time moment, $n = 0, 1, 2, \ldots$, $x_1(0) = 0$, $x_2(0) = 1$.

The nature of the stability of fixed points is determined by their multipliers. The multipliers are eigenvalues of the Jacobian matrix in a fixed point, and their number is equal to the dimension of map.

The Jacobian matrix of map (21) in the fixed point (18):

$$\mathrm{J} = \begin{pmatrix} 0 & -\dfrac{t}{2\cdot(b-t)} \\ -\dfrac{t}{2\cdot(b-t)} & 0 \end{pmatrix}. \tag{22}$$

From (22) we obtain two real multipliers:

$$\mu_{1,2} = \pm\frac{t}{2\cdot(b-t)}. \tag{23}$$

For $|\mu_{1,2}| < 1$ the fixed point is stable, for $|\mu_{1,2}| > 1$ the fixed point is unstable, for $|\mu_{1,2}| = 1$ the bifurcation occurs. From (23) it follows that the fixed point (18) is stable when $\mathrm{t} < 2\cdot b/3$ and is unstable when $\mathrm{t} > 2\cdot b/3$. The loss of stability occurs at the bifurcation point: $\mathrm{t} = 2\cdot b/3$.

The Jacobian matrix of map (21) in fixed point (19)–(20):

$$\mathrm{J} = \begin{pmatrix} 0 & -\dfrac{2\cdot(b-t)}{t} \\ -\dfrac{2\cdot(b-t)}{t} & 0 \end{pmatrix}. \tag{24}$$

From (24) we obtain two real multipliers:

$$\mu_{1,2} = \pm\frac{2\cdot(b-t)}{t}. \tag{25}$$

From (25) it follows that fixed point (19)-(20) is unstable when $\mathrm{t} < 2\cdot b/3$ and is stable when $\mathrm{t} > 2\cdot b/3$. The acquisition of stability occurs at the bifurcation point: $\mathrm{t} = 2\cdot b/3$.

So we can summarize results in

Proposition 1. At the value of the transport tariff $\mathrm{t} = 2\cdot b/3$ occurs a transcritical bifurcation, in which the spatial strategies exchange stabilities.

The transcritical bifurcation diagram for $\mathrm{b} = 1$ is depicted in Fig. 2. The dynamics of the total profit of firm 1 at crossing of the bifurcation point for $\mathrm{b} = 1$ is depicted in Figure 3.

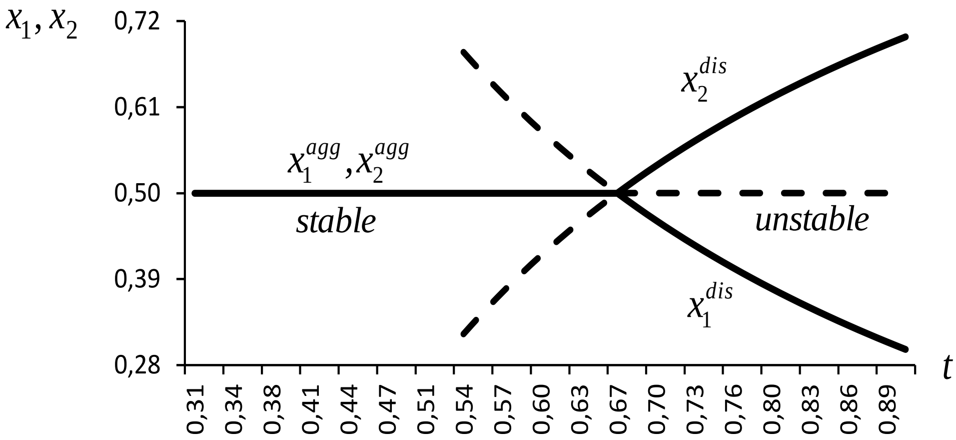

Fig. 2. Transcritical bifurcation diagram of map (21)

