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Network centrality and market prices: Empirical evidence☆

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HIGHLIGHTS

- We empirically investigate the importance of network centrality for pricing.
- Firms located closely to a local market center are more powerful in the pricing game.
- Centrality is more important in larger markets (as the number of firms increases).

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ABSTRACT

We empirically investigate the importance of centrality (holding a central position in a spatial network) for strategic interaction in pricing for the Austrian retail gasoline market. Results from spatial autoregressive models suggest that the gasoline station located most closely to the market center – defined as the 1-median location – exerts the strongest effect on pricing decisions of other stations. We conclude that centrality influences firms' pricing behavior and further find that the importance of centrality increases with market size.

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1. Introduction and background

The theory of social networks has provided a number of important insights for explaining social phenomena in a wide variety of disciplines from psychology to economics (Borgatti et al., 2009). It is a fundamental axiom in social network research that the centrality of a node's position within a network determines the opportunities and constraints that it encounters and thus plays an important role in determining a node's power to influence other nodes and the network as a whole (Ballester et al., 2006, 2010; Bramoullé et al., 2014; Helsley and Zenou, 2014).

This paper contributes to a growing body of research on networks in industrial organization by investigating the importance of centrality for firms' pricing behavior empirically. While textbook models on spatial markets typically make strong symmetry assumptions, recent theoretical work in industrial organization devotes more attention to firm heterogeneity and the implications of specific positions within a network for firm performance. Vogel (2008), for example, studies location decisions of firms that differ in their marginal costs. In equilibrium, more efficient firms will be more isolated and will set higher markups (because their competitors offer relatively poor substitutes). In Braid (2013) and Firgo et al. (2015) firms are located in a network of links and nodes that can be interpreted as roads and intersections. Both papers argue that firms characterized by a more central position in a spatial network are more powerful in terms of having a stronger impact on their competitors' prices and on equilibrium prices.

In networks with spatial patterns similar to a star graph, Freeman (1979) shows that the centrality of the central node

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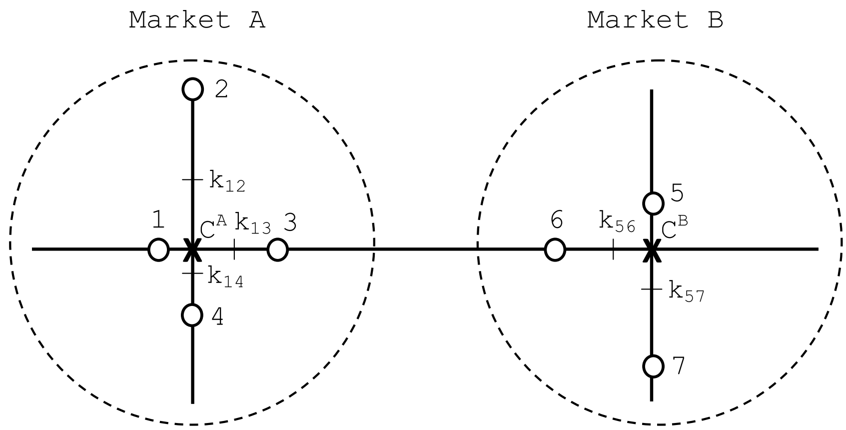

Fig. 1. Centrality on intersecting roads. Notes: The solid lines denote the road network, the white dots the firms, and the centers of the local markets are labeled by **X**. k_{ij} indicates the location of the marginal consumer (for particular prices and transportation costs) indifferent between purchasing at firm *i* or firm *j*, and the dashed lines denote the local market boundaries.

relative to remote nodes increases monotonically with the number of nodes, which holds for a number of different concepts of centrality. This suggests that the importance of a central supplier relative to remote firms in a pricing game increases with the number of firms in a local market.

