Market competition and firms' specialization choices

An application of the spokes model to the Dutch car repair market

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Abstract

We study the relationship between the level of specialization and the number of firms in a market using the spokes model. The model focuses on non-localized spatial competition and also allows for the presence of segments of the market where other firms have not located. We endogenize location in the spokes model and show that firms' optimal location (specialization) depends on the number of firms, the number of unoccupied spokes and whether consumers are captive or not. We also provide empirical evidence based on the specialization choice of Dutch car repair garages. We find a robust relation between specialization and the number of competitors.

JEL code: D43, L11, L13.

Keywords: specialization, location strategies, spokes model, car repair firms.

1 Introduction

Strategic product differentiation is a way for firms to avoid fierce direct competition. This notion is implicitly present in spatial competition models (starting with Hotelling, 1929), as well as in the management literature (Porter, 1980). Watson (2009) establishes empirically that the average per firm variety in the retail market for eye glasses decreases as the number of rivals increases, implying that firms specialize in response to an increase in the number of firms. Everyday experience allows to observe

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similar examples in many markets, e.g. restaurants, fashion stores and home decoration retail: in those contexts, the presence of several outlets makes it more likely to observe specialized activities.

Despite the high number of possible examples, the economic toolkit seems to lack an instrument to analyze the link between firms' specialization choice and the number of suppliers on the market. In textbook models of monopolistic competition (e.g. Dixit and Stiglitz, 1977), market variety is positively related to the number of suppliers but the varieties actually supplied by firms are exogenous in that settings. Models of spatial competition (e.g. Hotelling, 1929; Salop, 1979; Anderson *et al.*, 1992) treat product differentiation (location in the product space) as endogenous but predefine a constant product space. This clearly implies that by construction the level of specialization decreases as the number of suppliers increases. The spokes model (Chen and Riordan, 2007) has the potential to bridge the gap, as the number of firms and varieties is potentially unlimited and, given the spatial nature of the model, product differentiation can be endogenized.

In this context we study the location (i.e. specialization) choices of firms within a spokes market structure and we provide a first test of the model's empirical implications using data on car repair garages in the Netherlands.

The spokes model naturally extends the classical Hotelling approach to the case of several market segments by modelling the market as a collection of spokes with a common center. Consumers are distributed on all spokes and can buy from whichever firm they like: if no firm is located on their spoke, however, consumers have to travel through the center of the market. A firm's location within a spoke captures its specialization. In the spatial approach to product differentiation, the spokes model is an important alternative to the circular city model (Salop, 1979) when the neighboring effects of competition are not particularly relevant.

The market for car repairs fits the spokes model very well, as car owners are likely to have a preference for a specific variety, i.e. a repair firm specialized in their car brand. About half of the car repair garages is however not specific to a brand, implying that the brand preference is not absolute. Using the same dataset, Lijesen *et al.* (2016) show that repair prices are affected by the distance between firms specializing in the same brand, but not by the distance between generic repair garages or repair garages specializing in a different brand. Their result suggests that the way in which car repair firms compete is consistent with the spokes model.

Our paper, then, provides two analytical contributions, as well as a first empirical test of the implications of the spokes model. First, the paper endogenizes location in the spokes model. We do this by allowing for quadratic transport costs within the exact same framework of Chen and Riordan (2007). Second, we show how the results and implications of the spokes model crucially depend on the assumptions on consumers' preferences. Chen and Riordan (2007) focus on the case of consumers having a limited subset of brands they like between the possibly available ones (*captive consumers* case); we further extend their approach by allowing consumers to have preference for all brands, both the ones currently available and the ones that are not (*all-out competition* case).[1] We show that the two versions of the model lead to both similar and different empirical implications about the optimal location of firms. In particular, both models predict that a higher number of firms decreases the level of specialization of firms. Differently, the all-out competition version of the model predicts that the presence of segments not yet covered by firms makes it likely to observe generic firms, while the captive consumers model predicts a symmetric outcome with more specialized firms.

We empirically test the implications of the model for the market of car repairs in the Netherlands, using a dataset of nearly seven thousand car repair garages. We analyze the probability that any given car repair garage is specialized in a specific brand of car, depending on the presence of other repair garages, as well as a number of control variables. We find that the empirical pattern of specialization of Dutch car repair garages is consistent with the predictions of the all-out competition version of the spokes model.

The remainder of the paper is structured as follows. In Section 2 we briefly review the most closely related literature to better locate our contribution. The spokes model with quadratic transport costs is introduced in Section 3. Section 4 provides results on the price-location choices of firms both in case of captive consumers and all-out competition. Section 5 explains the empirical strategy, followed by a description of the data used in section 6. The empirical results are given in section 7, and the final section discusses the results and concludes. All the proofs are in Appendix A.

[1] It is important to emphasize that *all-out competition* identifies the pressure faced by firms to attract each individual consumer in that version of the model, including the ones located on empty spokes; the term does not refer to the *number of firms* present in the market. Similarly, the consumers located on empty spokes are captive to one firm in the *captive consumers* version of the model but firms are still competing in other segments of the market.

2 Related literature

Our paper relates to three streams of literature. First, we contribute to the recent and growing literature on the spokes model. Chen and Riordan (2007) show that the model captures Chamberlin's original idea of monopolistic competition; moreover, strategic interaction between firms may lead to price-increasing competition. The model has already been widely used in the literature for a variety of applications (Caminal and Claici, 2007; Caminal, 2010; Rhodes, 2011; Caminal and Granero, 2012; Germano and Meier, 2013; Mantovani and Ruiz-Aliseda, 2016; Chen and Schwartz, 2015; Chen and Hua, 2015; Piolatto, 2015, *inter alia*). A unifying characteristic of the previous papers using the spokes model is the focus on pricing and/or entry aspects of the interaction between firms. Reggiani (2014) also considers location in the spokes model as we do; the paper, however, focuses on product line choices (spatial price discrimination) rather than specialization (uniform pricing).

An extensive literature has tackled endogenous location in spatial models. Anderson (1988), Tabuchi and Thisse (1995) and Lambertini (1997) show that firms may go "beyond" maximum differentiation by locating outside the market area, a possibility also allowed by the spokes model. Neven (1986) considers the impact of non-uniform distributions on the Hotelling price-location game. The paper finds that firms concentrate if consumers concentrate. We also allow firms to locate outside the market area in the spokes market structure;[2] on top of that, we assess the impact of consumers' segments where no firm has yet located: these "empty" segments can be interpreted as masses of consumers located between the firms. This feature makes our framework comparable with Neven (1986) and our location results indeed also depend on the balance between the competitive and the market power effect.

Emprically, an issue close to competition and firms' *specialization* is the link between market concentration, mergers and product variety.[3] In that context, Sweeting (2012) uses playlist based proxies of variety to study the effect of mergers in the music radio industry. His measures allow studying the relative "specialization" of radios within a specific format (e.g. Country, Rock). Negligible changes in aggregate variety may hide relevant strategic playlist changes. As recalled, Watson (2009)

[2] All the model's implications about specialization and the number of firms, however, remain unaffected if firms are constrained to locate only where consumers are.