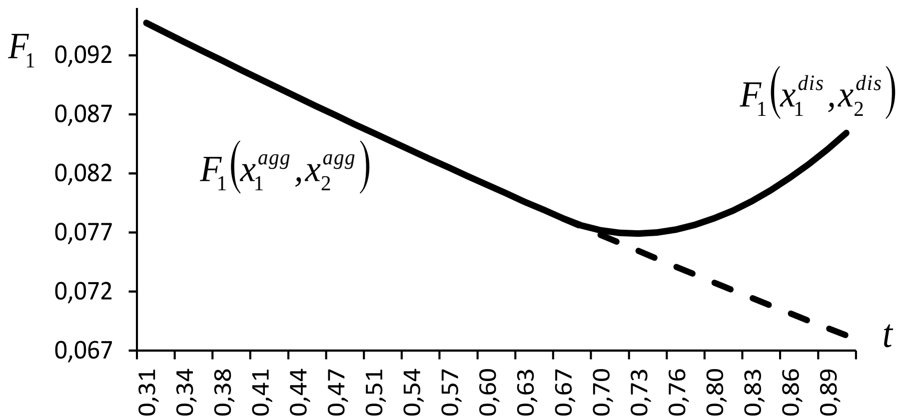

Fig. 3. Dynamics of the total profit of firm 1

In Fig.3 we see that in the case of multiple equilibria (18)–(20), exactly the stable solution provides a large profit (Fig. 3). The Fig. 3 illustrates the effects that affect spatial strategies of firms. Before bifurcation point the effect of minimizing transport costs is dominate[16]. Firms choose the central agglomeration strategy to minimize a total distance of transportation. The growth of the transport tariff leads to a decrease in the total profit. In the bifurcation point the effect of market segmentation begins to dominate. Firms choose a dispersed strategy to monopolize adjacent markets. The growth of the transport tariff leads to an increase in total profits. The growth of total profit with growth of the transport tariff is due to the fact that at dispersion strategy, the firms supply more to adjoining markets and less to distant markets.

Note that the equilibrium profits of firms (4) are squares of supply volumes and, thus, "ignore" their negative values. For this reason, dispersion strategies

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[16] Scrimitore, M. (2011). Spatial discrimination, product substitutability and welfare. *Bulletin of Economic Research*, 63, 231–244. doi: 10.1111/j.1467-8586.2010.00351.x

(19)–(20) do not take into account restrictions on full market coverage (4)–(5). Solving the systems of equations (4) and (19), (5) and (20), we find that dispersion strategies (19)-(20) are defined only for $t \le 10 \cdot b/11$.

A value of $t^{\text{cov}} = 10 \cdot b/11$ was first obtained in[17]. At point $t^{\text{cov}} = 10 \cdot b/11$, the potential for further differentiation of firms is exhausted. For $10 \cdot b/11 < t \le 2 \cdot b$ several solutions are possible. Rivas[18] considered a case when each firm monopolizes a segment on the boundaries of the market and competes with the rival firm in the rest choosing separated locations. Firms symmetrically refuse to cover all markets and this seems like an implicit collusion. In the future such pattern may lead to separation of the unit interval on the two monopoly segments. It is subject to continued coverage of all markets in proposed central agglomeration[19]. However, there is a better solution presented in

Proposition 2. For $10 \cdot b/11 < t \le 2 \cdot b$ the equilibrium spatial strategies lie on the boundary of the feasible region locations.

To provide full cover of markets when $10 \cdot b/11 < t \le 2 \cdot b$, firms optimize location based on condition (8), i.e. seek the conditional profit maximum.

The equilibrium spatial strategies and total profits of firms for $0 < t \le 2 \cdot b$ and $b = 1$ depicted in Fig.5 and Fig.6. In Fig.6 we see that for $10 \cdot b/11 < t \le 2 \cdot b$ the central agglomeration is the worst decision.

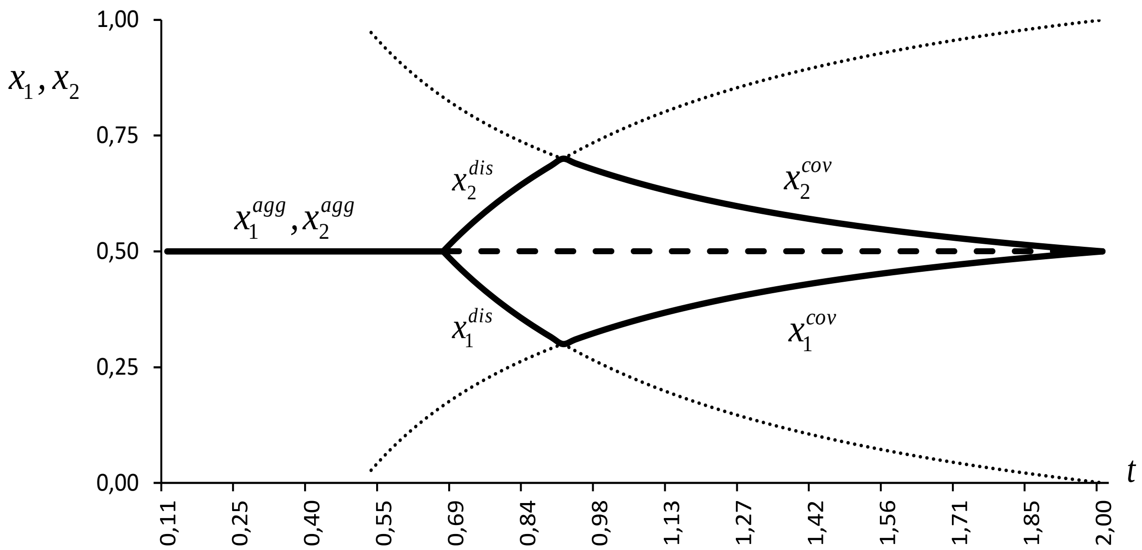

Fig. 4. Equilibrium spatial strategies of firms

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[17] Chamorro-Rivas, J. M. (2000). Spatial Dispersion in Cournot Competition. *Spanish Economic Review*, 2, 145–152.

[18] Ibid.

