

Biscaia, Ricardo; Mota, Isabel

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Models of Spatial Competition: A critical review

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MODELS OF SPATIAL COMPETITION: A CRITICAL REVIEW

Ricardo Biscaia^{1,2} (ricardo_biscaia@hotmail.com) and Isabel Mota^{1,3} (imota@fep.up.pt)

¹Faculdade de Economia, Universidade do Porto

Rua Dr. Roberto Frias, 4200-464 Porto

²CIPES and ³CEF.UP

Portugal

Abstract

This critical review focuses on the development of spatial competition models in which the location choice by firms plays a major role. Therefore, after a brief review of the roots of spatial competition modeling, this paper intends to offer a critical analysis over its recent developments. The starting point is the recognition of the increased importance of this topic through the quantification of the research in this field by using some bibliometric tools. After that, this study proceeds by identifying the main research paths within spatial competition modeling. Specifically, the type of strategy (Bertrand vs. Cournot competition) and its implications over location equilibria are discussed. Additionally, it is presented a comparison of the effects on the location equilibria of the most typical assumptions in literature, that respect to the market (linear vs. circular), production costs, transportation costs, as well as the number of firms. Finally, the type of information (complete vs. incomplete) and its effects over the equilibria are also discussed.

Keywords: spatial competition; review; Hotelling; game theory.

JEL codes: L13; R10 D82.

1. INTRODUCTION

Spatial economics is “concerned with the allocation of scarce resources over space and the location of economic activity” (Duranton, 2008: 1). Therefore, it may be related with a very broad set of questions, as most economic questions involve space and location issues. However, and according to Duranton (2008), the main focus of spatial economics is the location choice of the economic agents.

In order to explain how agents choose to locate in certain places, specific modeling problems arise because of the difficulty of inserting location in the framework in a realistic way.

The starting point is the neoclassical paradigm, which assumes perfect competition and constant returns to scale. Accordingly, Debreu (1959) suggested that spatial economics is all about adding a spatial dimension to the goods and agents, meaning that every commodity and agent had different characteristics because they were located in different places, while there exists transportation costs of commodities between different locations. In this framework, economic activities will be evenly distributed across a homogeneous space.

However, Starrett (1974) came with a particular case of the model where the locations are homogenous. Each location, as long as the production and consumption of goods are perfectly divisible and transportation is costly, will satisfy its own needs, minimizing its transportation costs to zero, operating as autarchy. Therefore, the equilibrium results failed to mirror the reality as there was no trade between different locations in the economy: every agent would maximize its utility by interacting only in its location. This finding gave rise to the Spatial Impossibility Theorem, which states that models of competitive equilibrium never involve transportation of commodities, which is counter-factual.

In order to explain the location choices of economic agents and the agglomeration of agents in certain locations, one must relax the core assumptions of the competitive framework. According to Fujita and Thisse (2002), three alternatives emerged and had huge attention in the literature: the assumption of heterogeneity of locations, in which there is an uneven distribution of resources, as in comparative advantage models (e.g. Ricardo, 1963 [1821]; Heckscher-Ohlin, 1919 [1991]) or in pioneering static location models (e.g. Von Thünen, 1966 [1826]; Weber, 1929 [1909]); the externality models, in which the economic activity endogenously generates spillovers that motivates the agglomeration of the agents (e.g. Marshall, 1920; Henderson 1974); the assumption of imperfect markets, implying that agents have to interact with each other, with location being an important variable, as in spatial

competition models (e.g. Hotelling, 1929) or in the monopolistic competition approach (e.g. Lösch, 1954 [1940]; Krugman, 1991).

This review will focus on the development of spatial competition models. Specifically, the main purpose is to study models in which the location choice by the firms plays a major role, instead of those models where, regardless of the spatial nature of price competition, the location of the firms is fixed.

This topic is extremely appealing, firstly, because it mixes game theory tools with Regional and Urban Economics in order to explain firms' location; secondly, it offers some interesting insights on Industrial Organization, because of firms' strategic interaction and behavior; finally, the huge literature in this research field and the recent insights about asymmetric information and its application to this subject. As a whole, this topic adds a very solid contribution to the micro-economic science.

In section 2, the roots of spatial competition are reviewed. In section 3, some of the most important developments in the field are presented, with the focus made on the optimal location decision. Section 4 presents the concluding remarks.

2. SPATIAL COMPETITION – THE ROOTS

Spatial competition is mainly concerned with the locational interdependence among economic agents under imperfect competition. According to Smith (1981), the first major contribution for studying the interdependence among firms was by Fetter (1924) who built the law of market areas. According to Fetter, consumers compare the prices in both firms and the freight costs needed to buy that product before making their choice, and the locations of consumers that are indifferent between buying on either location define the market boundary of those firms. Some of Fetter's ideas influence the work of most location theorists in the 1930s, but the more influential paper was Hotelling (1929).

In fact, one of the historical landmarks for the location theory was the model developed by Hotelling (1929). In his model there exists a city represented by a line segment, where a uniformly distributed continuum of consumers, have to buy a homogenous good in order to survive. Consumers have to support transportation costs when buying the good, which is to be bought in one of the two firms existing in the city. Within this framework, firms simultaneously choose their location and afterwards set their prices in order to maximize their profits.

Hotelling was actually more worried in proving the existence of a stable equilibrium in duopoly markets instead of developing a spatial framework. According to himself, the main feature of the paper was the elimination of discontinuities in the demand for each firm, that is, small changes in the price would only capture part of the demand existing in the market, which would solve the Bertrand (1883) paradox, in which small changes in price would capture the whole market for one of the firms, leading the firms to an (unrealistic) equilibrium situation with no profits.

Moreover, Hotelling did not think of his framework as a location model, in spite of mentioning transportation costs. He introduced “distance” between firms as a way to model differentiation between the goods produced in each firm, with the goods being homogenous except for the location where they are produced, which is a similar concept of location introduced later by Debreu (1959).

However, in the second part of the paper, Hotelling introduces the following question: given the location of a firm, which is the location for the other firm that maximizes its own profits? This question attracted the scientific attention to this framework, which was extended in innumerable ways in order to answer many different questions within, for instance, location theory (as will be shown later), game theory, industrial organization, social welfare or even mathematical issues like stability of equilibrium.