[3] See, *inter alia*, Berry and Waldfogel (2001); Götz and Gugler (2006); Fan (2013); Argentesi *et al.* (2016).

focuses on frames' display inventories to measure variety in eyeglasses retail: both market and firm level evidence suggest that firms specialize their product offerings in response to high competition. The spokes model distinguishes very clearly between the number of varieties (i.e. the spokes), the number of firms and specialization (i.e. the location on each spoke) and our evidence highlights a non-linear relationship between competition and firms' specialization choices.

3 The spokes model with quadratic transport costs

We consider the spokes model of Chen and Riordan (2007). The market is constituted of a set of N spokes with a common core. Each spoke has length $l_s = \frac{1}{2}$, $s = 1...N$. Consumers are uniformly distributed along all spokes from 0, the extreme of a spoke to 1/2, the center of the market: the assumption implies that there are $\frac{2}{N}$ consumers per spoke. Each consumer has an evaluation v for the good sold by firms.

Firms supply a product; the only source of differentiation is the distance between consumers and firms. We initially consider a duopoly: the product is supplied by $n = 2$ firms that can choose location on their own spoke or outside of it; however, they cannot "invade" other spokes, i.e. firms' strategies are $y_i \in]-\infty, 1/2]$.

Figure 1 illustrates the spokes model in case $N = 5$ and two firms: one firm is located in the interior of their spoke ($0 < y_i < \frac{1}{2}$) and the other firm is located outside of its spoke ($y_i < 0$). The dashed lines, describing possible locations outside the area where consumers are located, can potentially be extended indefinitely.

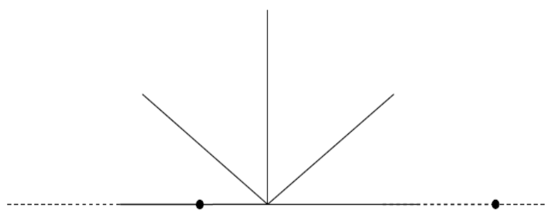

Figure 1. The spokes model, $n = 2$ firms, $N = 5$ spokes.

A consumer located on spoke s is identified by its location x_s, $x_s \in [0, 1/2]$. The distance between consumers at x_s and firm i, located at y_i is defined as $d(y_i, x_s)$. The expression for $d(y_i, x_s)$ depends on whether the firm and the consumer are located on the same spoke or not. If they are both located on spoke i then:

$$d(y_i, x_s) = |y_i - x_s| \qquad s = i$$

Otherwise the distance is:

$$d(y_i, x_s) = \left(\frac{1}{2} - y_i\right) + \left(\frac{1}{2} - x_s\right) = 1 - y_i - x_s \qquad \forall s \neq i$$

as the consumer has to travel through the center to join a firm on a different spoke.

We depart from Chen and Riordan (2007) assuming that the transportation costs are proportional to the square of the distance separating consumers from the firm. In other words, transport costs are specified as:

$$T_{is}(y_i, x_s) = \begin{cases} td^2(y_i, x_s) = t\,(y_i - x_s)^2 & s = i \\ td^2(y_i, x_s) = t(1 - y_i - x_s)^2 & \forall s \neq i \end{cases}$$

For analytical convenience and without loss of generality we set $t = 1$ and the constant marginal production cost to $c = 0$ throughout the analysis.

Firms play a two stage, simultaneous move game with the following timing:

0. Nature assigns a spoke i to each firm;
1. Firms choose location y_i;
2. Firms choose a uniform price p_i.

As usual for this class of games, the game can be solved using backward induction.

4 Price and location choices

4.1 Demand specification: captive consumers vs. all-out competition

The crucial step in defining the demand and payoff functions of firms is to identify the indifferent consumers. Two alternative assumptions can be made to this end. First, following Chen and Riordan (2007), we assume that each consumer has preferences for only two brands/spokes, no matter whether the brand is available on the market or not.[4] The assumption implies that a consumer located, for example, on spoke 1 surely likes the product of firm 1 while, as a second favorite brand, he may like the product of firm 2 or any of the other $N - 2$ not supplied brands. This implies that there are two types of consumers: first, consumers that have preference for the two existing brands and, second, consumers for which only one of the favorite brands is supplied. Firms compete for the first type of consumers, while the second type are

[4] As Chen and Riordan (2007) underline consumers could have preference for a proper subset of brands but, like them, we stick to this case, for analytical convenience.

captive to one of the firms. There are also consumers who like two brands that are not supplied; these consumers are not served and so the market is not fully covered. We label this version of the model as the *captive consumers* case. Second, we assume that any given consumer is indifferent between any alternative supplier that is not located on the same spoke. In other words, besides their most preferred brand, consumers base their choices solely on price and the (squared) distance of all other alternative options. Clearly, this implies that consumers located on the empty spokes are not captive to any firm. For this reason, we refer to this version of the model as the *all-out competition* case.

4.2 Captive consumers

In this case, consumers have a preference for only two brands, available or not available. Then, a firm's demand can be specified considering two types of consumers. First, consumers that like available brands i and j. To identify this segment, we focus on the following indifferent consumer:

$$x_{ij} \text{ s.t. } T_{is}(y_i, x_{ij}) + p_i = T_{js}(y_j, x_{ij}) + p_j \tag{1}$$

Second, captive consumers that like brand i and another brand that is not currently available on the market. For simplicity, we assume that v is high enough so that all the captive consumers are served in equilibrium, i.e. $x_{ik}^{k} = 0$, $i = 1, 2$, $k = 3...N$ and the superscript indicates the spoke on which the indifferent consumer lies. In other words, the assumption implies that we only focus on Chen and Riordan (2007)'s Region I.

4.2.1 Price choice

We now consider the price sub-game, assuming the vector of firms' locations, y_i, are given. Firms compete for consumers on their shared spokes and serve their captive consumers on the empty spokes. Focusing on firm i and assuming, without loss of generality, that x_{ij}^{j} lies on the j-th spoke, the profit function can be written as:

$$\pi_i = \frac{2}{N}\left\{\underbrace{\frac{1}{N-1}p_i\left(1 - x_{ij}^{j}\right)}_{\text{Competitive segment}} + \underbrace{\frac{1}{N-1}\sum_{k=3}^{N} p_i x_{ik}^{k}}_{\text{Captive segment}}\right\}, \tag{2}$$

where $\frac{2}{N}$ is the share of consumers on each spoke, $\frac{1}{N-1}$ is the proportion of consumers with second favorite brand any possible s. Notice that the proportion is exactly the same for both the existing alternatives $i = 1, 2$ and any of the $N - 2$ currently not available on the market. The first term in brackets constitutes the segment of consumers for which firm i and j are competing while the second term represents captive consumers that have preferences for a not currently available brand. Our first result can then be stated.

Lemma 1 *The unique Nash equilibrium of the price sub-game is:*

$$p_i^* = \frac{(6N - 9 + y_i - y_j)(1 - y_i - y_j)}{3}, \qquad \forall i, j = 1, 2. \tag{3}$$

The equilibrium price is increasing in N.

This preliminary result has an intuitive interpretation: for given locations, the higher number of empty segments in the market, the higher the proportion of captive consumers and, consequently, the higher the equilibrium prices. In choosing the price, the market power incentive to extract surplus from captive consumers predominates more and more the higher the fraction of these consumers. Finally but importantly, the second order conditions imply that the firms cannot be simultaneously located in the center: such a location pattern clearly minimizes profits.

