Discussion Paper No. 17-035

Competition, Collusion and Spatial Sales Patterns – Theory and Evidence

Matthias Hunold, Kai Hüschelrath,
Ulrich Laitenberger, and Johannes Muthers

Zentrum für Europäische
Wirtschaftsforschung GmbH

Centre for European
Economic Research

Discussion Paper No. 17-035

Competition, Collusion and Spatial Sales Patterns – Theory and Evidence

Matthias Hunold, Kai Hüschelrath,
Ulrich Laitenberger, and Johannes Muthers

First Version: September 26, 2017
This Version: December 31, 2017

Competition, collusion and spatial sales patterns - theory and evidence*

Matthias Hunold†, Kai Hüschelrath‡,
Ulrich Laitenberger§ and Johannes Muthers¶

First Version: September 26, 2017
This Version: December 31, 2017

Abstract

We study competition in markets with transport costs and capacity constraints. We compare the outcomes of price competition and coordination in a theoretical model and find that when firms compete, they more often serve more distant customers who are closer to the competitor's plant. If firms compete, the transport distance varies in the degree of overcapacity, but not if they coordinate their sales. Using a rich micro-level data set of the cement industry in Germany, we study a cartel breakdown to identify the effect of competition on transport distances. Our econometric analyses confirm the theoretical predictions.

JEL classification: K21, L11, L41, L61

Keywords: Capacity constraints, cartel, cement, spatial competition, transport costs.

*Part of this research was financially supported by the State Government of Baden-Württemberg, Germany, through the research program Strengthening Efficiency and Competitiveness in the European Knowledge Economies (SEEK). We are grateful to Cartel Damage Claims (CDC), Brussels, for providing us with the data set. Hüschelrath was involved in a study of cartel damage estimations which was financially supported by CDC. The study is published in German (Hüschelrath, Leheyda, Müller, and Veith (2012)). The present article is the result of a separate and independent research project. We thank Toker Doganoglu, Joe Harrington, Dieter Pennerstorfer, Shiva Shekhar, Christine Zulehner and participants at the seminar of the University of Linz for valuable comments.

†Düsseldorf Institute for Competition Economics (DICE) at the Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany; hunold@dice.hhu.de.

‡Schmalkalden University of Applied Sciences, Faculty of Business and Economics, Blechhammer 9, 98574 Schmalkalden, Germany and ZEW Centre for European Economic Research, Mannheim, Germany; k.hueschelrath@hs-sm.de.

§Télécom ParisTech, Département Sciences économiques et sociales, 46 Rue Barrault, 75013 Paris, France, and ZEW, Mannheim, Germany; laitenberger@enst.fr.

¶Johannes Kepler Universität Linz, Altenberger Straße 69, 4040 Linz, Austria; johannes.muthers@jku.at.

1 Introduction

It is well established in the literature that cartels between competitors typically lead to excessive prices and can also result in excess capacities. However, little is known about the spatial pattern of sales. In this article we study how competition affects which customers firms serve in markets with significant transport costs and capacity constraints. Our results help to better understand the competitive process and the relationship between industrial organization and allocative efficiency. The insights can also be used for distinguishing competition and coordination when analyzing market data in competition policy cases.

We set up a theoretical model of spatially differentiated firms which are capacity constrained and compare the market outcomes with price competition to coordination.[1] We show that competition creates an inefficiency in transport in a setting even when firms are symmetric and can price discriminate across customers. Moreover, we show that this inefficiency increases in the capacity of the firms. To fix ideas, consider that customers are located evenly on a line and that each of two symmetric suppliers is located at one end. The products are homogeneous and the only differentiation is due to location and thus transport costs. Cost minimization implies that all customers are served by the respectively closest firm. Surprisingly, in this setting competition does not achieve cost minimization in many instances.

If firms compete, there is a non-monotonic relationship between the average transport distance and the degree of excess capacity. When capacity is very scarce, firms are effectively local monopolists and transport costs are minimized. When capacities are abundant, fierce competition yields limit prices for each customer at the costs of the second most efficient firm, such that again the cheapest supplier wins the contract. For intermediate capacities, however, the average transport distance increases in the degree of overcapacity. The reason is that price competition turns out to be chaotic as firms cannot anticipate the exact prices of their capacity constrained competitors. With this strategic uncertainty, the more distant firm sometimes makes the more attractive offer to a customer, which results in inefficient allocations. Instead, our theory predicts that a well-organized cartel minimizes transport costs at any degree of overcapacity. The pattern that significant changes in the supply-demand balance are not accompanied by changes in the average transport distances is therefore indicative of coordination among the firms with intermediate levels of capacity.

In order to test our theory, we empirically investigate the allocation of customers to suppliers in the cement industry in Germany between 1993 and 2005. The cement industry

[1] We build on our previous theoretical work Hunold and Muthers (2017) where we used a simplified model to study competition and subcontracting. See the literature section for details.

is suitable for several reasons. Transport costs typically constitute a significant part of the cement price as cement is heavy and, due to scale economies, there is a limited number of cement production plants. The production capacity is limited by several factors, in particular the capacity of clinker kilns, which constitute costly long term investments. Demand for cement largely depends on the demand of the construction industry, which tends to be volatile and largely exogenous to the cement price. Indeed, the cement industry in Germany exhibited significant overcapacity in most of the investigated time-frame. Moreover, the industry had been cartelized during the first part of our observation period. There is a clear cut in 2002 when one of the cartel members deviated from the collusive agreement and the German competition authority (Bundeskartellamt) raided 30 cement producers, based on hints it had received out of the construction industry.[2] We therefore compare the allocation of customers in the cartel period of 1993 up to 2002 with that in the period following the cartel breakdown.

We use a rich data set with transactions of 36 cement customers in Germany from January 1993 to December 2005. Controlling for other potentially confounding factors, such as the number of production plants and demand, as well as possible retaliatory actions, we find that during the cartel period the transport distances between suppliers and customers were on average significantly lower than in the later period of competition. This provides empirical support for our theoretical finding that competing firms serve more distant customers in areas that are closer to their competitors' production sites. Moreover, we test the theoretical prediction that an increase in overcapacity increases transport distances, but only if firms compete. We provide empirical evidence for this result using variation in construction demand to compare different capacity levels relative to demand. We also find that the price variation is higher post cartel, which can be interpreted as supporting evidence that mixed strategy equilibria provide reasonable predictions for the mode of competition we observe in the cement industry.