One can notice that the Fetter’s law of market areas is present in Hotelling’s framework, given that each firm has a market area depending on its own price and the magnitude of the transportation costs of the linear city. However, Fetter overlooked the issue of the optimal location or even the optimal price decision of the firms and was more worried in modeling the demand behavior of the market. In spite of actually being more concerned in geographic issues than Hotelling, his law failed to be as important on the context of spatial competition. Hotelling never mentions Fetter in his paper, however the latter proved before that demand could respond in a continuous fashion to small changes in price, although Fetter never made an interpretation in that way.

In a quite different approach, Chamberlin (1950) introduces the concept of monopolistic competition. This approach arises because of product differentiation, in which firms may combine both characteristics of being in a monopoly and in pure competition as they have a somewhat unique product in a competitive market. Product differentiation may refer to many characteristics of the product, including its location. This “middle point” between pure

competition and monopoly has new implications on the behavior of the firms when it comes to maximize their profits. The parallelism with the Hotelling framework is evident, as the “linear city” is meant to represent product differentiation amongst the market in study.

The implication of the monopolistic competition theory in the location theory is better understood when looked upon the Hotelling framework: location can be viewed as a differentiation factor that allows firms to sell their differentiated product to their specific demand. A firm can set different prices for the same good by choosing a certain location more or less alike with the rest of the competing firms, facing a trade-off between the number of customers interested in the product and the monopolistic position obtained, which allows for a higher price for the good.

This review follows the framework of Hotelling, as the subsequent publications around this framework are more concerned with the agents’ location behavior while the developments of Chamberlin, which are more used as a building block for product differentiation or rather than the framework of Fetter, which is relatively forgotten.

3. RECENT DEVELOPMENTS IN SPATIAL COMPETITION MODELING: A CRITICAL REVIEW

3.1 A bibliometric exercise on the research in spatial competition

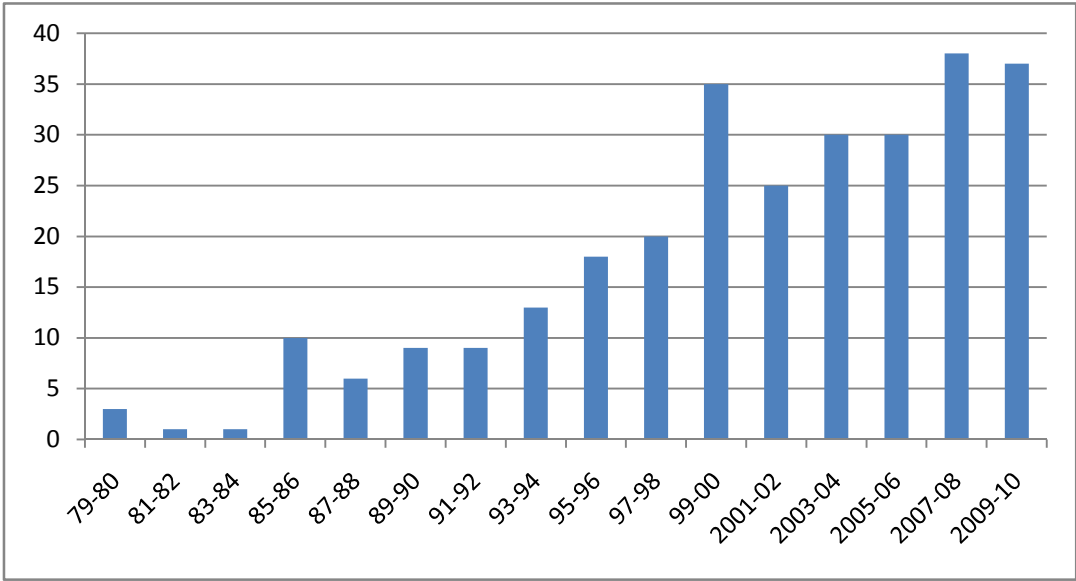
Before proceeding to the analysis of the main contributions in spatial competition modeling that focus on the location decisions of firms, a numerical study is done in order to better understand the temporal development of the field. The analysis begins in 1979, the year that d’Aspremont *et al.* (1979) published what now can be considered as a classic paper in the field, and ends up in 2010.

The search engine used was Scopus and only articles in the subject area of “Social Sciences & Humanities” were considered. Document type was filtered to only include peer-reviewed articles and exclude comments, rejoinders, book reviews and *corrigendas*. The database was constructed using the keywords “spatial competition” that was searched in the articles’ title, keywords and abstract¹. As a result, the database includes a total number of 285 journal articles since 1979. Our intention is to give an idea of the development of the field, without having the purpose of being completely exhaustive.

¹ Alternatively, we have searched for the keywords “spatial competition” for all text, obtaining a total of 1138 articles. However, most results were not directly related with the topic in study. We have chosen to search only in titles, abstracts and keywords.

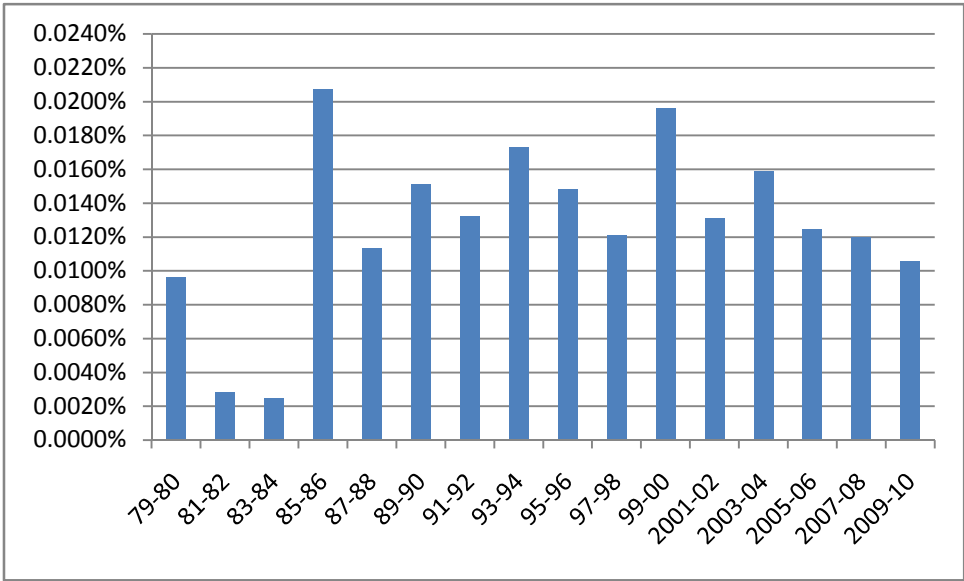
Analyzing the distribution through time, we can see a gradual increase of publications, suggesting an increase in the field (Figure 1). However, in relative terms, comparing with the total number of peer-reviewed articles in Scopus – Social Sciences and Humanities, that does not seem the case (Figure 2), with an irregular trend in the importance of spatial competition over time.