The following simple example illustrates the importance of centrality in firms' price interactions and outlines our contribution to the (scarce) empirical literature. Assume that seven firms (nodes) are located in a network of roads (edges) as in Fig. 1. Firms 1 to 4 are assigned to market A, firms 5 to 7 to market B.[1] Using standard assumptions in spatial competition models with respect to product characteristics, production costs and consumer behavior, this simple network suggests that firms 1 and 5 will have a more 'central' position in their markets than all other firms. Centrality, defined as the extent to which agents are connected to other agents, provides these two firms with a dominant role in strategic price interactions between firms. In market A (B), firm 1 (5) competes for the same marginal consumer $k_{1,j}$ ($k_{5,j}$) with all other *j* firms in this market. In contrast, the 'remote' firms (2, 3, and 4 as well as 6 and 7) compete for the same marginal consumer with the 'central' supplier only, but do not compete directly with other remote firms within their market. In their pricing decisions, remote firms will thus consider only the price charged by the central firm, but not the prices charged by other remote firms. The central firm, on the other hand, takes the prices charged by all other firms in the local market into account. Therefore, centrality endows the central supplier with a dominant role in strategic price interactions between firms in the respective local market: In their own pricing decisions remote firms will consider only the price charged by the central supplier, but not other remote firms' prices.

There is only very little empirical work on the importance of centrality in firms' pricing decisions.[2] In the remainder of the article we explore empirically whether central suppliers indeed play a more prominent role in pricing games in the Austrian retail gasoline market.

2. Data and identification of market centers

The empirical application is based on data for the geographical locations of the complete population of gasoline stations in Austria collected by the company Catalist in August 2003. Using the software ArcGIS, the geographical coordinates of each gasoline station are located and plotted on a map. The routing tool WiGeoNetwork by WiGeoGIS calculates distances between all gasoline stations. To account for differences in speed limits and one-way roads, all distances are measured in driving time. These spatial data are merged with an unbalanced panel of station-level pricing data collected and provided by the Austrian Chamber of Labor nationwide on a particular day every three months between October 1999 and March 2005 for a total of 23 points in time. These data are supplemented by Catalist data on station characteristics and regional data by Statistics Austria.

We follow Pinkse et al. (2002) and define markets via nearest-neighbor-relations. Each observation is connected to its spatially nearest neighbor, and all stations are considered to be in the same local market as long as they are connected by nearest-neighbor-relations. Applying this market definition all 2,814 gasoline stations are assigned to 761 non-overlapping local markets.[3]

The market center is defined as the unique point which minimizes the sum of distances to all gasoline stations in the local market (i.e. the 1-median location; see Hakimi, 1964). Potential market centers are restricted to points located on the road network. In Fig. 1, C^A and C^B represent the market centers for markets A and B. The central supplier (firm 1 in market A and firm 5 in market B) is the station located most closely to the market center, while all other stations are denoted as remote suppliers. Using actual data for the Austrian retail gasoline market, Fig. 2 illustrates four different local markets, their road networks, gasoline stations and market centers.

Observations are included in the empirical analysis only if prices are observed for all stations in the respective local market in a particular time period, which reduces the size of the initial sample to 501 stations in 171 local markets. We further exclude observations in 79 markets where a unique central position cannot be identified.[4] Eventually, the empirical analysis is based on an unbalanced panel of 343 stations in 92 different markets comprising three to six competitors (2,920 observations in total).

[1] The definition of markets will be discussed in more detail later.

[2] Firgo et al. (2015) assign different degrees of centrality to each supplier. The present paper is more closely related to a star-shaped graph which implies a dichotomous distinction between one central supplier and (all other) remote firms.

[3] In Fig. 1, for example, this approach defines two separate markets, comprising firms 1 to 4 and firms 5 to 7, respectively. The fact that this implies no interaction between local markets is a reasonable assumption in our application. In our sample, the average driving time to the closest station outside the respective local market is 4.3 min longer than the shortest (and 1.7 min longer than the average) distance to rivaling firms within the local market. This suggests that local markets (as defined by nearest-neighbor-relations) are only loosely related to other local markets.