Our theoretical results and empirical evidence point to an inefficiency that arises in case of spatial competition with capacity constraints, even if firms can price discriminate according to location. In case of industries with significant physical transport costs, like the cement industry, this cost inefficiency does not only reduce profits. The higher transport distances also cause environmental harm, for instance due to higher carbon dioxide emissions. Our empirical evidence indicates a transport inefficiency of about 30%, as measured in the average transport distance. This suggests that the organization of an industry can have a significant effect on environmental harm. According to the evidence, the harm depends on the level of excess capacities and the mode of competition. Moreover,

[2] See the Bundeskartellamt's press release "Bundeskartellamt imposes fines totalling 660 million Euro on companies in the cement sector on account of cartel agreements", April 14 2003, last accessed November 2017.

the literature has pointed out that cartels can lead to excess capacities. To the extent that this is the case, our finding that transport distances increase in the level of overcapacity points to a novel inefficiency caused by cartels, which materializes after the cartel has ended and firms compete again.

We continue with a discussion of the related literature in the next section and present the theoretical model in Section 3. In Section 4 we describe the German cement cartel, the data used for analysis and our empirical approach. In Section 5 we provide empirical evidence on the relationship between transport distances and the mode of competition using data of the cement industry in Germany. We also run various robustness checks to assess alternative explanations of the observed empirical patterns. We conclude in Section 6 where we relate our theoretical and empirical findings and discuss possible new empirical analyses for competition policy.

2 Related literature

This article contributes to several strands of the existing theoretical and empirical literature. There is a well-known literature based on Bertrand (1883) – Edgeworth (1925) that analyzes price competition in case of capacity constraints – and does so mostly for homogeneous products. A prominent example is Acemoglu et al. (2009). There are a few articles which introduce differentiation in the context of capacity constrained price competition, notably Canoy (1996); Sinitsyn (2007); Somogyi (2016); Boccard and Wauthy (2016). Canoy investigates the case of increasing marginal costs in a framework with differentiated products. However, he does not allow for customer specific costs and customer specific prices. Somogyi considers Bertrand-Edgeworth competition in case of substantial horizontal product differentiation in a standard Hotelling setting. Boccard and Wauthy focus on less strong product differentiation in a similar Hotelling setting as Somogyi. Whereas Somogyi finds a pure-strategy equilibria for all capacity levels, Boccard and Wauthy show that pure-strategy equilibria exist for small and large overcapacities, but only mixed-strategy equilibria for intermediate capacity levels. For some of these models equilibria with mixed-price strategies over a finite support exist (Boccard and Wauthy (2016); Sinitsyn (2007); Somogyi (2016)). This appears to be due to the combination of uniform prices and demand functions which, given the specified form of customer heterogeneity, give rise to interior local optima as best responses. Overall, these contributions appear to be mostly methodological and partly still preliminary. While these contributions are based on a Hotelling type framework, our approach can be summarized as introducing capacity constraints into a model of spatial competition in the spirit of Thisse and Vives (1988).

In our theoretical companion article Hunold and Muthers (2017) we consider a simplified model with only four customers to study price differentiation and subcontracting when firms compete. Different from that article, we contribute in the present article with a comparison between competition and coordination in a model with a continuum of customers, a general cost structure and comparative statics in the level of overcapacity. Additionally, we develop hypotheses and provide empirical evidence in their support by using a rich data set of the cement industry in Germany.

Another related theoretical literature is that on the efficiency of competition and cartels. Benoit and Krishna (1987) as well as Davidson and Deneckere (1990) have shown that in a dynamic game firms generally carry excess capacity in equilibrium in order to sustain higher collusive prices. Similarly, Fershtman and Gandal (1994) have shown that firms may build up excessive capacity in anticipation of a price cartel in which the rents are allocated in proportion to capacity shares. They have demonstrated that building capacities non-cooperatively can lead to lower profits in the subsequent price cartel, but may overall nevertheless decrease social welfare. Also in our model cartels may lead to inefficiently high capacity levels. However, our focus is different as we compare the spatial customer allocation in the cases of competition and coordination for given capacity levels. The derived insights can be used in competition policy to assess by means of market data on transport distances and customer allocations whether firms are competing or coordinating. As regards efficiency effects of cartels, Asker (2010) has analyzed a bidding cartel of stamp dealers and identified an inefficiency that stems from the coordination problem in the cartel which leads to overbidding. Overall, this strand of the literature points to additional inefficiencies caused by cartels. In contrast to this, we point out an inefficiency that arises when symmetric firms compete and do not coordinate their sales activities.

There are various economic studies of the cement industry which largely focus on investment behavior and environmental aspects (Salvo, 2010; Ryan, 2012; Miller et al., 2017; Perez-Saiz, 2015). More closely related is a study of the cement industry in the US Southwest from 1983 to 2003 by Miller and Osborne (2014). They use a structural model to analyze aggregate market data on annual regional sales and production quantities as well as revenues and argue that transport costs around $ 0.46 per ton-mile rationalize the data. In addition, Miller and Osborne find that isolated plants obtain higher ex-works prices[3] from nearby customers. Our study complements the study of Miller and Osborne as we can specifically test our theoretical predictions about transport distances by means of a rich customer data set that includes identified periods of collusion and competition.

The cement cartel in Germany which broke down in 2002 has been studied by various economists. Blum (2007) discusses the functioning and impact of the cartel in the eastern part of Germany. Friederiszick and Röller (2010) quantify the damage caused by the cartel

[3] This means prices net of transport costs.

due to elevated prices. A few other studies have also used parts of the transaction data which we use in the present article. Hüschelrath and Veith (2016) study pricing patterns during and after the cartel; Hüschelrath and Veith (2014) investigate the workability of cartel screening methods, and Harrington et al. (2015, 2016) investigate internal and external factors which might have destabilized the cartel.

Cement cartels in Finland, Norway and Poland have also been documented in the literature. Bejger (2011) report that the Polish cement firms fixed allocations according to historical shares. Regarding the legal Norwegian cement cartel, Röller and Steen (2006) report that the three firms decided to allocate the domestic market according to the capacity shares of the firms. Interestingly, this incentivized the firms to heavily invest in their capacity, leading to high overcapacity – in line with theoretical predictions of the theoretical literature discussed above. The Finnish cement cartel agreed on an allocation that apparently minimized transport cost (Hyytinen et al., 2014). We further discuss this point in Subsection 3.3.

3 Theoretical model

In this section we set up a spatial model where capacity constrained firms compete in prices. Firms are able to price discriminate and thus compete for each customer individually, while the optimal pricing for each location is linked through the common capacity constraint. We first study the competitive equilibria and then study the market outcome when firms coordinate their sales activities. Finally, we develop hypotheses about the relationship of the average transport distances and the mode of competition, which we test afterward in Section 4 with data of the cement industry. It is noteworthy that this model applies to various industries where capacity constraints and a form of spatial differentiation or adaption costs exist. Besides cement, these include other heavy building materials and commodities, but also specialized consulting services and customer specific intermediate products, as supplied for example to the automobile industry.

Setup

There are two symmetric firms. Firm L is located at the left end of a line, and firm R at the right end of this line. In between, customers of mass one are distributed uniformly. Each customer has unit demand and a valuation of v. Firms incur location specific transport costs $C(x)$, where x is the *distance* between firm and customer location on the line. Transportation costs are increasing in distance with $C(y) \geq C(x)$ for all $y > x$. Assuming $v > C(1)$ ensures that all customers are contestable.