Figure 1 – Number of articles in Spatial Competition, 1979-2010



The evidence of the noteworthy importance of the spatial competition literature was already expected, as it is shown later in this section. In fact, spatial competition was a hot topic in the eighties and nineties, when a huge modeling effort was devoted to test the effects of changing every Hotelling assumption on the subsequent equilibrium conditions.

Figure 2 – Published articles in Spatial Competition (% of total), 1979-2010



With respect to the authors' effort on the spatial competition modeling, information about the most relevant scholars is displayed on table 1. Ralph Braid is the author with most articles in this research field, while Debashis Pal and Jacques-François Thisse have 7 publications. However, when taking under consideration the average number of citations *per* paper, Jacques-François Thisse is the clearly the most preeminent researcher in this topic, immediately followed by James Adams and Debashis Pal.

Table 1 – Top authors in Spatial Competition, 1979-2010

Author	Number of Articles	Citations per paper
R. M. Braid	9	5.3(3)
D. Pal	7	17.571
J. F. Thisse	7	35.714
B. Gupta	5	13.2
J. Adams	4	21.75
S. P. Anderson	4	8.5
S. Merrill	4	10
G. Norman	4	6.25
Y. Sanjo	4	2
J. Sarkar	4	16.5
J. C. Thill	4	5.75

In order to assess the quality of the research in spatial competition modeling, a selection of the most frequent journals in the area has been done (Table 2). As expected, the great majority are journals specialized in Regional and Urban Economics, besides other journals from Industrial Organization, Public Economics and Operations Research. However, not only specialized journals are interested in spatial competition, as more general ones have also articles in the field, with *Economics Letters* and *European Economic Review* amongst the ones with more publications in this research field. Regarding the impact of these journals, we can see that at least (since not all journals are presented in table 2) 17.90% of the articles are

published in journals with an impact factor higher than 1. If the interval is slightly relaxed, at least 38.25% are published with an impact higher than 0.9, meaning that a significant number of publications in the field have at least moderate impact.

Table 2 – Top journals in Spatial Competition, 1979-2010

Journal	Number of Articles	Number of Articles, in % of total Spatial Competition	Impact Factor (2009)
Regional Science and Urban Economics	41	14.39%	0.910
Economics Letters	21	7.37%	0.359
International Journal of Industrial Organization	17	5.96%	0.924
Papers in Regional Science	10	3.51%	1.397
Journal of Urban Economics	9	3.16%	1.914
Public Choice	8	2.81%	0.750
European Economic Review	6	2.11%	1.131
Journal of Regional Science	6	2.11%	1.132
Environment and Planning A	5	1.75%	1.763
Social Choice and Welfare	5	1.75%	0.683
Annals of Operations Research	5	1.75%	N/A
Mathematical and Computer Modeling	4	1.40%	N/A
Acta Geographica Sinica	3	1.05%	N/A
Games and Economic Behavior	3	1.05%	1.239
American Journal of Agricultural Economics	3	1.05%	1.047
Management Science	3	1.05%	2.227
Economics Bulletin	3	1.05%	N/A

Journal of Economics Zeitschrift Für Nationalökonomie	3	1.05%	N/A
Annals of Regional Science	3	1.05%	0.822
Journal of Economics and Management Strategy	3	1.05%	1.239
Journal of Industrial Economics	3	1.05%	1.111