[4] In 'linear city' (Hotelling, 1929) markets with an even number of firms, a unique (1-median) central location does not exist.

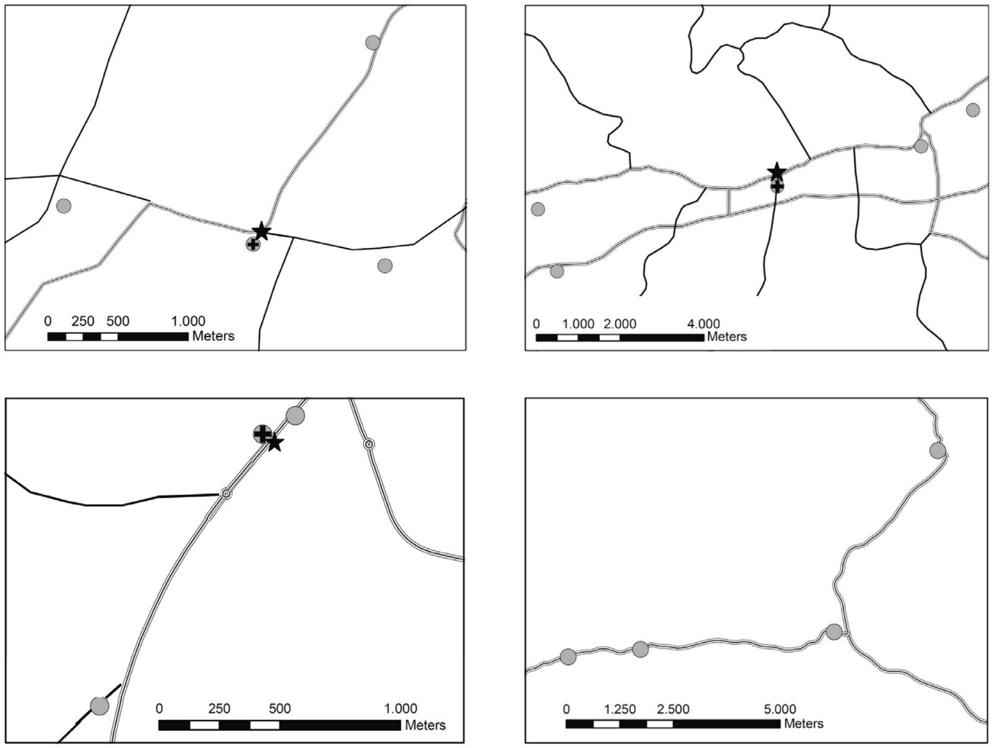

Fig. 2. Empirical examples of local markets and their centers. Notes: Each map represents a local market. Gasoline stations are marked by gray dots, the market centers by stars and the central stations by plus signs. Major (minor) roads are depicted by triple (single) lines.

Table 1
Summary statistics.

Variable	Mean	(S.D.)	Min.	Max.	# of Obs.
PRICE	75.600	(6.423)	61.900	92.000	2,920
CENTRAL	0.268	(0.443)	0	1	2,920
DIST TO CENTER	2.468	(3.660)	0	23.640	2,920

Summary statistics are provided in Table 1[5]: PRICE denotes nominal retail prices of diesel[6] measured in Euro-cents per liter, CENTRAL is a dummy variable indicating whether a particular station is the central supplier, and DIST TO CENTER measures the driving time (in minutes) from the gasoline station to the local market center.