Example. A simple form of costs that fulfills the above conditions are linear transport costs, as usually assumed in the Hotelling framework. Transport costs are captured by the parameter t with $C(x) = tx$. The above contestability assumption, $v > C(1)$, becomes $v > t$.

These costs could represent physical transport costs as, for example, in case of cement. In general, these costs could also be the costs for adapting a product, or service, to the needs and wishes of a customer. Interpreting costs as mainly adaption costs is suitable for example in industries where customer specific supplies are common, like in the supply chain of the automobile industry and in case of specialized consulting services.

Both firms have limited capacities. We focus on the symmetric case that each firm has a capacity of k, such that a mass k of customers can be served by each firm. If a firm has more demand than it can serve, efficient rationing takes place. We describe rationing in more detail below.

We assume that the firms are able to price discriminate by location. For the cement industry this is typically the case, as the price is set for each customer / construction site for which the location is typically known.[4] Formally the pricing of firm i is a function $p^i(x)$ of the distance x between firm and customer. Firms set prices (price functions) simultaneously. The resulting market allocation does not only depend on the prices, but also on capacities as a firm may be unable to serve all customers for which it has charged the lowest price with its capacity.

Rationing

Each customer attempts to buy from the firm with the lowest price if that price is not above the valuation of v. If more customers demand the good from a firm than it can serve, these customers are rationed such that consumer surplus is maximized. More precisely:

1. If one firm charges the lowest prices to more customers than it can serve with its capacity, we assume that the customers are allocated to firms such that the customers with the worst outside option are served first. In other words, this rationing rule maximizes consumer surplus.

2. If point 1. does not yield a unique allocation, the profit of the firm which has the binding capacity constraint is maximized (this essentially means cost minimization).

The employed rationing corresponds to efficient rationing (as, for instance, used by Kreps and Scheinkman (1983)) in that the customers with the highest willingness to pay are served first.[5] While this is not the only rationing rule possible, we consider this rule

[4] Note that due to customer specific pricing this model could be equivalently expressed in terms of customers bearing the transport costs und thus also interpreted as a model of product differentiation.

[5] A difference is, however, that the willingness to pay for the offers of one firm is endogenous in that it depends on the (higher) prices charged by the other firm. These may differ across customers, and so does the additional surplus for a customer from purchasing at the low-price firm.

appropriate for several reasons.[6] Arguably most important for the purpose of the present paper is that the rationing rule gears at achieving efficiencies, in particular for equilibria in which the firm's prices weakly increase in the costs of serving each customer. Our results of inefficiencies in the competitive equilibrium are thus particularly robust. For instance, in case of proportional rationing each firm would serve even the most distant (and thus highest cost) customer.

We solve the price game for Nash equilibria, taking the rationing rule into account. We focus on symmetric equilibria. We start by characterizing symmetric Nash equilibria for the case without capacity constraints. We then solve the symmetric mixed strategy Nash-equilibrium in differentiated prices when each firm has an intermediate level of capacity with $1 > k > 1/2$. Afterward, we consider the game when firms coordinate their sales activities.

3.1 Competition without capacity constraints

Suppose that each firm has capacity to serve all the customers. As a consequence, for each customer the two firms face Bertrand competition with asymmetric costs. It is thus an equilibrium in pure strategies that each firm sets the price for each customer equal to the highest marginal costs of the two firms for serving that customer, and that the customer buys the good from the firm with the lower marginal costs. This is again efficient in that all customers are served by the closest firm with the lowest transport costs. Each firm serves customers from its location up to the location of the customer at 0.5. The firms make the same profit, which for firm L is computed as $\int_0^{0.5} C(1-x) - C(x)dx$. Consumer surplus is given by $\int_0^1 \{v - \min[C(x), C(1-x)]\}\, dx$. We summarize the equilibrium characteristics in

Proposition 1. *If firms compete without capacity constraints, transport costs are minimized and each firm serves its closest customers up to a distance of* $1/2$*. Prices decrease from both ends of the unit line towards the center.*

3.2 Competition with capacity constraints

Non-existence of a pure strategy equilibrium

Suppose each firm can only serve at most k customers, with $0.5 < k < 1$, and both firms set prices as if there were no capacity constraints, as discussed in the previous subsection. Is this an equilibrium? For each firm, the candidate equilibrium prices charged to customers at a distance of more than 0.5 equal the firm's costs of supplying these customers (Bertrand

[6] See the theory paper Hunold and Muthers (2017) for a further discussion of rationing rules in a related model.

pricing with asymmetric costs). Hence, there is no incentive to undercut these prices. Similarly, there is no incentive to reduce the prices for the customers at a distance of less than 0.5 as these customers are already buying from the firm.

In view of the other firm's capacity constraint, the now potentially profitable deviation is to charge all those customers that the firm wants to serve the highest possible price, that is their valuation of v. All customers prefer to buy from the non-deviating firm at the lower prices which range between $C(1/2)$ and $C(1)$. However, as the non-deviating firm only has capacity to serve $k < 1$ customers, $1-k$ customers end up buying from the deviating firm at a price of v. Those $1-k$ customers are the customers closest to the deviating firm. When such a deviation is profitable, there is no pure strategy equilibrium. The profit of the deviating firm is $v \cdot (1-k) - \int_0^{1-k} C(x)dx$. This is larger than the pure strategy candidate profit[7] of $\int_0^{0.5} C(1-x) - C(x)dx$ if

$$\begin{aligned} v \cdot (1-k) - \int_0^{1-k} C(x)dx &> \int_0^{0.5} C(1-x) - C(x)dx \\ \Leftrightarrow v &> \frac{\int_{0.5}^1 C(x)dx - \int_{1-k}^{0.5} C(x)dx}{1-k} \equiv \tilde{v}. \end{aligned} \tag{1}$$

Lemma 1. *A pure strategy equilibrium does not exist if the valuation, v, is sufficiently large for a given cost structure $C(x)$ and (over)capacity level $k \in (0,5;1)$. A higher valuation of the product is necessary for the non-existence result if the costs of serving the home market are larger, if the difference in costs for intermediate customers is larger and if the capacity is larger.*

With linear costs t per unit of distance, as in the Hotelling framework, the latter condition for the non-existence of the pure strategy equilibrium reduces to

$$v > t\left[\frac{1}{4(1-k)} + \frac{1-k}{2}\right]. \tag{2}$$

The condition holds for sufficiently small transport costs.