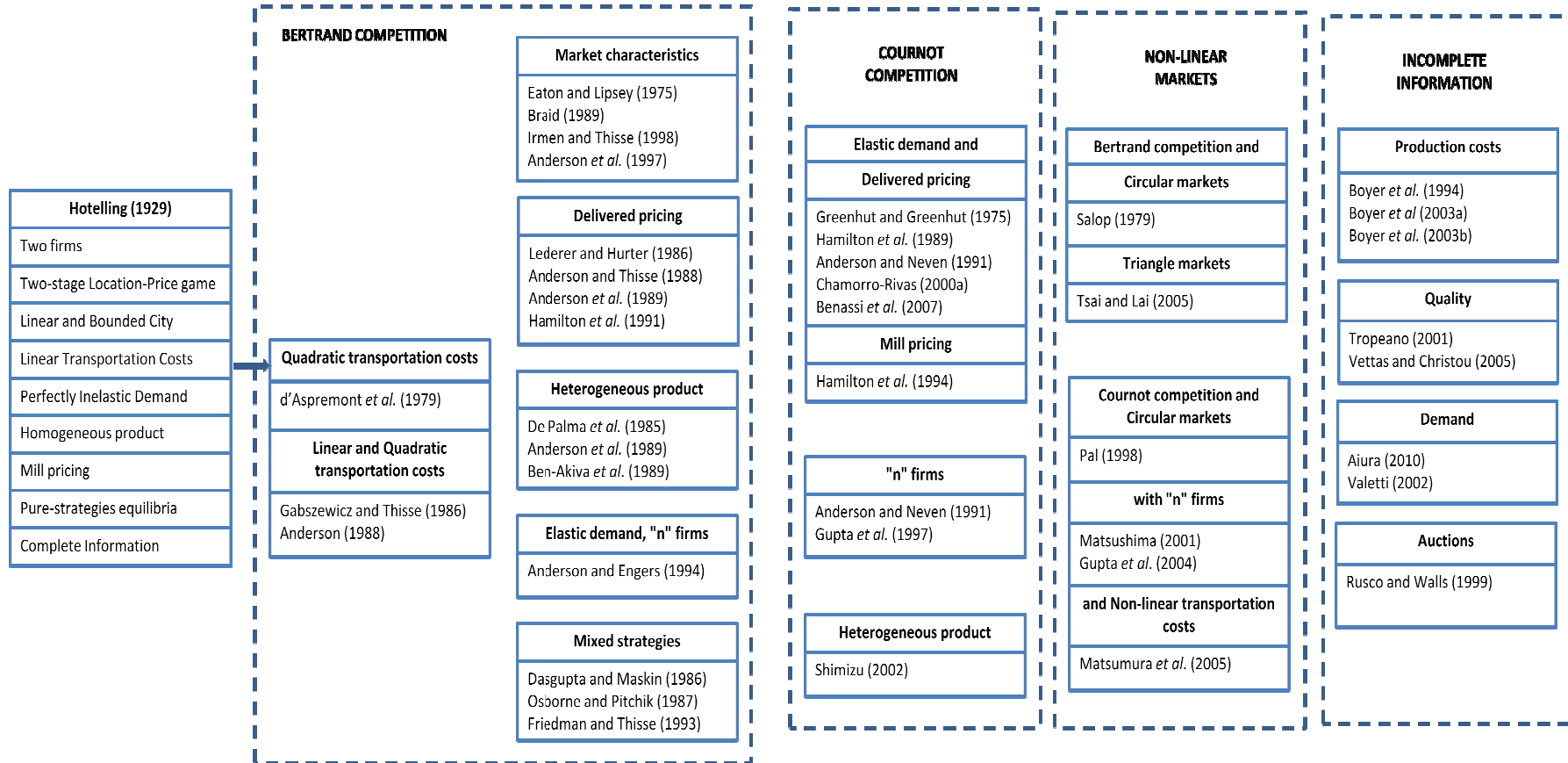
Summing up, spatial competition models have had a regular growth in terms of number of publications. However, in the end of the 90s, it seems that the weight of the field has declined, comparing to number of articles in Scopus. Also, most of those models have been published in journals with at least “moderate” impact.

After a brief bibliometric overview of the research in spatial competition modeling, this paper critically reviews the main models of each research path that we have identified. Four main research paths in the area were identified, after the work from Hotelling (1929), ordered according to the time their publications were most frequent as exemplified in figure 3. The first group is Bertrand competition, which immediately follows Hotelling (1929)’s model and has the highest number of publications; secondly, Cournot competition, different than Hotelling’s spatial-price competition, focusing on Quantity competition in the second stage; in the third place, non-linear markets such as circular or triangular markets and divergent to Hotelling’s linear city; more recently, models of incomplete information between players have appeared, which extends the Hotelling’s complete information model.²

Throughout the remaining of the review, the focus is given to the papers related with the location behavior of the agents, rather than their pricing or quantity behavior. This means that other important articles of “spatial competition”, possibly included in the bibliometric search done earlier, are not reviewed.

² It should be said that in the bibliometric approach, it is impossible to separate the papers between these different research paths because of the difficulty of finding keywords that are able to do so. For example, comparisons between Cournot and Bertrand competition are very frequent in papers of both research paths. As a result, any keyword could not identify if a paper contained in the search belongs to the expected research path.

Figure 3 – Research paths in Spatial Competition



3.2 Bertrand Competition

The Hotelling model was an ideal basic model for justifying the behavior of the firms when it comes to their price and location decisions because of having an easy understanding, an appealing logic and also because of its usefulness in studying firms' interaction. The Hotelling model was based in the following assumptions: two firms are the players of a two-staged location-price game, in which in the first stage, firms must choose their location in a linear and bounded city and in the second stage compete in prices. The good sold by the firms is homogenous except for the location they have chosen in the first stage. Demand is perfectly inelastic, that is, consumers in that city must buy one unit of the good, while incurring in a linear transportation cost in order to buy the good. Hotelling concluded that firms would agglomerate at the center of a linear city, therefore making the foundations for the "Principle of Minimum Differentiation", called so by Boulding (1966). This principle was undisputed and was used as a starting point for research, with its conclusions being studied and extended in many studies.

However, almost half a decade later some scientists started to question this principle, mainly by using the Hotelling model with some different, usually more realistic, assumptions. The most important conclusion is the one withdrawn from d'Aspremont *et al.* (1979), which introduced quadratic transportation costs. The introduction of this feature removed the discontinuities verified in the profit and demand functions, which was a problem in Hotelling model since there was no price equilibrium solution for all possible locations of the firms. Also, the authors showed that for some parameters of their model, the maximum differentiation is an equilibrium location for the firms.

After this paper, the majority of the models abandoned the linear transportation costs assumption, except for the cases where scientists were testing again the cost functions, such as Gabszewicz and Thisse (1986) and Anderson (1988), who tested a transportation cost function with a linear and a quadratic component. They respectively proved that in some cases there is no price equilibrium for fixed symmetric locations and that no location-price equilibrium exists in the two-stage location game for most cases.

The assumption for the bearer of the transportation costs was changed in, for instance, Lederer and Hurter (1986), Anderson and Thisse (1988), Anderson *et al.* (1989) and Hamilton *et al.* (1991). However, it was only to guarantee the feasibility of the model

when testing how would the decisions of the firms change if they had the chance to price discriminate the consumers. Lederer and Hurter (1986) conclude that firms never agglomerate in the case of an inelastic demand function but they choose to locate in the socially optimal way, minimizing transportation costs; Hamilton *et al.* (1991) introduce a model where consumers are allowed to bargain between the two firms, which make the firms to choose the social optimum locations, 0.25 and 0.75; while the others had no specific conclusions about location patterns. Anderson and Thisse (1988) and Anderson *et al.* (1989) focus more on the existence of equilibrium instead of the location of the firms.

In the model of Hotelling, firms were interacting in a linear and bounded market, with only one differentiating dimension and selling homogenous goods. Demand was assumed as perfectly inelastic, meaning that consumers, whatever the price (if there is no reservation price) will always buy one unit of the good.