4.2.2 Location choice

Given the price stage equilibrium characterized in Lemma 1, we now turn to the location sub-game. The profit function, given the optimal prices, is:

$$\pi_i = \frac{2}{N}\left\{\frac{1}{N-1}p_i^*(y_i, y_j)\left[1 - x_{ij}^j(p_i^*(y_i, y_j), p_j^*(y_i, y_j), y_i, y_j)\right] + \frac{1}{N-1}\sum_{k=3}^{N} p_i^*(y_i, y_j)x_{ik}^k\right\} \tag{4}$$

Using standard techniques, the following result follows:

Proposition 1 *The game has a unique symmetric sub-game perfect Nash equilibrium characterized by locations:*

$$y_i^* = -\frac{3}{2}N + \frac{11}{4}, \qquad i = 1, 2. \tag{5}$$

The optimal locations are decreasing in N.

An implication of the result is that no firm occupies the central spot in a duopoly market with captive consumers: minimum differentiation, clearly, can never be an outcome. In fact, under these assumptions, firms have an incentive to specialize rather than provide a generic product that appeals all segments of the market. In particular, if $N = 2$ (i.e. there are no segments of the market that are not covered by firms) the usual Hotelling model result is obtained: firms locate symmetrically at $y_i^* = -1/4$. On top of that, equilibrium locations decrease as N increases: this implies that firms always locate outside the area of the market occupied by consumers, i.e. maximum differentiation is obtained as an equilibrium.

To gain further intuition, these results can be compared with the findings in Neven (1986). Our result that equilibrium differentiation increases with the number of uncovered market segments, N, may seem at odds with Neven's conclusions: in fact, the paper finds that firms concentrate if consumers concentrate. In our model, the empty spokes can be interpreted as a mass of consumers located in the center of the market. Hence, following Neven (1986) it might be expected that firms aggregate towards the center rather than increasing their differentiation. Our result, however, can be rationalized by distinguishing between two classical distinct effects: the *market power effect* and the *market stealing effect*. Denoting as $D_i(.)$ a firm's overall demand, the impact of a change of location for firm i on its own profits can be denoted as $\frac{\partial \pi_i}{\partial y_i} = p_i \frac{\partial D_i}{\partial y_i} + D_i \frac{\partial D_i}{\partial y_i}$. A firm moving towards the center of the market will increase its demand (i.e. the *market stealing effect*, captured by the first term on the right-hand side), but by moving closer to its competitor will enhance price competition (i.e. the *market power effect*, or the second term on the right-hand side). The recalled trade-off between these effects essentially drives any spatial competition model. In our context, the result that firms move further out as the number of (empty) spokes increases follows from the assumption that any consumer on the empty spokes is *captive* to one of the firms. If the percentage of captives (i.e. the number of empty spokes) increases, it pays for firms to move further outside, since the market power effect becomes more important relative to the market stealing effect.

4.3 All-out competition for consumers

In this section, we investigate the effects of relaxing the assumption that consumers on the empty spokes are captives and we allow firms to compete for any consumer present in the market. In this case consumers are indifferent between alternative suppliers that are not located on their spokes: besides their most preferred one, all brands are considered as a possible option by consumers.

4.3.1 Defining the demand functions

We focus on the generic $N \geq 2$ spokes case but it is worth remarking that also in this setting $N = 2$ corresponds to the standard Hotelling model. The demand on the spokes where firms are located (each with a share $2/N$ of consumers) is defined in the same way as in the previous case: the indifferent consumer is still identified by (1). The demand of consumers located on the empty spokes now depends on the location configuration of firms (symmetric or asymmetric).

Symmetric locations If firms are located symmetrically ($y_i = y_j$) and $N > 2$, the distance separating them and any consumer on the empty spokes is identical and so are transport costs. This implies that the firm with the lowest price attracts all the consumers on the empty spokes; if, instead, the prices are equal the consumers on empty spokes are divided somehow between the two firms. Hence, if $N > 2$ there is a discontinuity in the demand and profit functions at $p_i = p_j$. As shown by Chen and Riordan (2011), the discontinuity implies that there is no pure strategy Nash equilibrium in prices in this case.

Asymmetric locations Adapting equation (1), a consumer located on one of the empty spokes k will be indifferent between firm i and firm j if and only if:

$$x_{ij}^k \text{ s.t. } p_i + (1 - y_i - x)^2 = p_j + (1 - y_j - x)^2 . \tag{6}$$

To gain some more insight about the all-out competition case is worth reporting the explicit expression of the indifferent consumer:

$$x_{ij}^k = 1 - \frac{y_i + y_j}{2} + \frac{p_j - p_i}{2(y_i - y_j)}, \quad k = 3...N.$$

Without loss of generality suppose that firm i locates closer to the center, i.e. $y_i > y_j$. Given the convex nature of transport costs, if x_{ij}^k lies on spoke k, then consumers closer to the center than the indifferent ones (i.e. those located on the segment between x_{ij}^k and $1/2$) buy from firm j, whereas consumers further from the center (located between 0 and x_{ij}^k) prefer buying from firm i. If, instead, $x_{ij}^k < 0$, all consumers on the empty spokes buy from firm j. This is a distinguishing feature of our framework:

in case of linear, rather than quadratic, transport costs all consumers on the empty spokes would operate the same choice; in our framework, this is not necessarily the case. Finally, we note that x_{ij}^k is the same on all empty spokes k. The above discussion is summarized in the following demand functions:

$$\begin{aligned}
D_i &= \frac{2}{N}\left[\frac{1}{2}(1+y_i-y_j)+\frac{p_j-p_i}{2(1-y_i-y_j)}\right] \\
&\quad +\frac{N-2}{N}\max\left\{0,\min\left\{\frac{2-y_i-y_j}{2}+\frac{p_j-p_i}{2(y_i-y_j)},\frac{1}{2}\right\}\right\}, \\
D_j &= \frac{2}{N}\left[\frac{1}{2}(1+y_j-y_i)+\frac{p_i-p_j}{2(1-y_i-y_j)}\right] \\
&\quad +\frac{N-2}{N}\max\left\{0,\min\left\{\frac{y_i+y_j-1}{2}+\frac{p_i-p_j}{2(y_i-y_j)},\frac{1}{2}\right\}\right\}.
\end{aligned}$$

4.3.2 Price choice

Having characterized demand, we now turn to the pricing stage of the game. We know that if the equilibrium locations chosen in the first stage are symmetric, there is no pure strategy price equilibrium. Hence, suppose that the equilibrium locations are asymmetric: this result on equilibrium prices follows.

Lemma 2 *If $y_i > y_j$, the unique Nash equilibrium of the price sub-game is characterized as:*

$$p_i^* = \frac{(y_i-y_j)(y_i+y_j-1)}{3}\frac{3(N-1)-(N-3)y_i-(N-1)y_j}{2-N+(N-3)y_i+(N-1)y_j}, \tag{7}$$

$$p_j^* = \frac{(y_i-y_j)(y_i+y_j-1)}{3}\frac{3+(N-3)y_i-(N-1)y_j}{2-N+(N-3)y_i+(N-1)y_j} \tag{8}$$

Comparing the price expressions (7) and (8) in Lemma 3, it is easily checked that $p_i^* > p_j^*$: this confirms the basic intuition of spatial competition that the firm located closer to the center can charge higher prices. It can also be noted that the price difference increases with N: as the relevance of the segments not occupied by firms becomes relatively large, the higher the price that the firm located closer to the center can charge.