3. Model specification and results

The following econometric model has frequently been estimated to account for spatial interactions in pricing between neighboring firms (Pennerstorfer, 2009).

$$\boldsymbol{p} = \rho \boldsymbol{W}\boldsymbol{p} + \boldsymbol{X}\beta + \epsilon, \tag{1}$$

with $\boldsymbol{p}$ as the vector of prices. $\boldsymbol{W}$ is a spatial weights matrix of dimension $N \times N$ (N is the total number of observations) and summarizes the dependence structure between gasoline station i at time t and station j at time u. The typical element $w_{it,ju} = 1$ if stations i and j are in the same local market, $i \neq j$ and $t = u$, and 0 else. $\boldsymbol{X}$ includes station- and location-specific characteristics, time period fixed effects as well as dummy variables for each local market, with $\boldsymbol{\beta}$ as the respective vector of parameters to be estimated and $\boldsymbol{\epsilon}$ as the error term. Parameter ρ measures the pricing interaction between neighboring gasoline stations.

This model, however, does not allow measuring differences in the importance of central and remote suppliers in pricing interactions. To explore such differences explicitly, we extend this model in various ways. First, we explore whether the intensity of price interaction between pairs of stations changes with market size:

$$\boldsymbol{p} = \sum_{s=3}^{6} \boldsymbol{M}_s \left(\rho_s \boldsymbol{W}\boldsymbol{p}\right) + \boldsymbol{X}\beta + \epsilon. \tag{2}$$

The size of the market (i.e. the number of stations within a market) is denoted by s ($s = 3, \ldots, 6$). $\boldsymbol{M}_s$ is a diagonal matrix of dimension $N \times N$ with $m_{s,it,it} = 1$ if station i is located in a market of size s, and 0 else. As the effect of one station's decision on other stations' decisions are expected to diminish as the number of stations in a local market increases (Barron et al., 2008), separate parameters (ρ_s) are estimated for markets with different numbers of stations.

Second, to explore whether interaction in pricing between stations depends on the stations' positions within the network (centrality), we estimate the following model:

$$\boldsymbol{p} = \sum_{s=3}^{6} \boldsymbol{M}_s \left(\rho_s^{C\to R} \boldsymbol{W}\boldsymbol{C}\boldsymbol{p} + \rho_s^{R\to C} \boldsymbol{C}\boldsymbol{W}\boldsymbol{p} + \rho_s^{R\to R} \boldsymbol{R}\boldsymbol{W}\boldsymbol{R}\boldsymbol{p}\right) + \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{\epsilon}. \tag{3}$$

$\boldsymbol{C}$ ($\boldsymbol{R}$) is a diagonal matrix with element $c_{it,it} = 1$ ($r_{it,it} = 1$) if station i is a central (remote) supplier, and 0 else. Parameter $\rho^{C\to R}$ can be interpreted as the effect of the price of a central supplier on a remote competitor within the same local market (i.e. $\rho^{C\to R} = \frac{\partial p_{it}}{\partial p_{jt}}$ for station i as a remote and station j as the central supplier), $\rho^{R\to C}$ as the effect of a remote supplier's price on the central supplier's price (i.e. $\rho^{R\to C} = \frac{\partial p_{it}}{\partial p_{jt}}$ for station i as the central supplier and

[5] The definition of all other variables and summary statistics related to them are reported in Appendix A (available online).

[6] Unlike in North America, diesel-engined vehicles are most popular in Austria, accounting for more than 50% of registered passenger vehicles in 2005 (Statistics Austria, 2006).

Table 2
Results of the maximum likelihood estimations.