While the linear and bounded market assumptions seem not too binding, the others seem quite unreasonable in terms of reality, but are easily understandable. The analysis of the equilibrium of the two-stage game with more than one dimension or with elastic demand proved to be a hard obstacle, while finding a way to quantify heterogeneity of the goods was not that obvious. Next follows the conclusions in terms of location equilibrium found by some authors when changing these assumptions.

In an ambitious paper, Irmen and Thisse (1998) extend the Hotelling problem to an n -dimension market where consumers may weight differently those different dimensions. They conclude that when a characteristic is sufficiently strong, the situation where the firms full differentiate in that characteristic and locate in the center in all the others is a global equilibrium for the usual two-stage game. Therefore “Hotelling was almost right”, in the sense that firms apply the principle of minimum differentiation except for the most important characteristic.

Some authors addressed the assumption of homogenous goods by introducing heterogeneity in the model. Three different approaches appeared in the literature: De Palma *et al.* (1985), Anderson *et al.* (1989) and Ben-Akiva *et al.* (1989). The first two papers use the logit model to model heterogeneity of the goods produced by the firms and all the papers use the logit to model tastes of consumers regarding those differentiated goods.

De Palma *et al.* (1985) only changed the homogeneity of the goods and concluded that when prices are fixed and equal for both firms, agglomeration at the center occurs and the profits for the firms grow with the degree of heterogeneity of the products (when the degree equals zero, we have the Hotelling case). In the two-staged game, agglomeration equilibrium may occur but only if the degree of heterogeneity is high enough. Anderson *et al.* (1989), tested different price schemes for a fixed location by comparing consumer and producer surplus in those cases but since locations are fixed no conclusions can be withdrawn regarding location theory. Ben Akiva *et al.* (1989) introduced a second dimension to the problem by introducing brands, which are intended to model heterogeneity. When firms play for location and price simultaneously with exogenous brands, there may exist agglomeration equilibrium at the center of the city if the heterogeneity in consumer tastes is not too small.

Anderson and Engers (1994) solved the two-stage location/price game for more than two firms and enabling an elastic demand. The conclusion for the case of two firms is that if the demand is perfect inelastic (Hotelling) or inelastic enough, firms will still prefer to agglomerate at the center.

The main feature of Anderson *et al.* (1997) was to change the density of the consumers to a symmetric log-concave function. The conclusion is that if the density function is too concave, asymmetric equilibrium appears in the location decision. Also, if the density function is more concentrated at the center that does not always mean closer equilibrium locations. Transportation costs make no difference to the equilibrium location. Also with this specification of the density function, there is excess differentiation in the product comparing to the social optimum.

Hotelling considered the case of only two firms in a two-staged game, deciding their location and afterwards prices simultaneously with pure strategies. However, the characteristics of this game were also changed to address different issues or to search for a better overall realistic framework.

Dasgupta and Maskin (1986) proved the existence of mixed-strategy equilibrium for the pricing sub-game, paving the road for Osborne and Pitchik (1987) to make an experiment, leading that when mixed strategies are allowed only in the second stage, the symmetric location where firms are located in 0.27 and 0.73 is an equilibrium. This equilibrium is near the social optimum, which are the location of firms that minimize the transportation costs of the population. Anderson (1988), as previously mentioned,

concluded that there is no pure strategy perfect equilibrium for most cases when the transportation cost has a linear and a quadratic component. However, allowing for mixed strategies at the price stage, the game becomes well-defined, but if the transportation function is not convex enough, symmetric location equilibria must involve mixed strategies in pricing.

Two very different approaches follow: Ben Akiva *et al.* (1989) introduced exogenously brands in the firms: a brand “is given” to both firms, which have to choose simultaneously location and price in the market. However, consumers face linear transportation costs when travelling for location and quadratic costs when “travelling” to a different brand regarding to their tastes. In this setting, there exists agglomeration equilibrium at the center of the city only if heterogeneity in tastes is big enough. This result is very similar to the one found in Irmen and Thisse (1998), since that if firms are able to differentiate themselves apart from location, they have the incentive to choose the center location because price competition is already softened due to the differentiation in the product.

Friedman and Thisse (1993) introduce a game where location is played in the first stage, and then there is a repeated game in which players keep choosing prices for n periods. As the game is repeated, firms play a trigger strategy in prices. The equilibrium for this game is agglomeration at the center of the city, with collusion only in the price-stage for both firms.

Boyer *et al.* (1994) study the case of sequential location decision within a delivered price setting. In this game with three stages, one firm chooses first its location, followed by the choice of other firm and then both firms enter in price competition. With transportation costs $t=1$ and equal marginal costs, firms choose to locate at $2/5$ and $4/5$, respectively. The same framework but with the mill pricing setting was studied by Boyer *et al.* (2003a). If firms have the same marginal costs, the results are the same that d’Aspremont *et al.* (1979). However, if one firm has an advantage in its marginal costs, it starts to move progressively to the center, while the higher marginal costs firm always chooses the extreme of the market.

Lambertini (2002) builds a model where two firms enter sequentially in a market *a la* Hotelling, but taking as a variable the lag between the entries of both firms. The main conclusion is the longer the second firm takes to entry, the closer to the center the first firm will locate, while the second firm will always choose the extremes of the market.

More recent extensions have been identified. Liang and Mai (2006) applied vertical subcontracting to the model; Aguirre and Espiñosa (2004) introduced consumer arbitrage; Matsumura and Matsushima (2004) introduced heterogenous firms with endogenous production costs; Lai and Tsai (2004) introduced zoning regulation and Degryse *et al.* (2009) introduce different transportation costs for each consumer.

3.3 Cournot Competition

Now, this review deals with the two-staged location game in which firms compete à la Cournot (in quantities), instead of competing à la Bertrand (using prices), in the second stage. Hotelling originally created this game with price competition and maybe that is why the most frequent literature uses this assumption.

The assumption of competition in quantities is usually less realistic than the competition in prices when we think about competition among firms. The price of a good is an important determinant of its demand in most cases, while the quantities produced/placed in a market seems to be a more indirect determinant of demand. However, in modeling duopoly cases, the Bertrand (1883) model produces less realistic results than the Cournot (1897 [1838]) model.