4.3.3 Location choice

Moving back to the location stage, we know that a symmetric (pure strategy) price-location equilibrium only only arises if all spokes are occupied, i.e. $N = 2$. The captive and the all-out competition versions of the model coincide in this special case and the usual Hotelling result is obtained: the firms locate at $y_i^* = -1/4$.

We can now characterize the asymmetric equilibrium locations.

Proposition 2 *If $N > 2$ the unique sub-game perfect Nash equilibrium of the game is characterized by locations:*

$$y_i^* = \frac{1}{2}, \qquad y_j^* = \frac{N-5}{6(N-1)}, \qquad i,j = 1,2. \tag{9}$$

The optimal interior locations are increasing in N.

If there are empty segments of the market, i.e. $N > 2$, firms' optimal location is asymmetric. In particular, firm i locates in the center of the market independently on the number of empty spokes; the optimal location of firm j, instead, positively depends on N. In other words, firm j locates outside of the spokes structure at $-1/6$ if there is only one non occupied segment of the market but then moves closer to the center as the number of empty spokes increases up to a maximum of $1/6$. These results are generally consistent with the findings of Neven (1986): an increase in the concentration of the distribution of consumers leads to equilibrium locations closer to the center. As already discussed, empty spokes can be viewed as a mass point distribution of consumers at the center of the market: as their relative density increases (higher N), so does the average location chosen, reducing the differentiation between the firms in the market.

4.4 Triopoly

We focused so far on the case of duopoly. In particular, we analyzed the impact on firms' optimal locations of segments of consumers whose preferred brand is not available. A number of interesting questions, however, arise if more firms are active in the market. Whereas a full characterization of price-location equilibria of the spokes model for a generic number of firm is extremely challenging and beyond the scope of this work,[5] some relevant insights can be gained by extending the model at least to the case of three firms.

[5] The challenges posed by allowing for a larger number of active firms are not particularly surprising. In the related context of price and location choices in the Hotelling model, the only extension to a higher number firms (Brenner, 2005) relies on computational solutions rather than analytical ones.

Captive consumers Starting with the assumption of captive consumers, the following result can be stated:

Proposition 3 *The game has a unique symmetric sub-game perfect Nash equilibrium characterized by locations:*

$$y_i^* = -\frac{3}{8}N + \frac{5}{4}, \qquad i = 1, 2, 3. \tag{10}$$

The optimal locations are decreasing in N.

A corollary of the previous result is that if $n = N = 3$, the optimal location configuration is: $y_i^* = \frac{1}{8}$.

All-out competition Turning to the assumption of all-out competition, the game becomes hardly tractable as soon as empty spokes are introduced. As such, only a few special results are obtained and we summarize them in what follows.

Proposition 4 *(i) If $n = N = 3$, the game has two sub-game perfect Nash equilibrium configurations characterized by locations:*

$$(1)\ y_i^* = \frac{5}{16}, \qquad i = 1, 2, 3; \tag{11}$$

$$(2)\ y_i^* = \frac{1}{2},\ y_j = \frac{1}{8} \quad i \neq j; \tag{12}$$

(ii) If $n = 3 < N = 4$, one sub-game perfect Nash equilibrium of the game is characterized by locations:

$$y_i^* = \frac{1}{2},\ y_j = \frac{1}{8} \quad i \neq j. \tag{13}$$

First, the special case $n = N = 3$ can be compared with the analogous special case under the assumption of captive consumers. In both cases, in a triopoly firms locate within the market area where consumers reside and not outside of it, as in the case of duopoly. However, in presence of all-out competition, firms are located closer to the center of the market than if consumers are captive. This holds true in both the symmetric outcome and in the asymmetric one, in terms of the average location of firms. The finding has an intuitive interpretation: the presence of a third competitor in the market makes competition fiercer. Such a pro-competitive effect implies that firms face a *stronger market stealing effect*: intuitively, the effect is relatively stronger under all-out competition than in presence of captive consumers on the empty spokes.

Second, in case there are spokes not occupied by firms, we can only provide a complete comparison of the two cases if $N = 4$. In fact, under all-out competition, if $N > 4$ important challenges arise in specifying the demand structure of firms: given their relative location and the quadratic transport costs, several plausible demand configuration arise. Whereas we cannot exclude that equilibria may exist, for $N \geq 5$ none of the possible demand configurations that we considered returned a candidate price-location equilibrium consistent with the initial assumptions. Some insights, however, can be obtained in the case $N = 4$. Under the assumption of captive consumers, $y_i^* = -1/4$: an empty spoke leads firms to locate outside of the region occupied by consumers, just like in the case of duopoly. Under all-out competition, instead, firms locate asymmetrically and well inside the area of the market occupied by consumers. The intuition for these opposite results can be found once again in the different impact that empty spokes have on firms location incentives: if consumers are captive, the *market power effect* dominates *market stealing* and exactly the opposite applies in presence of all-out competition.

4.5 Overview of the main findings

The results of our theoretical analysis of endogenous location in the spokes model, although restricted to a limited and fixed number of firms, provide several predictions: the main findings are summarized in Table 1. Notwithstanding the recalled limitations the findings presented do, however, provide some clues on what to expect if the number of firms is higher and the number of spokes/brands is fixed, as observed in the real world at least in the short run.

[TABLE 1 HERE]

We note that, with or without empty spokes, increasing the number of firms from two to three leads to firms locating closer to the center (i.e. a *lower* level of specialization), regardless of which assumption on demand the model rests upon. The difference between the two assumptions is that under *all-out competition*, the predicted equilibrium market structure features a firm located in the center if one or more empty spokes exist; in presence of *captive consumers*, instead, the model predicts that all firms chose a location internal to their spoke. Importantly, the findings have implications for the *average level of specialization* in the market. According to the *captive consumers* version of the model, the average level specialization should decrease as the number of firms in the market, n, increases. In the *all-out competition* version, instead, the prediction on the average level of specialization is less clear cut. In fact, holding fixed the number of spokes, we can expect average specialization to increase at first as the share of specialized firms increases; the level of specialization of specialized firms, however, is likely to decrease in the number of firms, also according to this version of the model. Hence, if the number of firms becomes sufficiently large, the average specialization should eventually start to decrease.

5 Empirical specification

This section sets out to translate our theoretical findings into an empirically testable specification to be used in the context of the *car repair* market. Rather than measuring the *level* of specialization, we focus on the probability that a firm labels itself as specialized (on the spoke) or generic (in the centre). The choice is not only dictated by data availability but it may also better reflect the *strategic choice* made by firms. A firm that is specialized in a certain brand may still repair other brands when asked to do so by a customer. Similarly, a generic firm may have a high percentage of repairs of a specific brand if many customers owning a car of that brand happen to live nearby or if no specialized repair garage of that brand is located nearby. These outcomes follow from other causes than the strategic choice of the repair garage.[6]

The data available don't allow us observing from what level of specialization a firm labels itself as specialized, nor whether this level is the same for all firms. It seems plausible that the mix between specialized and generic firms is formed by patterns of entry and exit, rather than firms switching from one to the other. If the predicted optimal location for firms would be in or near the center, one may expect that the next entrant is more likely to be a generic firm than a specialized one. We also note that some repair garages have adopted a specialization other than brand, such as tires or car windows. Some other repair garages are generic, but are part of a chain, which might be perceived as a different product by consumers. This, as well as several unobserved differences, might explain why several generic firms may coexist in the

[6] The dataset, as described in the next section, contains a small number (about 0.5 percent of the sample) of firms specializing in a two or three brands, rather than only one. The very small share of these firms and the fact that they still label themselves as specialized, leads us to treat these firms as specialized firms.

same market.