Specification	[1]		[2]	
	Coef.	(S.D.)	Coef.	(S.D.)
ρ_3	0.317	(0.005)***		
ρ_4	0.212	(0.004)***		
ρ_5	0.166	(0.003)***		
ρ_6	0.131	(0.004)***		
$\rho_3^{C\to R}$			0.306	(0.033)***
$\rho_3^{R\to C}$			0.311	(0.006)***
$\rho_3^{R\to R}$			0.335	(0.032)***
$\rho_4^{C\to R}$			0.288	(0.029)***
$\rho_4^{R\to C}$			0.207	(0.004)***
$\rho_4^{R\to R}$			0.177	(0.015)***
$\rho_5^{C\to R}$			0.438	(0.002)***
$\rho_5^{R\to C}$			0.163	(0.004)***
$\rho_5^{R\to R}$			0.079	(0.001)***
$\rho_6^{C\to R}$			0.403	(0.103)***
$\rho_6^{R\to C}$			0.127	(0.004)***
$\rho_6^{R\to R}$			0.061	(0.027)**
CONSTANT	29.682	(1.269)***	29.017	(1.303)***
CENTRAL	0.238	(0.162)	1.674	(0.822)**
DIST TO CENTER	0.039	(0.018)**	0.033	(0.018)*
CENTRAL × DIST TO CENTER	0.077	(0.365)	0.178	(0.361)
Market Fixed Effects		Yes		Yes
Time Fixed Effects		Yes		Yes
Station-Specific Characteristics		Yes		Yes
Location-Specific Characteristics		Yes		Yes
ℓ	−4,688.585		−4,669.098	
σ_μ^2		0.315		0.302
σ_ν^2		1.965		1.943

Notes: # of obs.: 2,920; Inference is based on a variance–covariance matrix of ϵ that is clustered at the station level (with $\epsilon_{it} = \mu_i + \nu_{it}, \mu_i \sim IID(0, \sigma_\mu^2)$ and $\nu_{it} \sim IID(0, \sigma_\nu^2)$). Parameter estimates on station- and regional-specific control variables are reported in Table 5 in Appendix B (available online).
*** Significant at 1% level.
** Significant at 5% level.
* Significant at 10% level.

station j as a remote supplier), and $\rho^{R\to R}$ as pricing interaction between two remote suppliers (i.e. $\rho^{R\to R} = \frac{\partial p_{it}}{\partial p_{jt}}$ for both station $i \neq j$ as remote suppliers). If gasoline stations located most closely to a market center actually exert the strongest effect on pricing decisions of other stations, we would expect to find $\rho_s^{C\to R} > \rho_s^{R\to C}$ and $\rho_s^{C\to R} > \rho_s^{R\to R}$.

Clearly, competitor prices on the right hand side of Eqs. (2) and (3) are endogenous and OLS will produce biased results. As a common solution in applied spatial econometrics the reduced form of the regression equation is estimated via maximum likelihood (see Anselin, 2001 for an overview). Cost shocks over time, which are common to all stations (such as fluctuations of crude oil prices), are captured by fixed time effects. Spatial autocorrelation due to differences in local demand or costs across markets are controlled for by local market-level fixed effects.

Results from the benchmark specification (Eq. (2)) are reported in column [1] of Table 2. This model does not allow for asymmetries and restricts the parameters such that $\rho_s^{C\to R} = \rho_s^{R\to C} = \rho_s^{R\to R} = \rho_s$. All parameter estimates for ρ_s are significantly positive; a higher price charged by one station is associated with higher prices of rival stations within the same local market. In addition, column [1] clearly suggests that the interaction in pricing between neighboring stations (ρ_s) becomes smaller as the number of stations (s) increases.

Column [2] in Table 2 reports parameter estimates of the model in which the pricing interaction parameters ρ_s are allowed to differ between central and remote suppliers (Eq. (3)). In small markets (with three stations only; $s = 3$) our results suggest that there is hardly any difference in the parameters ρ_s between central and remote stations. The two-sample t-tests reported in Table 3 indicate that none of the null hypotheses $\rho_3^{C\to R} = \rho_3^{R\to C}$, $\rho_3^{C\to R} = \rho_3^{R\to R}$ and $\rho_3^{R\to C} = \rho_3^{R\to R}$ can be rejected at any reasonable level of significance. Thus, centrality does not seem to matter in small markets.