In some industries, however, competition in quantities is a better assumption than competition in prices: the Cournot assumption is more appropriated for markets where quantity is less flexible than price at each market point (Anderson and Neven, 1991; Pal and Sarkar, 2002), and also when there are significant lags between the production decision and the price setting (Hamilton *et al.*, 1994). It is not a surprise, then, that some authors decided to analyze these kinds of location games.

Although this assumption has been changed in the previous section, it is important now to define the difference between the mill pricing and the delivered price setting. A mill pricing setting is when consumers need to travel to the firms in order to buy their good and therefore incurring in a transportation cost, while in the delivered price setting, firms will incur in the transportation cost to deliver its good to every consumer that wishes to buy their products. This definition is important because when competing in quantities, the mill pricing setting is not adequate.

Also, the assumption of inelastic demand must be dropped since competition in quantities would result in corner-solutions, similar to the zero-profit condition in Bertrand competition (Hamilton *et al.*, 1989).

Greenhut and Greenhut (1975) adapted the setting of spatial price discrimination, which is a classical problem of the monopolist, allowing for more than one firm competing in the market. Although not based on Hotelling framework, firms select quantities when interacting with each other. This paper derived the profile of the delivered price schedule, paving the way for future studies on Cournot Competition.

The baseline case used in this section will be the one from Hamilton *et al.* (1989), which compared the case of price and quantity competition. The framework is similar to Hotelling but with firms incurring on the transportation costs in place of the standard mill pricing assumption and with each consumer having a linear demand function for the product. The change in the perfectly inelastic assumption is due to the tractability in the case of the quantity competition.

In this case, the authors conclude that in the framework for quantity competition, for all values in which there exists a solution, firms will always agglomerate in the central location of the city. This comes in contrast with the case of price competition, in which firms never agglomerate for any feasible range of values for the transportation costs, given the exactly same assumptions.

Anderson and Neven (1991) extend these results by studying the equilibrium conditions of this two-staged location game. Imposing that the reservation price is high enough such that in all locations every consumer buys from both firms, they conclude that when the demand is linear and transportation costs are convex, there is a unique equilibrium in the game where both firms locate at the center of the market. Also, for any changes in the demand or cost transportation functions, any location equilibrium in this game must involve symmetric locations between firms.

Later, Chamorro-Rivas (2000a) relaxed the assumption of the reservation price and found out that for lower reservation prices, the agglomeration equilibrium at the center ceases to be unique, although it is still equilibrium. For even lower reservation prices, Benassi *et al.* (2007) find out that the central agglomeration location is no longer an equilibrium result. The unique equilibrium found is a dispersed symmetric equilibrium. Therefore, agglomeration does not hold when the reservation price (transportation costs) is too low (high).

Hamilton *et al.* (1994) test the two-staged game of location and quantities with Cournot competition in the case where consumers support the linear transportation costs (mill

pricing). However, this framework still differs from Hotelling as the demand is not perfectly inelastic: one consumer may change its quantity of goods bought depending on the price.

This framework is mathematically weaker than the one used in Hamilton *et al.* (1989), as there is no pure strategy equilibrium in quantities for all possible locations of the two firms (see Hamilton *et al.* (1994), p. 913, for a very intuitive graphical explanation). However, considering only the case for symmetric firm locations, the authors solve the two-staged game and conclude that firms locate very near to the center given low values for the transportation costs, even if in the second-stage are played mixed strategies, therefore predicting the existence of (nearly) agglomeration in the center of the city.

Mayer (2000) introduces the assumption of different production costs along the city, meaning the location of the firms also matters to the cost structure for the production of the goods. The main result is that if the global convexity of the production cost distribution holds, there is an agglomeration equilibrium result between the minimum cost location and the center. Depending on the cost distribution of the city, they face a trade-off between the demand effect and the diminution of the marginal cost of production. However, firms may still agglomerate even if it is not at the central location.

Shimizu (2002) introduced product differentiation in the Hamilton *et al.* (1989) framework. However, the result does not change: the central agglomeration equilibrium is unique for any degree of differentiation of the product.

Gupta *et al.* (1997) change the distribution of consumers in the city using a consumer density function, similarly to Anderson *et al.* (1997) in the case of Bertrand competition. They conclude that in the case of two firms, non-agglomeration cannot occur if the population density is sufficiently “thick” for all point of the city. Also, the agglomeration equilibrium found is unique.

There also appeared extensions for the case of competition within n firms. Anderson and Neven (1991) concluded that all firms agglomerate at the center given linear demand and linear transportation costs, while Gupta *et al.* (1997) proved that agglomeration is the unique equilibrium if the non-uniform consumer density is not too “thin” along the city.

Pal and Sarkar (2002) introduced the interesting case where two firms compete by having more than one store, meaning they can choose more than one location in the city.

The main conclusion is that if the two firms have the same number of stores and the demand is big comparing to transportation costs, both firms choose their monopoly locations, therefore partially agglomerating around the city. The results for the case where firms have a different number of stores vary a lot depending on those numbers.

More recently in Cournot competition, Chen and Lai (2008), similarly to Lai and Tsai (2004), extend the literature by analyzing the effects of zoning regulation to the optimal decision of firms; Wang and Chen (2008) introduce the hiring of workers by firms and analyze the equilibrium conditions with wage bargaining.

We can see that fewer assumptions from the Hotelling model in the location-quantity game were changed throughout time comparing with the location-price game. This is one proof that the literature on price competition is more developed and that is the result of the high attention that location theorists have attributed to this kind of competition, seeking to solve the Bertrand paradox.

3.4 Non-linear markets

One of the lines of research that followed Hotelling (1929) abandons the assumption of a linear market while remaining in the two-stage location-price framework.

Although his paper was not the first to work on circular markets (see Vickrey [1999 (1964)] or Eaton and Lipsey (1975) for an early reference), Salop (1979) modeled the concept based on the Hotelling framework, that is, instead of having a linear city, consumers and firms will be located in a circular city. The choice of this city specification is due to “*allow the "corner" difficulties of the original Hotelling model to be ignored*” (Salop 1979: 142). This paper does not make an analysis of the two-stage location game, because it takes location as given. However, it is important as a starting point for all the subsequent two-staged game analysis in circular markets.