We specify our empirical model as a binomial logit, where the probability of firm i in market j being specialized depends on the number of firms in market j, n_j:

$$\Pr\left(\text{Firm}_{ij} = \text{Specialized}\right) = \frac{\exp\left(f(n_j)\right)}{1 + \exp\left(f(n_j)\right)}. \tag{14}$$

If the results are consistent with the *captive consumers* version of the model, we expect the level of specialization to be monotonically decreasing in n_j, for any number of firms present in market j. Given the discussion on the average level of specialization in Section 4.5, we would expect the *all-out competition* version of the model to yield a parabolic relationship. Whether the peak of the parabola lies within the observed sample is an empirical question.

Apart from the number of firms in market j, we correct for demand shifters (e.g., the number of cars, the number of households, the average income), as well as the level of urbanization. Moreover, we distinguish between three distance bands for these variables. All the details are provided in the next section.

6 Market and Data

The market for car repairs in The Netherlands We focus our empirical analysis on the market for *car repairs* in the Netherlands. The spokes model is especially relevant to analyze this market (or any market for repairs of durable goods), as consumers have located themselves on a specific spoke by buying a certain brand of car. It is realistic to assume that most consumers have, *ceteris paribus*, a preference for a specialized repair; however, if this is not available in their area, then generic repairs or other brands have to be considered. We exploit a large data set on Dutch car repair garages to model the choice between specializing or providing generic assistance and we relate such a choice to some of the variables suggested by the spokes model. Lijesen *et al.* (2016) use a partially overlapping data set on the Dutch car repair industry, focusing on the pricing stage of a spatial competition model. They find that the price level of specialized car repair garages respond to the proximity of a repair shop of the same brand, but not (significantly) to the proximity of a generic repair shop or a garage repairing different brands.

About half of all car repair firms in the Netherlands are specialized in repairing one brand of car, suggesting that they are located within one of the spokes. Moreover, there are few, if any, possibilities to substitute a car repair for economic goods offered by firms in other sectors: this suggests that the importance of substitutes outside the market is relatively small.[7]

Distance bands We use the address list of BOVAG, the Dutch industry association for car repair firms, for 2011. BOVAG covers 86 percent of the car repair market in terms of firms and a much higher percentage in terms of turnover. Competition law restricts the association from advising its members about price setting (Beusmans and van Ommeren, 2004).

The availability of addresses allows us to use geographical data in our analysis.[8] In our theoretical model, *distance* is used figuratively to express the *level of specialization*, i.e. it can be interpreted in terms of distance in the product space. *Geographical distance* is obviously important as well in the market studied. Our first step is to define the geographical size of the areas to analyze. Most existing area classifications are not fit for this purpose, as they are based on administrative borders. We prefer to use distance bands (around each repair garage) to obtain an objective measure of the area size. We note, however, that distance doesn't have the same "meaning" everywhere, implying that distance bands should be differentiated between regions with different levels of urbanization.

In order to capture the assumption in the model that every spoke holds at most one firm, we compute distances between repair garages of the same brand for the *five* most popular brands (Opel, Volkswagen, Ford, Renault and Peugeot) and assess the nearest distance between these repair garages by level of urbanization.[9]

[TABLE 2 HERE]

Not surprisingly, the overall image from Table 2 is that firms in less urbanized regions are located further apart. The *minimum value* of the constructed variable

[7] Outside goods, often modelled in spatial competition through a reservation price, lower the strategic value of product differentiation: this is because any market power obtained it is dampened by the competitive influence of the outside good.

[8] To maintain consistency with the other geodata used, we do not use actual addresses, but post codes at the four digit level.

[9] We use the definition of urbanization as defined by The Netherlands Bureau of Statistics: http://www.cbs.nl/en-GB/menu/methoden/toelichtingen/alfabet/u/urbanisation-rate.htm

shows a pattern that is probably dominated by outliers and doesn't seem to correspond to the patterns observed in the remainder of the table. We therefore set the first distance band in our analysis at the level of the *5th percentile* of the distance in kilometers between two nearest repair garages of same brand. Since there hardly seems to be any difference between the values for areas with a high and a moderately high urbanization rate, we do not distinguish between them and set the distance band for both at 2 kilometers.

Although we define the local market by this distance band, we note that some effects may carry further. We also use distance bands of 10 and 20 kilometers to control for these effects.

Demand control variables The Dutch Bureau of Statistics (CBS) publishes an online database [10] that, among others, contains a wide range of data at a the highly disaggregated level of 4 digit zip codes. We use these data to compute control variables for demand, such as the number of households, the average household income and the number of cars. The level of urbanization, discussed earlier, is drawn from the same database.

Summary Statistics After adding these data and dropping incomplete observations, our dataset contains 6,798 observations. Table 3 provides descriptive statistics for the variables in our analysis.

[TABLE 3 HERE]

About 45 percent of all repair garages in our sample are specialized and nearly half of the shops are located in a high or moderately high urbanization areas. The average number of repair garages indicates the presence of "unoccupied spokes in the inner distance band. The difference between the various distance bands suggest that collinearity will probably not be a problem for the ensuing analysis. Note that the radius of the distance bands differs by at least a factor 2 and hence the surface of each circle is at least 4 times that of the previous circle around the same firm.

[10] http://statline.cbs.nl/Statweb/?LA=en

7 Empirical findings

We estimate the model introduced in Section 5, using a binomial logit specification and clustering standard errors at the four digits postcode level (2031 clusters).

[TABLE 4 HERE]

The estimation results in Table 4 suggest a *parabolic relationship* between the level of specialization, which is consistent with the *all-out competition* version of the spokes model. Figure 2 graphs the predicted probability of a firm being specialized against the number of firms in the inner band, for firms located in a highly urbanized region. The parabolic shape is clearly visible, with the majority of observations located in the increasing part of the parabola.[11] The peak of the parabola is reached at about twenty firms within the inner band. This might seem to suggest that the peak lies outside the relevant region, as the number of spokes (car brands) in our analysis equals 16. As an additional check, we compute the expected number of specialized firms within the inner band of every firm and find that less than 3 percent of the firm operates in a market where the (rounded) expected number of specialized firms exceeds 16.

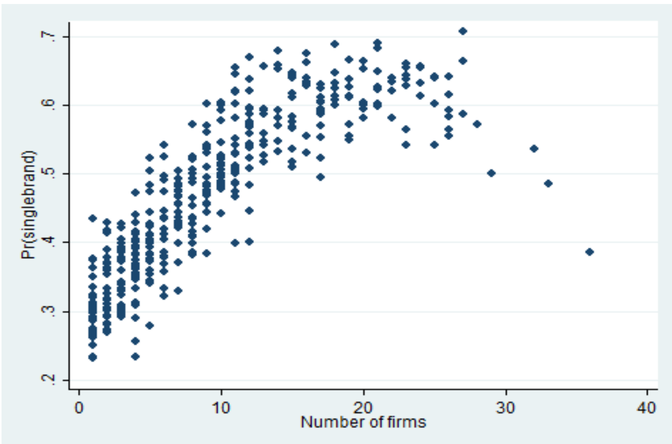

Figure 2. Predicted probability of a repair being specialized and the number of firms, highly urbanized areas.