Mixed strategy equilibria

We now focus on the case that $v > \tilde{v}$, such that no pure strategy equilibria exist and solve the price game for symmetric mixed strategy Nash equilibria. Such an equilibrium is defined by a symmetric pair of joint distribution functions over the prices of each firm. We proceed by first postulating that both firms play uniform prices and derive the

[7] There are, however, potentially equilibria with even lower prices, in which firms set prices below costs for customer that are closer to the competitor. We exclude those equilibria as it is usual in the literature in case of asymmetric Bertrand competition. In these cases, deviations to the high price level of v are even more profitable, and the range for the interesting mixed strategy equilibria is larger.

corresponding distribution functions. We later derive a parameter range in which firms indeed play uniform prices albeit they could charge different prices for each customer.

Proposition 2. *If firms are restricted to play uniform prices, in the symmetric mixed strategy equilibrium both firms play prices according to the atomless distribution function defined in 3 and mix over the interval* $\underline{p}$*, defined in* (4)*, to* v*. In equilibrium, almost surely either one of the two firms sets lower price than the other firm and serves customers up to its capacity limit, starting with the closest customers.*

Proof. If both firms play uniform price vectors, there cannot be mass points. Assume to the contrary that a firm would have a mass point in the symmetric equilibrium at any price. The best response of the other firm would be to put zero probability at that price. This contradicts symmetry and implies that in any symmetric equilibrium with uniform prices both firms play prices without mass points in a closed interval between the lowest price, denoted by $\underline{p}$, and the maximal price v. With uniform price vectors in the mixed strategy equilibrium, only two basic outcomes are possible: either one firm has the lowest price for all customers or both firms have identical prices. In the mixed strategy equilibrium, the later outcome does not occur almost surely as both firms play prices from atomless distributions and mix independently. The case that one firm offers a lower price to all customers is thus the outcome which occurs almost surely. In this case the capacity constraint of one firm is binding and the rationing rule determines the customer allocation. The efficient rationing rule ensures that the firm with the lower price serves its closest customers up to the customer at distance k, which equals the capacity limit of the firm. This is the case because there is a unit mass of customers uniformly distributed on the line. As a consequence, the mass of customers located up to a distance of x from a firm is just x.

Thus we can write the expected profit of a firm as a function of the price distribution chosen by the other firm. We do this exemplary for firm L:

$$\begin{aligned}\pi_L^e(p^L) &= \left(1 - F^R(p^L)\right)\int_0^k p^L - C(x)dx + F^R(p^L)\int_0^{1-k} p^L - C(x)dx \\ &= p^L k - \int_0^k C(x)dx + F^R(p^L)\left(-p^L(2k-1) + \int_{1-k}^k C(x)dx\right).\end{aligned}$$

As there are no mass points, the expected profit for each price p^L must be equal to the profit at a price of v, which is given by

$$\pi_L^e(v) = v \cdot (1-k) - \int_0^{1-k} C(x)dx.$$

We can derive the equilibrium distribution $F^R(p^L)$ for each price by equating $\pi_L^e(p^L) =$

$\pi_L^e(v)$, which is equivalent to

$$p^L k - \int_0^k C(x)dx + F^R(p^L)\left(-p^L(2k-1) + \int_{1-k}^k C(x)dx\right) = v\,(1-k) - \int_0^{1-k} C(x)dx,$$

and implies

$$F^R(p^L) = \frac{p^L k - v\,(1-k) - \int_{1-k}^k C(x)dx}{p^L(2k-1) - \int_{1-k}^k C(x)dx}. \tag{3}$$

The lowest price that will be played, $\underline{p}$, is the price that yields the same profit as $\pi_L^e(v)$ and is weakly below any price of firm R with probability of 1:

$$\underline{p} \cdot k - \int_0^k C(x)dx = v \cdot (1-k) - \int_0^{1-k} C(x)dx$$

$$\implies \underline{p} = \frac{v \cdot (1-k) + \int_{1-k}^k C(x)dx}{k}. \tag{4}$$

□

Let us now analyze how the average transport distance depends on the capacity in the market. There are two groups of customers in equilibrium. First, there are customers who are located in a distance of up to $(1-k)$ to a firm and will always be served by that firm. One may call these customers the "home market" of the nearest firm. Second, there are customers who are located in between at distances above $(1-k)$ to any of the firms; these customers are always served by the firm with the lowest price in equilibrium. One may call this group "intermediate customers". The size of the home markets is given by $2 \cdot (1-k)$ as each firm always serves the closest customers for which the other firm does not have capacity (that is $1-k$). The size of the the group of intermediate customers is the remainder of mass $2k-1$. The average transport distance for customers of the second group depends on the capacities of the more distant firm to each customer in the second group. Both firms have the lowest price with equal probability. The transport distance for a customer of the second group of intermediate customers is its average distance to the two firms. This average distance is 0.5 for any customer on the line between the two firms. The average transport distance across all customers is

$$2\int_0^{1-k} x \cdot dx + 0.5(1 - 2(1-k)) = 0.5 - k + k^2, \tag{5}$$

where the first term on the left hand side represents the average transport distance in the home market, and the second term the distance for the intermediate customers. The derivative with respect to k of the average distance is $-1 + 2k$, which is positive, as k is larger than $1/2$ by the assumption that each firm can serve more than half of the market, such that there is competition.

Proposition 3. *In the mixed strategy equilibrium (Proposition 2), the average transport distance increases in the level of overcapacity k.*

So far we have assumed that the firms (have to) set uniform prices across customers. We now derive necessary and sufficient conditions for the existence of an equilibrium with endogenously uniform prices when price discrimination is possible.

To check that uniform prices are indeed an equilibrium even if firms can price discriminate based on customer location, we derive the conditions for which the best-response to a uniform price function by the competitor is to also charge a uniform price to all customers. Consider that firm R plays uniform price functions according to the distribution function F_R stated in equation (3) above. The distribution function F_R is defined such that firm L is indifferent between all uniform prices on the support $[\underline{p}, v]$.

To prove that such an equilibrium exists, we proceed in two steps. We first show that a best response to uniform prices is a price function that weakly increases in distance. We then derive the condition under which the best weakly-increasing price function is a uniform price. One can show that the most critical price for an individual deviation from uniform prices is that for the most distant customer which a firm serves in equilibrium. From the perspective of firm L, this is the customer at location k. For this customer, firm L has the largest transport costs and thus the strongest incentive to deviate to higher prices. It turns out that the most critical deviation for firm L is to increase the lowest price $\underline{p}$ for the customers at a distance of k. Such a deviation is not profitable if

$$v \geq C(k) + \frac{\int_{1-k}^{k} C(k) - C(x)dx}{(1-k)^2}. \tag{6}$$

Overall, if condition (6) holds, there is a symmetric equilibrium in mixed uniform prices.