[19] Ibid.

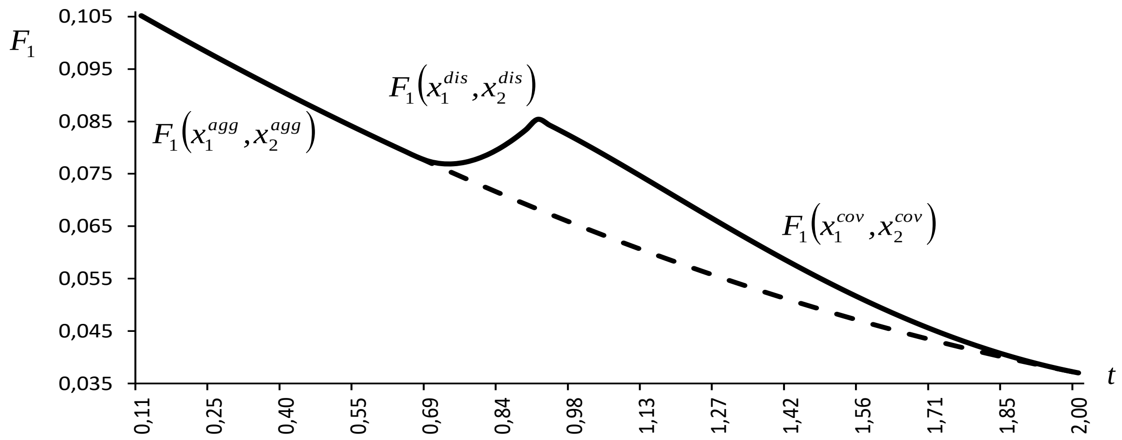

Fig. 5. Total profit

CONCLUSIONS

We generalize Rivas[20], Anderson and Neven's analysis[21] by considering a broader interval of the transport tariff. The solution says that when $0 < t \le 10 \cdot b/11$ we still replicate the previous results. For $0 < t \le 2 \cdot b/3$, firms locate at the center, for $2 \cdot b/3 < t \le 10 \cdot b/11$ there are multiple equilibria: a dispersed equilibrium together with the agglomerated one obtained before. Subject to continued coverage of all markets for $10 \cdot b/11 < t \le 2 \cdot b$, the equilibrium spatial strategies lie on the boundary of the feasible region locations. In the process of the analysis of equilibrium stability, it is proved that the transport tariff is a bifurcation parameter for firms. It has shown that a change in the central agglomeration strategy to the dispersion strategy occurs at the point of transcritical bifurcation. The different effects come into play. Before bifurcation point the effect of minimizing transport costs is dominate. Firms choose the central agglomeration strategy to minimize a total distance of transportation. The growth of the transport tariff leads to a decrease in the total profit. In the bifurcation point the effect of market segmentation begins to dominate. Firms choose a dispersed strategy to monopolize adjacent markets. The growth of the transport tariff leads to an increase in total profits. The growth of total profit with growth of the transport tariff is due to the fact that at dispersion strategy, the firms supply more to adjoining markets and less to distant markets.

The purpose of further research is to analyze the competitive interaction of firms in the Hotelling's linear city model under the conditions of other equilibrium types.

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[20] Chamorro-Rivas, J. M. (2000). Spatial Dispersion in Cournot Competition. *Spanish Economic Review*, 2, 145–152.

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SUMMARY

A lot of works suggest that Cournot oligopolists competing in a spatial model, with a uniform distribution of consumers, agglomerate in the center of the market. In this paper some results from paper[22] are revisited, where showed that Cournot-type oligopolists, which discriminate over space, will tend to agglomerate. The paper[23] considers the spatial model used to study firms' decisions on locations without restricting the consumers' reservation price. This paper extends the analysis of the standard model of spatial discrimination with Cournot competition along the linear city for a high enough transport tariff. It was obtained that for a high enough transport tariff the firms have a decision, which lies on the boundary of the feasible region locations. We show that a change in the central agglomeration strategy to the dispersion strategy occurs at the point of transcritical bifurcation. The different effects come into play. Before bifurcation point the effect of minimizing transport costs is dominate. Firms choose the central agglomeration strategy to minimize a total distance of transportation. The growth of the transport tariff leads to a decrease in the total profit. In the bifurcation point the effect of market segmentation begins to dominate. Firms choose a dispersed strategy to monopolize adjacent markets. The growth of the transport tariff leads to an increase in total profits. The growth of total profit with growth of the transport tariff is due to the fact that at dispersion strategy, the firms supply more to adjoining markets and less to distant markets. In the case of multiple equilibria, it is shown that exactly the stable solution provides a large profit. The conditions for full coverage of the markets for both strategies are defined. In this paper we show that firms under Cournot competition will tend to dispersion. Thus, the article extends the analysis of the standard Hotelling spatial competition model. The results allow a deeper look at the causes of agglomeration and dispersion of firms. The analysis of equilibrium stability shows that the transport tariff is a bifurcation parameter for firms when choosing a spatial strategy.

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