The negative sign for nearby households and their income may appear puzzling at first. However, it probably reflects the fact that specialized car dealers are often

[11] The shape of the plot is very similar for other levels of urbanization, although areas with a very high level of urbanization have fewer observations with a large number of firms and areas with a very low level of urbanization have a considerably lower overall level of predicted probabilities.

located at dedicated industrial sites, whereas general car repair garages are relatively often found in residential areas. The number of households within 10 km has a positive effect, because a bigger customer base allows for more specialized stores and the number of firms within 10 km has a negative effect, as this increases the probability that the same brand is already represented fairly nearby. None of the income variables or the variables in the 20 km band are significant.

We use dummies for urbanization classes to correct for anything related to the level of urbanization that was not taken into account otherwise. The most frequent class (Moderately high and high urbanization) is used as a benchmark. The class of very high urbanization does not significantly differ from it; markets with low or very low urbanization have instead a significantly lower share of specialized firms.

In order to test the robustness of these results, we have repeated the analysis under several alternative specifications, e.g. using the number of cars instead of the number of households; without urbanization dummies, cluster based on urbanization classes rather than the postcode, classifying generic repair shops as specialized if they specialize in something else than brand. We also implemented a linear probability version of the model. The qualitative conclusions and order of magnitude were not significantly affected by any of these changes.

8 Concluding remarks

The paper addressed the issue of firms' specialization in relation to how many other firms are present in the market. Our theoretical analysis of location (specialization) choice is based on the spokes model, a recently introduced approach to non-localized spatial competition. Compared to alternative approaches in the literature, the model provides a first theoretical set-up that can *potentially* explain a positive relationship between endogenous product differentiation and the number of firms. In order to endogenize location choice, we deviate from the benchmark version (Chen and Riordan, 2007) by assuming quadratic rather than linear transport costs. The analysis allows reaching a number of testable conclusions. The results depend on the presence of consumers' segments where firms have not located and on the assumptions made on consumers' preferences in those segments (*captive consumers* vs *all-out competition*), on the number of firms and on the number of consumer segments not served by firms. First, no matter the assumptions on consumers' demand, we find that individual firms specialize less if the number of firms increases from two to three. The result, however, needs to be qualified if consumers on the empty spokes do not have a strict preference for an alternative brand, i.e. in the *all-out competition* version of the model. In that context, in fact, the presence of empty spokes leads to one firm occupying the center of the market, i.e. not specializing. Hence, the *average specialization* of firms first increases as the number of firms grows larger, despite the specialized firms specializing less and less. These theoretical predictions were then taken to the data. Car repair garages provide an ideal setting as consumers preferences are likely to be well approximated by the assumptions of the spokes model. The empirical analysis, focusing on car repair garages in the Netherlands, seems consistent with the predictions of the *all-out competition* version of the model. We find, in fact, a robust non-linear relationship between the probability of specializing and the number of firms in the market.

Our work also opens up new opportunities for further research. First, despite the fact that our analysis is *potentially* able to encompass a positive relationship between the number of firms and endogenous product differentiation, our results do not fully reconcile theoretical predictions with everyday experience and the available empirical findings indicating that individual firms specialize more if more firms are present in the market. Second, the explicit modelling of location choice in the spokes model provides ample room for further expansions and applications of this new branch on the tree of spatial competition models. For example, sequential (and eventually endogenous) entry, with or without perfect foresight, could be an interesting extension. Not only this might allow to solve the model for a larger number of firms, it is also likely to better reflect actual firm decisions and allow for closer and wider empirical testing of the model. Third, a limit of our theoretical analysis is to focus only on duopoly and triopoly. Whereas a complete characterization of the solutions of the model may not be possible, comparative statics may deliver more general results for a higher number of firms and spokes. Finally, the empirical analysis focused on the strategic choice of individual garages to be on the market as specialized or generic: more detailed data on the characteristics of garages and the actual repairs could offer the possibility of a more in depth analysis of demand, supply and the equilibrium outcomes in this market.

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A Appendix

Proof of Lemma 1

The demand is identified by solving (1). This amounts to:

$$x_{ij}^{l}=\begin{cases}\frac{1}{2}-\frac{1}{2}(y_i-y_j)-\frac{p_j-p_i}{2(1-y_i-y_j)} & \text{if} \quad l=j\\ \frac{1}{2}+\frac{1}{2}(y_i-y_j)-\frac{p_j-p_i}{2(1-y_i-y_j)} & \text{if} \quad l=i\end{cases}$$

depending on whether the indifferent consumer is located on spoke i or spoke j.[12]

Focusing on firm i and assuming, without loss of generality, that x_{ij} lies on spoke j, the profit function (2) can be rewritten as:

$$\pi_i=\frac{2p_i}{N}\left\{\frac{1}{N-1}\left[\frac{1}{2}+\frac{1}{2}(y_i-y_j)+\frac{p_j-p_i}{2(1-y_i-y_j)}\right]+\frac{N-2}{N-1}\right\}.$$

Following standard procedures, we get:

$$\begin{aligned}\frac{\partial\pi_i}{\partial p_i} &= \frac{-2p_i+p_j+(2N-3+y_i-y_j)(1-y_i-y_j)}{N(N-1)(1-y_i-y_j)}=0,\\ \frac{\partial^2\pi_i}{\partial p_i^2} &= -\frac{2}{N(N-1)(1-y_i-y_j)}<0.\end{aligned}$$

The second order conditions reveal that in equilibrium we must have $y_i^*+y_j^*<1\ \forall\ N>1$, yielding the straightforward implication that the firms can not be located in the center simultaneously. The best response in prices for firm i:

$$p_i=\frac{p_j}{2}+\frac{(2N-3+y_i-y_j)(1-y_i-y_j)}{2}.$$

Hence, the Nash equilibrium prices are:

$$p_i=\frac{(6N-9+y_i-y_j)(1-y_i-y_j)}{3}.$$

The impact of the number of spokes on equilibrium prices is:

$$\frac{\partial p_i}{\partial N}=2(1-y_i-y_j)=\frac{\partial p_j}{\partial N},$$

which is strictly positive, since the second order conditions require $y_i^*+y_j^*<1$.

Q.E.D.

[12] Recall that the distance is measured from 0 to 1/2 on all spokes, with 1/2 representing the center of the market.

Proof of Proposition 1

The profit function (4) is equivalent to:

$$\pi_i = \frac{2}{N}p_i(y_i, y_j)\left\{\frac{1}{N-1}\left[\frac{1}{2}+\frac{1}{2}(y_i-y_j)+\frac{p_j(y_i,y_j)-p_i(y_i,y_j)}{2(1-y_i-y_j)}\right]+\frac{N-2}{N-1}\right\}.$$

Substituting the equilibrium prices (3) into the profit function and following standard procedures leads to:

$$\begin{aligned}\frac{\partial \pi_i(y_i,y_j)}{\partial y_i} &= \frac{(6N+y_i-y_j-9)\,(6N+3y_i+y_j-11)}{9N\,(N-1)}=0,\\ \frac{\partial^2 \pi_i(y_i,y_j)}{\partial y_i^2} &= -\frac{2\,(y_j-3y_i-12N+19)}{9N\,(N-1)}<0.\end{aligned}$$

From the first order condition, two candidate solutions are found:

$$\text{(a) } y_i=-\frac{3}{2}N+\frac{11}{4},\ y_j=-\frac{3}{2}N+\frac{11}{4};\qquad \text{(b) } y_i=\frac{1}{2},\ y_j=-6N+\frac{19}{2}.$$

Solution (b) violates the second order condition of firm j, hence, it is not a Nash equilibrium of the location sub-game. Solution (a) satisfies both second order conditions and it is the unique symmetric sub-game perfect Nash equilibrium. Equilibrium locations are clearly negatively related to the number of spokes N.