Proposition 4. *The symmetric mixed equilibrium in uniform prices exists even when firms can price discriminate if condition* (6) *holds, i.e., whenever for a given cost structure the valuation of the product is sufficiently high. The condition holds for a given valuation if the transport costs at the distance corresponding to the capacity limit of a firm, $C(k)$, are not too large compared to the transport costs for intermediate customers: $C(x)$ with $x \in (1-k, k)$.*

Proof. See Annex I. □

The proposition establishes that mixed strategy equilibria with endogenously uniform prices exist for a certain parameter range. Compared to standard models of competition where perfect price discrimination is feasible, a surprising consequence of the uncertainty in the mixed strategy equilibrium is that transport costs are not minimized when the firms compete. In equilibrium, almost certainly some of the intermediate customers are served by the more distant firm. These are either the customers left or right of the center. The size of this transport inefficiency increases in k (Proposition 3).

The full analysis of equilibria for the case that the above condition does not hold is beyond the scope of this article. In a less general setting with linear costs and only four customers, we have obtained a similar mixed strategy equilibrium with endogenously uniform prices in a certain parameter range, and increasing prices in the part of the parameter range where no pure strategy equilibria exist (Hunold and Muthers, 2017). In that setting, however, it is not possible to analyze how the average transport distance changes in the level of overcapacity. We conjecture that also in a more general setting with a continuum of customers and a general cost function, similar equilibria with strictly increasing prices exist. However, this is left for future research.

Nevertheless, the parameter range for which the equilibrium with uniform prices arises can be large. To see this, consider the case of linear transport costs, where the condition (6) for an equilibrium with endogenously uniform prices becomes

$$v \geq t\,\frac{1-2k+2k^3}{2(1-k)^2}. \tag{7}$$

For a given level of transport costs, recall that there is no pure strategy equilibrium if the valuation is sufficiently large. For linear transport costs, the relevant condition is (2). For overcapacity of up to approximately 25%, there is always a mixed strategy equilibrium with uniform prices, i.e. condition (7) holds if condition (2) holds.[8] For larger overcapacity, the uniform price equilibria only exist if the transport costs are not too large. For instance, for overcapacity of about 50%, the valuation must be at least twice as large as the costs for serving the most distant customer for which each firm has capacity.[9]

3.3 Market outcome when firms coordinate

If firms coordinate and maximize joint profits, they can achieve prices above the competitive level. Moreover, recall that the competitive equilibrium features strategic uncertainty when firms are capacity constrained. A result of this uncertainty is an inefficient allocation of suppliers and customers and thus too high transport cost. Reducing costs by minimizing transport distances is thus another motive for firms to coordinate.

A simple way to coordinate would be to agree on non-overlapping local markets that are exclusively served by one of the firms. In our model firms could agree to only serve customers that have a distance of less than 0.5 to the firm. This agreement minimizes transport costs. In that case each firm could simply charge the customers closest to its plant the monopoly price of v.

---

[8] This can be seen when setting the right hand sides of equations (7) and (2) equal and solving for k.

[9] Condition (7) reduces to $v \geq 2.75t$ for $k = 0.75$. The costs for serving the customer at the distance equal to the capacity limit are thus $0.75 \cdot t$, which yields that the valuation must be larger than 2.06 times the cost of serving that customer.

Let us now illustrate that the customer allocation which minimizes transport cost is also the allocation that maximizes the stability of a collusive agreement between the symmetric firms. Consider a collusive agreement that coordinates prices and customer allocation among firms in an infinitely repeated interaction with a common discount factor δ. For coordination to be stable, it is necessary that none of the coordinating firms has incentives to deviate from the coordinated strategy. In particular, if firms play trigger strategies, they will choose a punishment strategy in response to a deviation which yields profits for the deviating firm that are lower than the cooperative profit. Denote by π^C the collusive profit in each period, by π^D the profits of the deviating firm and by π^N the profit a deviating firm makes in the punishment phase. For stability of the collusive agreement, the present value of cooperation must be higher than the present value of deviation, which is the sum of the deviation profit (π^D) and the discounted present value of the profits in the punishment phase (π^N). Note that π^N is defined by the punishment strategy, which could be Nash reversal, i.e., playing the competitive equilibrium of the stage game. The important point is that π^N is independent of how customers are allocated when coordination is successful. What matters is that the punishment profit π^N is lower than the coordination profit π^C such that when firms care sufficiently about future profits, coordination is stable. The stability condition can be formally expressed as

$$\pi^C \frac{1}{1-\delta} \geq \pi^D + \frac{\delta}{1-\delta}\pi^N. \tag{8}$$

The allocation of customers when firms coordinate affects π^C. For a given uniform price level p, choosing an allocation that reduces transport costs increases the coordinated profit π^C. In particular, if a firm serves the closest and thus lowest cost customers under coordination, the symmetric coordination profit π^C per firm is maximized. In contrast, the deviation profit π^D is essentially unaffected by the customer allocation as a deviating firm can marginally underbid the collusive prices of exactly those customers which it wants to serve. For a uniform collusive price level, these are the customers for which it has the lowest transport costs, which are its closest customers. In summary, minimizing transport costs increases the collusive profits and has essentially no effect on the punishment profits. This means that improving the collusive customer allocation facilitates cooperation as it increases the range of discount factors which satisfy the incentive compatibility condition (8).

For example, consider the German cement cartel where indeed a local market delineation was observed. We discuss the case in more detail in Section 4.1. As regards the former legal cement cartel in Finland, Hyytinen et al. (2014) report that the allocation was based on territories which minimized the transport costs. The central plant supplied the center and north-centric region by rail, while the remaining plants, which were located at the coast, supplied the east and western parts of Finland.

Finally, let us point out that the effect of a change in the level of overcapacity differs between coordination and competition. Note that optimal coordination among symmetric firms implies that the market is split in half, this is independent of the level of capacity relative to demand. In contrast, the average transport distance of the competitive equilibrium depends on the level of overcapacity ($1 > k > 0.5$). Whereas the average transport distance is 0.25 in case of successful coordination, we know from (5) that it is $0.5 - k + k^2$ in the competitive mixed strategy equilibrium, and thus increases in the degree of overcapacity (recall that $k > 0.5$). Compared to successful coordination, the average transport distance is larger by $0.25 - k + k^2$ with competition. This difference is 0 for $k = 0.5$ and increases in k. For a sufficiently large degree of overcapacity, there is again a pure strategy equilibrium with marginal cost pricing where transport distances are minimized. We summarize in

Corollary 1. *If there is no pure strategy equilibrium under competition (Condition* (1) *holds), the average transport distance is larger if firms compete than under coordination. The average transport distance increases in the level of overcapacity k under competition, but does not change under coordination.*

3.4 Hypotheses for the empirical analysis

Our theory provides a clear and distinct empirical prediction for the sales pattern in an industry with coordination compared to competition. In case of overcapacity the average transport distance in case of competition between firms is higher than if firms coordinate – as in case of a cartel. Moreover, if firms compete, the average transport distance increases in the level of overcapacity. The economic intuition for this is that mis-coordination is worse if each firm has larger capacities. With larger capacities, even more inefficient allocations of customers to firms materialize as, in addition to its close-by customers, each firm is able to serve a larger number of more distant customers with higher transport costs. Note that our model does not predict excess transport distances if capacities are very limited or abundant.