In a short paper, Pal (1998) introduced the circular market in the two-staged location game in order to prove that Cournot competition does not yield spatial agglomeration in all situations. He concluded that, in equilibrium, two (or more) firms will locate equidistantly from each other in the city circle, which is a maximum differentiation result. Matsushima (2001) extended the conclusions to the case of n firms and proved the existence of partial agglomeration equilibrium, that is, half of the firms agglomerate in a point and the other half will agglomerate in the diametrically opposite point of the circular city.

Chamorro-Rivas (2000b) extended the analysis for two firms that can have more than one plant. In the case of two firms and two plants, the conclusion is that in the equilibrium location, the plants will be located in each quarter of the market, with the two firms setting their plants in diametrically opposite points.

Gupta *et al.* (2004) give an important step to the study of circular markets, by identifying multiple equilibrium locations for every number of firms, in which the findings from Pal (1998) and Matsushima (2001) are included. The highlight of the results is the existence of a huge amount of equilibrium positions, but none of them involves agglomeration of all firms in the same point. An interesting result is that in the case of an even number of firms, all equilibrium situations gives equal profits and equal consumer surpluses.

Matsumura *et al.* (2005) extend the previous framework by assuming nonlinear transportation costs. However, the paper considers the existence of four isolated markets in the city rather than a continuum of consumers. The main objective was to assess which equilibrium (Pal, 1998 *vs.* Matsushima, 2001) was more robust, by checking its existence given different configurations of the transportation costs function. It is shown that for the case of simultaneous entry, the location pattern identified by Pal is always an equilibrium, while the one identified by Matsushima only happens if the transportation costs is not “too concave or too convex”. For the case of sequential entry, the location pattern of Pal is the unique equilibrium if the transportation costs are non-linear. Therefore, dispersion equilibrium seems more robust than partial agglomeration equilibrium.

Alternative uses of the Salop’s circular city model are used in a variety of cases, for instance, Brueckner *et al.* (2000) distributes the firms and the skill of the workers in a circular city, adapting the framework to the study of labor markets; Arakawa (2006) applies the framework to study the location problem of shopping centers.

In summary, the conclusions arising from the assumption of circular markets are quite different from the ones found in the previous sections of this review. The main differences are while an unique equilibrium was easier to find in a linear market setting, multiple equilibria often arise in a circular market. Also, agglomeration of all firms in one location is never an equilibrium outcome in circular markets, where at most, partial agglomeration arises.

Another interesting suggestion is done by Braid (1989). The author tests the two-stage location-price game along intersecting roadways, that is, the consumers are uniformly distributed along n roads that intersect in the same point. The author concludes that there is no equilibrium in the first stage of the game, for any number of firms.

Focusing on triangle markets, Tsai and Lai (2005) studied the two-stage location-price game in the case where the consumers are uniformly distributed along the three sides of a triangle. Firms can be located in the larger side of the triangle but are unrestricted horizontally. In order to buy the good, consumers may “walk” into the interior of the triangle, travelling less comparing to the case where the consumers could only “walk” in the sides of the triangle. The paper is built by comparing the triangular consumer density function case of Tabuchi and Thisse (1995).

When the triangle is symmetric, firms would locate outside the larger side of the triangle, in $-1/4$ and $5/4$, while in the case of Tabuchi and Thisse, firms are located asymmetrically. When the triangle is asymmetric, firms prefer to locate even farther away instead of competing in prices. The more asymmetric the triangular market, more profits both firms are able to make.

3.5 Incomplete Information

Now turning on to a more recent strand in the literature, dedicated to study the location equilibrium of the firms in the case where the agents do not have perfect information about the game. As it is known, the assumption of perfect information is quite unrealistic, as firms usually do not know exactly the cost structure of the other firms or even the tastes of the consumers regarding their product and other competitor's products.

The literature in this subject will be divided depending on the type of lack of information assumed, which appeared in the microeconomics theory, and that type will be briefly explained.

In some of the following models, location is usually observed by all the firms and therefore it is used by the incumbent or by the first mover as a signal to the other firm of its cost structure or quality of its good, previously determined by the “nature”, which may be defined as a signaling game (Macho-Stadler and Perez-Castrillo, 2001).

Boyer *et al.* (1994) study the case of sequential location decision within a delivered price setting, where two firms choose their location and afterwards their prices in a

context of asymmetric production costs. Firm 1 chooses first its location and having equal or lower marginal costs advantage depending on some probability. Asymmetric information arises because firm 2 does not know the marginal costs of firm 1 before choosing its location, therefore, location for firm 1 is used as signaling mechanism for its cost structure.

When the difference between the marginal costs is low, a unique refined separating Perfect Bayesian equilibrium (PBE) exists, with firm 1's location being closer to the center comparing to the case of complete information when it has low cost and being the same when it has an higher cost (2/5). However, when the difference between the efficiency of high and low cost firms becomes too high, the only refined PBE is pooling and the incumbent finds it more profitable to locate in the same place independently of its cost efficiency. Its position in the linear city will depend on the beliefs of the firm 2 that firm 1 is a lower cost firm.

Later, Boyer *et al* (2003a) develop a similar model but with the mill pricing setting. In this case, there is a unique separating equilibrium if the firm 1 possible disadvantage is not high enough or if it's possible advantage is very high, which implies that the high-cost firm 1 locates at the extreme and the low cost firm moves progressively to the center as its possible advantage is high, while firm 2 locates at the other extreme.

If the relative advantage is not too big (for either of the sides), there is a unique pooling equilibrium at the extremes of the city for both two firms.

In a similar case, Boyer *et al.* (2003b) study the case where there is an incumbent who might have a high or low marginal cost and an entrant who has to decide if it enters the market. However, the entrant does not know the true cost of the incumbent, which allows the latter to use location as signaling mechanism. Agglomeration equilibrium never occurs, for both delivered and mill price setting. This happens because in the pooling equilibrium, the incumbent chooses a central location, preventing the entry of the second firm, while for the separating equilibrium, whenever the incumbent chooses a location closer to the center it is because it is a low-cost firm, therefore pushing the entrant to the other extreme of the market.

The following models have problems of lack of information, but have a different modeling perspective, other than the signaling game explained by Macho-Stadler and Perez-Castrillo (2001).