Q.E.D.

Proof of Lemma 2

Based on the demand functions specified for the asymmetric locations case and assuming $y_i > y_j$, the profit functions at an interior solution are:

$$\begin{aligned}\pi_i &= p_i\left\{\frac{2}{N}\left[\frac{1}{2}+\frac{1}{2}(y_i-y_j)+\frac{p_j-p_i}{2(1-y_i-y_j)}\right]-\frac{N-2}{2N}\left(2-y_i-y_j+\frac{p_j-p_i}{y_i-y_j}\right)\right\}\\ \pi_j &= p_j\left\{\frac{2}{N}\left[\frac{1}{2}+\frac{1}{2}(y_j-y_i)+\frac{p_i-p_j}{2(1-y_i-y_j)}\right]+\frac{N-2}{2N}\left(y_i+y_j-1+\frac{p_i-p_j}{y_i-y_j}\right)\right\}\end{aligned}$$

From the system of the first order conditions for firm i and firm j, the following unique solution is obtained:

$$\begin{aligned}p_i^* &= \frac{(y_i-y_j)\,(y_i+y_j-1)}{3}\,\frac{3(N-1)-(N-3)y_i-(N-1)y_j}{2-N+(N-3)y_i+(N-1)y_j},\\ p_j^* &= \frac{(y_i-y_j)\,(y_i+y_j-1)}{3}\,\frac{3+(N-3)\,y_i+(N-1)y_j}{2-N+(N-3)y_i+(N-1)y_j}.\end{aligned}$$

Q.E.D.

Proof of Proposition 2

For firm i, it is sufficient to show that $\frac{\partial \pi_i}{\partial y_i} \geq 0$ at $y_i^* = \frac{1}{2}$. Substituting the equilibrium prices (7)-(8) into the profit function of firm j yields, after simplification:

$$\pi_j = \left(y_i - y_j + y_j^2 - y_i^2\right) \frac{\left[3 - 3y_i - y_j + N(y_i + y_j)\right]^2}{9N^2(1 - y_i - y_j) + N(27y_i + 9y_j - 18)}.$$

The first order condition, evaluated at $y_i^* = \frac{1}{2}$, is:

$$-\frac{(2y_j - 1)^2 (N-1) \left[5 - N + 6(N-1)y_j\right] \left[(N+3) + 2(N-1)y_j\right]}{144N \left[(N-1)\left(\frac{1}{2} - y_j\right)\right]^2} = 0.$$

A solution requires that either:

$$(N+3) + 2(N-1)y_j = 0, \tag{15}$$

or:

$$5 - N + 6(N-1)y_j = 0, \tag{16}$$

holds. Moreover, as $\frac{1}{2} - y_j \neq 0$, the central location cannot be a solution, $y_j^* \neq \frac{1}{2}$. From (15) and (16) above, candidate solutions are (a) $y_j = -\frac{N+3}{2(N-1)}$ and (b) $y_j = \frac{N-5}{6(N-1)}$. The evaluation of the second order condition for firm j reveals that solution (a) leads to a minimum of the profit function, while at (b) maximum profit is reached. Turning to the profit function of firm i, after simplification:

$$\pi_i = \frac{(y_i - y_j)(y_i + y_j - 1)}{9N} \frac{(3 - 3N - 3y_i - y_j + Ny_i + Ny_j)^2}{(2 - 3y_i - y_j - N(1 - y_i - y_j))}.$$

Differentiating with respect to the firm's location, y_i, and evaluating the derivative at $y_1^* = \frac{1}{2}$ and $y_2^* = \frac{N-5}{6(N-1)}$ leads to:

$$\frac{\partial \pi_i}{\partial y_i} = \frac{(7N-2)(5N-4)(N-3)}{81N(N-1)^2} > 0, \quad \forall N > 2.$$

Q.E.D.

Proof of Proposition 3

We look for a symmetric price-location equilibrium. To specify the demand if consumers on empty spokes are captive and there are $n = 3$ firms, we use the convention that $x_{i,i+1}^{i+1}$ belongs to spoke $i+1$. If that is the case, the indifferent consumers between two firms lie on the spoke of the firm labelled with the highest number. Under these assumptions, the profit functions of all three firms can be then written as:

$$\begin{aligned}
\pi_1 &= \frac{2p_1}{N(N-1)}\left[\left(1-x_{12}^2\right)+\left(1-x_{13}^3\right)+(N-3)\right], \\
\pi_2 &= \frac{2p_2}{N(N-1)}\left[x_{12}^2+(1-x_{23}^3)+(N-3)\right], \\
\pi_3 &= \frac{2p_3}{N(N-1)}\left[x_{13}^3+x_{23}^3+(N-3)\right].
\end{aligned}$$

The indifferent consumers can be identified using (1) also in this case. The procedure then follows closely the case of duopoly (i.e. Proofs of Lemma 1 and Proposition 1): we first find an equilibrium of the price subgame for a given vector of locations y_i. We then substitute the equilibrium prices to find the objective functions at the location stage. The expressions are rather daunting and not particularly insightful, hence we do not report them.[13] The first order condition for maximum profits at a symmetric equilibrium ($y_i = y, \forall i = 1,2,3$) simplifies to:

$$500(1-2y)^7(10-3N+8y) = 0,$$

hence, the only allowed candidate solution is:

$$y_i = -\frac{N}{8}+\frac{1}{2}.$$

We then check that the second order conditions at the candidate equilibrium are verified:

$$-\frac{1184625(N-2)^7}{2048} < 0.$$

Q.E.D.

[13]The Mathematica files with full details of the derivations are available upon request.

Proof of Proposition 4

First, we look for a symmetric price-location equilibrium. Under the assumption of all-out competition and $n = 3$ firms, it is easy to verify that a symmetric equilibrium can only exists if all spokes are occupied, i.e. $N = 3$. In that case, under the usual convention on labelling firms, the profit functions are:

$$\begin{aligned}
\pi_i &= \frac{2p_i}{3}\left[\frac{1}{2} + \left(\frac{1}{2} - x_{ij}^j\right) + \left(\frac{1}{2} - x_{ik}^k\right)\right], \\
\pi_j &= \frac{2p_j}{3} x_{ij}^j, \\
\pi_k &= \frac{2p_k}{3} x_{ik}^k.
\end{aligned}$$

The indifferent consumers are identified using (1) also in this case. Proceeding in the usual way (e.g. following similar steps as in Lemma 2) we find an equilibrium of the price subgame for a given vector of locations y_i. We then substitute the equilibrium prices to find the objective functions at the location stage. Also in this case the long expressions are omitted.[14] The first order condition for maximum profits at a symmetric equilibrium ($y_i = y, \forall i = 1, 2, 3$) simplifies to:

$$-\frac{(16y - 5)}{30} = 0,$$

so clearly the only candidate solution is:

$$y_i = \frac{5}{16},$$

and, finally, the second order conditions at the candidate equilibrium are verified. This proves claim (i), part (1).