If firms coordinate, they have incentives to minimize transport costs. This might be achieved by agreeing to allocate customers to firms based on location and transport distances. For instance, one strategy of the cement cartel in Germany was that firms focus on their customer bases and avoid "advancing" competition for customers of other firms (see Subsection 4.1). As a prediction for the empirical analysis, we thus expect that a cartel is associated with lower transport distances and that in case of a cartel there is no effect (or at least a lower effect) of an increase in overcapacity on the way markets are shared and thus on transport patterns.

In summary, our theory yields the following hypotheses. *In an industry with capacity constraints, but overall excess capacity and spatial competition:*

H1. *The average transport distance is larger if there is competition instead of coordinated firm behavior.*

H2. *An increase in demand for a given level of capacity decreases the average transport distance if firms compete, but has no effect on the average transport distance if firms coordinate.*

The theoretical predictions could be used as a guide for analyzing market data with respect to the prevalence of coordinated firm behavior. To test our hypotheses for their empirical relevance, we continue with an econometric analysis of the cement industry in Germany, which has a verified period of cartelization.

4 Empirical setup

We now test the hypotheses developed in the previous section, in particular how the average transport distance depends on whether firms compete or coordinate their sales, and how the transport distance depend on regional variation in capacity utilization. For this, we use data of cement customers in Germany in the years 1993 to 2005. We exploit variations in supply and demand as well as the fact that there was a cement cartel in Germany until 2002, which broke down for reasons that are exogenous to the cement market in Germany, as we explain below. We start with a description of the cement industry in Germany which shows that the industry fits our model well because of its significant transport costs, customer specific pricing, and industry wide overcapacity (4.1). Subsequently, we present the data set in Subsection 4.2 and describe the econometric model.

4.1 Background

The cement industry. Cement is a substance that sets and hardens independently, and can bind other materials together. The most common use for cement is in the production of concrete. The costs of transporting cement from the production plant to the customer location are a significant fraction of the overall cement production costs.[10]

The cement production consists of essentially two stages. The first is heating of lime stone to produce clinker and the second consists of grinding and mixing with other materials to produce cement. The capacity is limited by several factors, in particular the capacity of clinker kilns, which constitute costly long term investments. Demand for

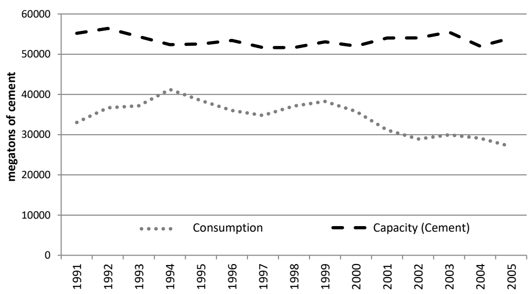
[10] Friederiszick and Röller (2002) report that the cost of transporting cement by truck over a distance of 100km (approx. 62 miles) amount to more than 20 percent of production cost. See Subsection 5.2 for a more detailed discussion of transport costs.

cement largely depends on the demand of the construction industry, which tends to be volatile and largely exogenous to the cement price. Substantial excess cement production capacity existed in Germany since the beginning of the 1980s when the capacity utilization declined from 85 percent to 50 percent within five years (see Friederiszick and Röller (2002)). Domestic cement consumption increased in the early 1990s – driven by a construction boom after the reunification of Germany in 1990. However, the boom was rather short lived and the cement capacity remained at a high level (cf Figure 1). As a consequence, the average utilization rate during the 1990's remained at levels below 70 percent (Friederiszick and Röller (2002)).

The cement cartel. Let us now explain how the cartel was organized and how it broke down. At least since the early 1990s, the largest six cement companies in Germany – Dyckerhoff, HeidelbergCement, Lafarge Zement, Readymix, Schwenk Zement and Holcim (Deutschland) – were involved in a cartel agreement that divided up the German cement market by a regional quota system. The 'backbone' of the cartel was the division of Germany into four large regions: North, South, West and East. For every region, one market leader was nominated. The quota system was partially applied to smaller subregions within the four major regions.[11] The cement producers also discussed to avoid "advancing competition", but rather focus on established market shares and customer bases.[12] This is consistent with our theoretical predictions of cartel behavior in such an industry, according to which each producer serves the customers for which it has the lowest costs.

To understand how the cartel broke down, it is important to understand previous changes of the cement producer Readymix. Readymix had not only been a member of

Figure 1: Cement capacity, production, demand and capacity utilization



Source: German Cement Association,
Friederiszick and Röller (2002) and own calculations.

11 For further information on the German cement cartel, see for instance Blum (2007); Friederiszick and Röller (2010); Hüschelrath and Veith (2016); Hüschelrath and Veith (2014).

12 See the judgment VI-2a Kart 2 – 6/08, 6 June 2009 of the higher regional court (OLG) Düsseldorf, par 130 and 131.

the cement cartel in Germany, but was also part of a cartel in the concrete market. This cartel was reported by an insider in 1999, which subsequently led the German competition authority to charge 69 firms fines totaling 370 million Deutsche Mark (189.19 million Euros).[13] Readymix received by far the largest fine of about 100 million Deutsche Mark.[14] Readymix was part of the the RMC group, which is a multinational building materials producer headquartered in the United Kingdom. Possibly in reaction to the large fines and the recently introduced leniency programs, RMC announced a new corporate policy in its annual report of 2000/2001:[15]

"A strengthened competition law compliance policy was introduced across the Group in 1999. Under the policy, relevant employees in each country receive guidance and training and are required to confirm compliance with the policy. The policy is monitored at Group level through a combination of reporting requirements and internal audits. The Group is now taking further extensive measures to reinforce its compliance procedures including a programme of more frequent internal audit reviews supervised by the Executive Committee of the Board. The Board notes the recent investigations by the competition authorities in Germany into the concrete business in some specific local markets. The compliance policy in place, as reinforced by the further measures, is intended to prevent any anti-competitive activities in the Group occurring in the future."