In a quite different setting, Tropeano (2001) studies the location of firms given the existence of asymmetric information between the agents. There is a significant difference between his framework and the one from Hotelling, since the city is not actually a linear segment: Tropeano's "city" only has two locations and a transportation cost between the locations.

In fact, in this model, there are two firms, one incumbent and one entrant. The quality of the good of the entrant is randomly assigned, while the incumbent's is fixed, but not superior to the one from the entrant. The game has three stages. In the first, the entrant chooses one of the two locations. In the second and third stages, firms compete à la Bertrand. The asymmetry of information in this paper arises because the quality of the good of the entrant is not known by the other agents until the beginning of the third stage.

If the entrant chooses to agglomerate with the other firm, it is showing that it has a high quality product, because a low quality product firm would have more profits locating far from the other firm. This signaling power allows the entrant to choose the agglomeration equilibrium more often, comparing to the symmetric information case. Therefore, asymmetric information fosters firm's agglomeration.

Vettas and Christou (2005) study the Hotelling's two-staged location game allowing for vertical differentiation. Two firms know the existing quality difference between them, but do not know who has the better quality, which is a problem of lack of information. In the first stage decide their location, in the second know the relationship between both qualities and then compete on prices.

If there is no quality difference between the firms, the results for the location game are the same than the one of D'Aspremont *et al.* (1979). As the quality difference rises, firms tend to get close to the center. This mechanism happens because firms compete à la Bertrand, which implies that the equilibrium prices when the firms are agglomerated are exactly the quality difference for the firm with higher quality and zero for the other firm. Therefore, there is an incentive to agglomerate whether this quality difference (keeping the transportation cost constant) improves because the possible monopoly profits are very high in the case of a firm having a better quality.

In a rather different setting, Aiura (2010) studies the equilibrium locations of three firms when location is decided sequentially among them, that is, the game has three stages in

which in the first stage firm 1 chooses its location and so on until all the three firms chose their location. Prices are fixed which implies that maximizing profits is equal to maximizing demand. The linear city is $[-1, 1]$, but the consumers of the good are only located in $[\theta, \theta+1]$, with θ belonging to interval between -1 and 0 . The asymmetric information problem arises because firms do not know θ when choosing their locations. However, the subsequent firms can observe the demand of the firms that have already chosen their location, therefore updating their beliefs about θ . Although is not a classical problem of information presented in microeconomics, it is very similar to a signaling problem.

The Perfect Bayesian Equilibrium result is that firm 1 locates in the center, firm 2 also locates in the center and firm 3 unambiguously chooses to locate infinitesimally to the left or the right or both firms. The rationale is very intuitive: firm 1 chooses the value that is expected to capture the maximum demand possible in the future. Firm 2 chooses the same as firm 1 in order to not provide firm 3 with any kind of information. Firm 3, since it does not know anything about the true location of θ , will choose randomly to capture one of the two sides of the market. Therefore, agglomeration equilibrium at the center of the city occurs in this interesting case.

The following model by Valetti (2002) is a typical case of adverse selection. The consumer has private information before the purchase of the good and therefore the firm has to design different goods and prices for each type of consumer (Macho-Stadler and Perez-Castrillo, 2001).

Valetti (2002) builds a setting where consumers are distributed among a linear city but there is also a vertical component, determined by the quality of the good. In each location, there are two types of consumers: the one that prefers a high-quality product and other that prefers the low-quality one.

Therefore, the two-stage location game played by the duopoly firms is slightly different from the Hotelling location-price game. Firms in the first period choose their location but in the second period, firms offer discriminatory contracts, as usual in principal-agent problems.

The conclusions regarding the location in the two-stage location game depend on the ratio between the high-quality and the low-quality demanded by the consumers. However, firms' location will always be around the socially optimal level for any value

of this ratio. The main changes that different values for the ratio induce are in the distribution of the surpluses between the firms and the consumers.

To conclude, the agglomeration results in this literature seem to depend heavily on the type of asymmetric information assumed. Models without the standard specification of asymmetric information are able to find more easily conditions for agglomeration of the firms.

In a different framework, Rusco and Walls (1999) develop an auction model, in which two firms located at the extremes of the market compete for the purchase of some good, which is randomly located somewhere in Hotelling's linear city. The game has two stages: in both stages, firms participate in an auction in order to acquire the good. The main feature of the model is that the firm that wins the first stage will have an expected lower utility in the second stage auction. The imperfect information issue arises because firms do not know where the second auction is made, which will condition their behavior in the first stage, since if they lose the first auction they will have a relative advantage over their opponent in winning the second auction.

Although this approach does not conclude about the location of the firms, its interesting framework may be developed in order to explain the location behavior of the firms when participating in an auction.

4. CONCLUSIONS

After the appearance of the Hotelling (1929) model and the important finding by d'Aspremont *et al.* (1979), scientists had access to a simple and successful way to introduce a spatial component in the modeling behavior of economic agents. This review focused on the developments that intended to justify the optimal location of the firms, mainly when competing in a duopoly. However, many successful variants of this framework were used to justify, for instance, price discrimination, and different market specificities.

In the 80s and 90s, this field was a hot topic for research. There are innumerable applications of the Hotelling model, which are mainly focused on changing the framework assumptions. The field developed significantly with the successful modeling experience of Hamilton *et al.* (1989), which allowed for competition in quantities.

More recently, Pal (1998) combined the circular framework of Salop (1979) in order to study the location decision of the firms. Also, the development of the asymmetric information framework in microeconomics and its successful adaptation to the context of spatial competition led again to the extension of field. However, these last approaches did not receive similar attention.

After looking briefly to the numerical exercise done in section 3.1, it seems that most of the important features that justify the spatial behavior of firms have already been explored. The future of the field depends on the researchers' capacity of finding an (even more) interesting and innovative way of modeling spatial competition. There is an high proportion of spatial competition models *a la* Bertrand or *a la* Cournot, comparing with the most recent assumptions displayed in this review. In that sense, future researching efforts in spatial modeling might be done in the incomplete information.

Furthermore, researchers could intensify the relationship between spatial competition and Industrial Organization. As an example, spatial competition may provide a more complete answer about vertical differentiation/integration of duopoly firms or about the R&D investment decisions by firms, in line with the seminal work of d'Aspremont and Jacquemin (1988).

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