Second, we look for asymmetric price-location equilibria. There are clearly many possible location and demand configurations. We start by assuming that firm i locates at $y_i = 1/2$ and firms compete to share the empty spokes. The profit functions are then:

$$\begin{aligned}
\pi_i &= \frac{2p_i}{N}\left[\frac{1}{2} + \left(\frac{1}{2} - x_{ij}^j\right) + \left(\frac{1}{2} - x_{ik}^k\right) + \frac{(N-3)}{2}\right], \\
\pi_j &= \frac{2p_j}{N} x_{ij}^j, \;\; \pi_k = \frac{2p_k}{N} x_{ik}^k, \; j, k \neq i,
\end{aligned}$$

and the indifferent consumers can still be identified using (1). Notice that under the assumptions made on the demand structure firm i serves all the consumers on

[14] The Mathematica files with full details of the derivations are available upon request.

the empty spokes. This is not necessarily the case: given the quadratic transport cost structure, firms j and k could potentially attract part of the empty spokes consumers. The assumption will then have to be checked in equilibrium. The price stage first order conditions can then be computed as:

$$1-y_j-y_k-\frac{4p_i}{(1-2y_j)(1-2y_k)}+\frac{2p_j}{(1-2y_j)}+\frac{2p_k}{(1-2y_k)}+(N-2)=0,$$

$$p_j-\frac{1}{8}-\frac{p_i-y_j^2}{2}=0,\ p_k-\frac{1}{8}-\frac{p_i-y_k^2}{2}=0.$$

from which the equilibrium prices are identified. Recalling the assumption that firm i locates in the center, $y_i=1/2$, the equilibrium expressions can be substituted into the objective functions of firms j and k in the location stage. These are:

$$\begin{aligned}\pi_j &= \frac{p_j^*}{4N}\left[2y_j(N-2)+6-N+\frac{4(N-2)(p_i^*-p_j^*)}{1-2y_j}\right],\\ \pi_k &= \frac{p_k^*}{4N}\left[2y_k(N-2)+6-N+\frac{4(N-2)(p_i^*-p_k^*)}{1-2y_k}\right].\end{aligned}$$

From the first order conditions, whose expressions are omitted, several candidate equilibria are obtained. The second order conditions for a maximum profit of firms j and k lead to discard all candidates apart from:

$$y_i=\frac{1}{2},\quad y_j=y_k=\frac{1}{8}.$$

To complete the proof we check that, in the candidate equilibrium the indifferent consumers location on the empty spokes is such that firms j and k do not serve consumers on those segments. Finally, we also verify that firm i does not have incentives to deviate from the central location. The effect of a small deviation $\delta>0$ to a location inside the spoke, $y_i=1/2-\ \delta$, has the following effect on firm i profits:

$$\pi_i^D\left(\frac{1}{2}-\delta,\frac{1}{8},\frac{1}{8}\right)-\pi_i^*\left(\frac{1}{2},\frac{1}{8},\frac{1}{8}\right)=-\frac{\delta\,(8N-5)\,(19-4N+24\delta)}{96N\,(3+8\delta)},$$

which is not positive and, hence the deviation is not profitable, as long as $N<5$. We then conclude that the price-location configuration identified is an equilibrium for $N=3,4$. This proves claims (i) part (2) and (ii).

Q.E.D.

B Tables

Table 1. Summary of the model predictions on firms location.

	Captive	All-out Competition
$n = N = 2$	$y_i = -\frac{1}{4}$	$y_i = -\frac{1}{4}$
$n = N = 3$	$y_i = \frac{1}{8}$	$y_i = \frac{5}{16}$ & $y_i = \frac{1}{2}, y_j = \frac{1}{8}, j \neq i$
$n = 2 < N$	$y_i = -\frac{3}{2}N + \frac{11}{4}$	$y_i = \frac{1}{2}, y_j = \frac{N-5}{6(N-1)}$
$n = 3 < N$	$y_i = -\frac{3}{8}N + \frac{5}{4}$	$y_i = \frac{1}{2}, y_j = \frac{1}{8}, j \neq i$ if $N = 4$

Table 2. Distance in kilometers between two nearest repair garages of same brand (5 most popular brands).

Urbanization rate	Min.	5th Perc.	10th Perc.	Median	Observations
Very high	1.3	1.4	1.8	3.7	113
High	1.3	2.1	2.6	5.8	296
Moderately high	1.6	2.0	2.6	5.6	352
Low	1.3	3.0	4.0	7.7	390
Very low	3.6	4.7	5.4	9.2	130

Table 3. Descriptive statistics for the variables in the sample.

Variable	Mean	Std. Dev.	Min.	Max.
Repair garages				
Specialized garages	0.45	0.50	0	1
Very high urbanization	0.10	0.29	0	1
High/moderately high urbanization	0.48	0.50	0	1
Low urbanization	0.29	0.45	0	1
Very low urbanization	0.14	0.34	0	1
Inner distance band				
Number of firms	11.12	7.47	0	43
Number of cars (x1000)	8.17	5.26	0	42.94
Number of households (x1000)	8.19	6.75	0	62.93
Average household income (x1000 euros/annum)	34.35	4.74	17.67	96.60
10 km distance band				
Number of firms	87.28	50.06	2	251
Number of cars (x1000)	101.06	76.48	1.29	357.46
Number of households (x1000)	109.56	105.64	1.25	514.93
Average household income (x1000 euros/annum)	33.82	2.81	23.21	43.13
20 km distance band				
Number of firms	284.09	149.4	2	740
Number of cars (x1000)	323.50	207.63	2.08	990.63
Number of households (x1000)	341.80	260.41	2.13	1.192.36
Average household income (x1000 euros/annum)	33.50	2.02	24.07	38.19

Table 4. Binomial logit results for the probability that a firm is specialized.

Variable	Coefficient	Std. Err.	Odds ratio
Inner distance band			
Number of firms	0.1507	0.0143	1.162
Number of firms Squared	-0.0034	0.0005	0.997
Number of households (x1000)	-0.0197	0.0057	0.981
Average household income (x1000 euros/annum)	-0.0126	0.0086	0.987
10 km distance band			
Number of firms	-0.0090	0.0034	0.991
Number of firms Squared	1.2E-5	1.5E-5	1.000
Number of households (x1000)	0.0021	0.0011	1.000
Average household income (x1000 euros/annum)	0.0199	0.0227	1.020
20 km distance band			
Number of firms	-0.0015	0.0012	0.998
Number of firms Squared	1.6E-6	1.7E-6	1.000
Number of households (x1000)	0.0003	0.0006	1.000
Average household income (x1000 euros/annum)	0.0119	0.0279	1.012
Urbanization dummies			
Very high urbanization	-0.2631	0.1325	0.768
Low urbanization	-0.5409	0.0751	0.582
Very low urbanization	-1.1978	0.1094	0.302
Constant	-0.8551	0.5750	0.425
Log likelihood ratio (compared to constant only, 15 df)			413.0
Pseudo R^2			0.063
No of observations			6,798