This announcement was also accompanied by changes in the German subsidiary Readymix, which aimed at ending involvements in cartels. For instance, Readymix mandated an internal study about current involvements in anti-competitive conduct in the fall of 2001.[16] In addition, a new CEO of Readymix took over in 2002.[17]

According to testimony in the public case, Readymix declared its exit from all cartel agreements to the other cement producers in Germany in the end of 2001. In early 2002, Readymix started to supply its own concrete plants in the south of Germany with its own cement produced in Rüdersdorf. As a consequence, Heidelberg and Schwenk were not able to sell sizeable quantities in the south anymore. This fostered the cartel breakdown and led to a strong price decrease.[18]

In May 2002, the German competition authority opened a cartel investigation of the cement market. In July 2002, Readymix started cooperating with the authority in exchange for a relatively low fine. This was possible due to the change in the year 2000 when the German competition authority introduced a corporate leniency program which

[13] See "Verbrechen lohnt sich nicht", ManagerMagazin, May 5th 2001, (last accessed November 2017).
[14] See Rekordstrafe gegen Betonkartell, Der Spiegel, November 3rd, 1999, (last accessed November 2017).
[15] See RMC Annual Report 2001, available at Investis.com Reports, (last accessed November 2017).
[16] See judgment VI-2a Kart 2 – 6/08, 6 June 2009 of the higher regional court (OLG) Düsseldorf, p.31.
[17] See Readymix Webpage (In the WebArchive), (last accessed November 2017).
[18] See judgment VI-2a Kart 2 – 6/08, 6 June 2009 of the higher regional court (OLG) Düsseldorf, p. 209.

rewards cartel members that contribute to uncovering a cartel with reduced fines.[19]

4.2 Data set and descriptive statistics

The raw data was collected by the Brussels-based law firm Cartel Damage Claims (CDC). The data consists of about 500,000 market transactions from 36 smaller and larger customers of German cement producers from January 1993 to December 2005. The market transaction data is based on customer bills and includes information on product types, dates of purchases, delivered quantities, cancellations, rebates, early payment discounts, free-of-charge deliveries as well as locations of the cement plants and unloading points. We added information on all cement plants located in Germany and near the German border in neighboring countries. The data contains 220 unloading points of the 36 customers, which are either permanent (such as a concrete plant) or temporary (such as a construction site).[20] For each of these unloading points, we calculated the number of plants and independent cement producers located within a radius of 150 km road distance in each year. This yields measures of local supply concentration. Based on the geographical information for both cement plants and unloading points, we also calculated the road distances for all possible plant-unloading-point relations. As the unit of observation we employ the aggregate cement shipments to an unloading point of a customer in a year. In certain cases this involves the aggregation of shipments from different plants to this unloading point.[21] We restrict our analysis to one specific cement type called 'CEM I' (Standard Portland Cement) which accounts for almost 80 percent of all available transactions. We account only for shipments from German plants.[22] This leaves us with almost 1,300 observations at the customer - unloading-point - year level, around 1,700 if we account for the delivering plant additionally, and around 2,000 if we account for the cement type.

Table 1 shows descriptive statistics of the data set. The "cartel period" includes January 1993 to February 2002 and the "post cartel period" includes March 2002 to December 2005.[23] The indicator *post cartel* (PC) is defined accordingly.

The demise of the cartel was clearly associated with a strong decrease in prices. According to our data, the price during the cartel period was 71 Euros (2005 value including transport), while in the period after it fell to 50 Euros. For a specific unloading point and cement type, we calculated the variation coefficient of the annual average prices across

[19] See Leniency Programme of the German competition authority, (last accessed November 2017).

[20] Unloading points are defined on the ZIP code level.

[21] In 63% of the observations the deliveries came from one plant only, and in only 20 percent of the other cases the quantity share of the biggest supplier was below 80 percent. In case of multiple plants, we computed the quantity-weighted average.

[22] This restriction is done as production cost is more comparable inside Germany. Shipments within Germany account in our data set for more than 94 percent of the sold CEM I quantity.

[23] We split the shipments in the year 2002 in separate observations for the cartel and post cartel period.

suppliers. One can clearly see that when reverting to competition, the variation of prices increased. Table 1 also shows that freight costs per ton and per ton-km did not change substantially between the periods. The freight costs per ton-km were even higher in the post cartel period.

Table 1: Descriptive statistics

	Cartel period		Post Cartel Period		Overall	
Post Cartel (PC)	0.00	(0.00)	1.00	(0.00)	0.22	(0.42)
Outcomes						
Price (FOB, 2005) €	70.96	(11.13)	49.64	(14.45)	66.26	(14.86)
Variation coefficient	0.04	(0.17)	0.71	(4.78)	0.19	(2.27)
Freight cost (p.t. 2005) €	8.05	(3.88)	7.70	(4.38)	7.98	(3.99)
Freight cost (p.t.km. 2005) €	0.13	(0.19)	0.14	(0.32)	0.13	(0.23)
Distance measures						
Shipment distance (km)	91.43	(58.06)	122.89	(103.48)	98.44	(71.95)
Rank supplying plant	3.31	(2.84)	5.52	(7.12)	3.80	(4.29)
Customer size (year)	0.09	(0.10)	0.15	(0.18)	0.11	(0.12)
Demand and market structure						
Constr. employment	94.11	(8.78)	79.84	(14.70)	90.22	(12.46)
Plants in 150km	7.39	(5.00)	7.09	(4.49)	7.33	(4.90)
HHI (0-100)	28.68	(15.29)	31.17	(16.93)	29.23	(15.70)
Distance nearest plant	53.89	(33.66)	51.51	(33.26)	53.36	(33.58)
RMC plant in 150km	0.28	(0.45)	0.26	(0.44)	0.27	(0.45)
Other controls						
East	0.25	(0.43)	0.27	(0.44)	0.25	(0.44)
West	0.32	(0.47)	0.27	(0.45)	0.31	(0.46)
North	0.09	(0.29)	0.07	(0.25)	0.09	(0.28)
South	0.34	(0.47)	0.39	(0.49)	0.35	(0.48)
Cement consistency 32.5	0.30	(0.46)	0.38	(0.49)	0.32	(0.47)
Cement consistency 42.5	0.66	(0.47)	0.54	(0.50)	0.63	(0.48)
Cement consistency 52.5	0.04	(0.20)	0.08	(0.27)	0.05	(0.22)
Observations	1471		574		2045	

Note: Quantity-weighted averages. In the table the number of observations refers to the aggregates at the annual, customer-unloading point, and cement type level. A different number of observations occurs in analyses at different aggregation levels.

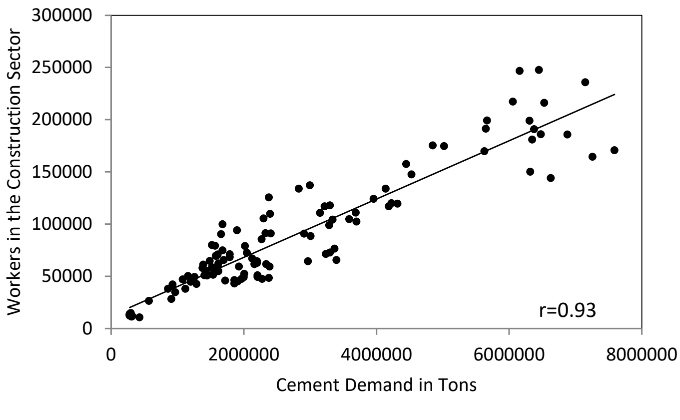
In order to capture changes in supply relationships, we calculate the average shipment distance (in road km) between the supplying cement plant and the customer's unloading point for each year. Table 1 shows that in the period after the cartel broke down the average transport distance is almost 30km higher. As the distance can fluctuate due to changes in the positions of both unloading points and customers, we also calculate the rank of the delivering plant relative to the unloading point: the plant nearest to the unloading point has rank 1, the second nearest rank 2 etc. Similar to the distance, also the rank is higher in the period after the cartel broke down.