However, we find that centrality matters in larger markets. Fig. 3 illustrates the parameter estimates for ρ_s, $\rho_s^{C\to R}$, $\rho_s^{R\to C}$, and $\rho_s^{R\to R}$ for markets of different size s obtained from column [2] of Table 2. The parameter estimates for ρ_s, $\rho_s^{R\to C}$, and $\rho_s^{R\to R}$ decline with the size of the market, which corresponds to the results obtained in column [1]. Interaction in pricing between two neighboring stations becomes less intense as the number of stations (s) increases. In contrast, the parameter estimates for $\rho_s^{C\to R}$, i.e. the impact of the central supplier on price-setting of remote firms, remains stable (or even increases slightly) as market size increases. The difference between parameter estimates for $\rho_s^{C\to R}$ and all other ρ_s parameters is significantly different from zero at the 1% significance level for all markets with $s \geq 4$ stations. Including state-fixed effects and/or regional characteristics instead of local market-fixed effects hardly affects the parameter estimates (the results are shown in Appendix C, available online).

Our results thus add empirical evidence to the literature on (social) networks investigating the linkage between centrality and performance. We conclude that (a) centrality matters for firms' pricing behavior and (b) this effect of centrality becomes more important as the size of the market (i.e. the number of firms in

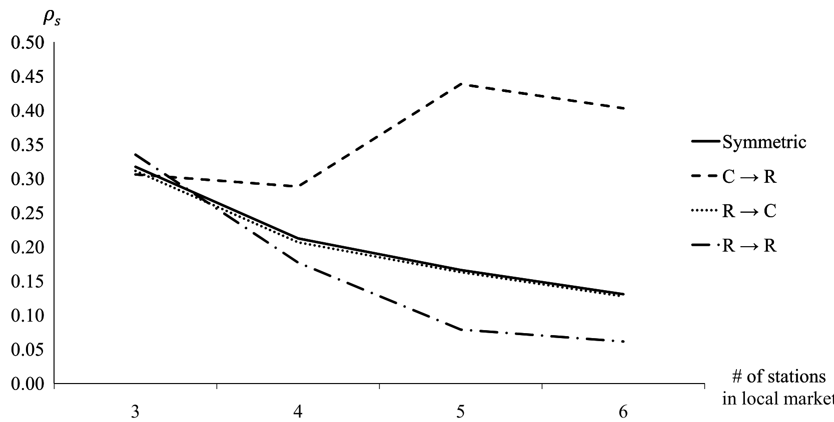

Fig. 3. Asymmetry in the spatially autoregressive parameters. Notes: The solid line denotes the slope parameter ρ_s (on the vertical axis) depending on the number of stations in a local market (horizontal axis) in the symmetric case (specification [1]). The dashed (dotted) [chain dotted] line denotes the parameter $\rho_s^{C\to R}$ ($\rho_s^{R\to C}$) [$\rho_s^{R\to R}$] of specification [2] in Table 2.

Table 3
t-test statistics for asymmetry in the spatially autoregressive parameters.

Market size	Number of observations	$\rho_s^{C\to R} = \rho_s^{R\to C}$	$\rho_s^{C\to R} = \rho_s^{R\to R}$	$\rho_s^{R\to C} = \rho_s^{R\to R}$
$s = 3$	1176	0.215	0.887	1.034
		(0.830)	(0.375)	(0.301)
$s = 4$	1016	3.891	4.768	2.652
		(0.000)[a]	(0.000)[a]	(0.008)[a]
$s = 5$	470	89.449	317.510	28.957
		(0.000)[a]	(0.000)[a]	(0.000)[a]
$s = 6$	258	3.792	4.557	3.476
		(0.000)[a]	(0.000)[a]	(0.001)[a]

Notes: Test statistics are based on two sample t-tests with unequal variances for the respective parameter estimates.
[a] Significant at the 1% level; p-values in parentheses.

this market) increases. Future research should provide additional empirical evidence using alternative concepts for delimiting markets by applying new methods for identifying 'the key player' (Ballester et al., 2006) and by investigating the importance of centrality in different market environments.

Appendix A–C. Additional explanatory variables and sensitivity analysis

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.econlet.2015.11.032.

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