To control for the size of the customers, we calculate the total quantity shipped to the respective customer by aggregating across purchases of all cement types and locations.

The average of this variable in the data set is 106,330 tons thousand tons per year.[24]

In terms of the development of capacity utilization, plant level data is unfortunately unavailable. However, the clinker kiln capacity is relatively constant during the observation period and, with clinker being the most important cement input, this capacity is crucial for the cement production capacity. Based on this insight, our approach has two elements: We control for the number of cement plants located around an unloading point in 150km road distance and approximate variations in capacity utilization by variations in the local cement demand in the county of the unloading point in a given year.[25] We use the the local number of workers in the construction industry as a proxy variable for local demand because we do not have data on cement consumption at a local level. This information is available from 1996 onward. As evidence of a strong empirical relationship between cement consumption and the number of workers in construction, we provide a scatter plot for the most disaggregated data available which is at the level of German states (Bundesländer). One can see the yearly cement consumption and the number of workers in construction are highly correlated, with a correlation coefficient of 0.93 (Figure 2).

Figure 2: Cement consumption and construction employment for German Bundesländer 1993-2005



Sources: German Statistical Office,
Regional Statistical Offices and own calculations.

In order to eliminate county size effects, we normalize the number of workers by the respective value in 1996 and multiply it by 100. While during the years 1996 and 2001 the number of workers were on average at 94 percent of the level of 1996, the respective mean after the cartel break down is 80 percent. There is substantial variation reflected

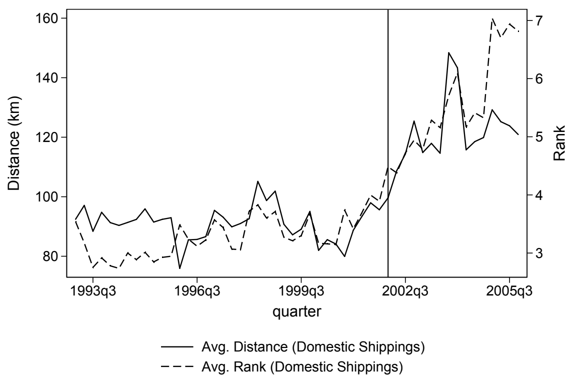
[24] As some of the 36 customers have several unloading points, they appear more often within one year in the data set. The reported average therefore has an upward bias. Taking into account every customer only once for each year, the average is 31,461 thousand tons per year.

[25] County refers to a German "Landkreise und kreisfreie Städte", which corresponds to the NUTS3-level.

by the high standard deviation of 12 percent.

We account for differences in the regional supply structure by including the number of cement plants and a plant-based HHI for a radius of 150 km road distance around the customers' unloading points. The HHI is defined as the sum of squared share of plants by distinct owners and is thus a measure of ownership concentration.[26] The number of cement plants around the unloading points after the cartel breakdown is by 0.3 lower while the HHI increased by less than 3% (note, however, that the locations of unloading points also vary over time, for instance, this is the case for some construction sites). It is interesting to note that the minimum between an unloading point and the nearest cement plant decreased from on average about 54 to 52 km. Other things equal, this suggests that distances should have rather decreased than increased. As a robustness check, we will investigate how the presence of a plant belonging to the cement supplier Readymix AG (RMC group) that deviated from the cartel affected the average transport distance in the area. For this we use the indicator RMC which takes on the value of one if a plant of this supplier is within 150km distance of the unloading point (which is the case in 27 percent of the cases), and is zero otherwise.[27] Finally, the location of the unloading point within Germany is captured by the indicators East, West, North, South and we can distinguish the cement consistency, of which 42.5 is the most frequent throughout.[28]

Figure 3: Average distance from unloading point to cement plant and rank of plant



As an initial examination of distances during and after the cartel, Figure 3 plots the average distance and rank of all (quantity weighted) shipments from domestic plants.

26 For example, if there are two plants of owner A and one plant of owner B in the area, the HHI – normalized to the range 0 to 100 – equals $100 \cdot \left[(2/3)^2 + (1/3)^2\right] = 100 \cdot [4/9 + 1/9] = 100 \cdot 5/9$.

27 This is to rule out that higher distances in the years after the cartel break down are caused by extraordinary retaliation measures against the deviating producer, which could consist of other producers shipping cement over long distances into the "home markets" of the non-compliant cartel member.

28 Regions are defined in the same way as it had been done by the colluding cement producers in Germany, see judgment VI-2a Kart 2 – 6/08, 6 June 2009 of the higher regional court (OLG) Düsseldorf.

Please note that the average distance and rank do not differ much in their development over time, suggesting that changes in the position of unloading points or closures of cement plants are unlikely to drive the results. The figure also shows that both average distance and rank were rather stable while there was a cartel but increased substantially after the cartel breakdown.

As later analysis will reveal, the post cartel increase in the transport distances is robust to taking account of changes in the local market structure. However, we will see that there is a more nuanced post cartel relationship between the transport distances and local capacity utilization, as measured by our demand proxy.

4.3 Empirical model and identification

In order to identify the effects of the mode of competition and the level overcapacity on the average transport distances in the cement market, we estimate the linear model:

$$y_{c,u,t} = \beta_1' X_{c,u,t} + \beta_2 post\,cartel_t + \beta_3 post\,cartel_t \cdot Z_{c,u,t} + \varepsilon_u + \epsilon_{c,u,t}. \tag{9}$$

We use two different specifications of the dependent variable $y_{c,u,t}$: The distance between the delivering cement plant and the unloading point of the customer as well as the rank of the delivering plant (with the plant closest to the customer or its delivery point having rank 1).[29] We use these two specifications for robustness, where we consider the rank to be more robust to location changes on the supply or demand side. Subscript c is an index for the customers, u for the unloading point and t for the year. Recall that we aggregate the billing data on a client-unloading-point-year basis.[30] Vector X includes characteristics of the (customer-related) unloading points and their surrounding market structure. *Post cartel* (PC) is an indicator with value 1 if the delivery was invoiced after the cartel breakdown in February 2002. Vector Z consists of market structure variables which we interact with the *post cartel* (PC) indicator to test whether the impact of these factors on the distance (or rank) changes with the cartel breakdown. Finally, we eliminate local time-constant unobserved heterogeneity by the inclusion of unloading points fixed effects ε_u. The standard errors are clustered at the unloading point level and robust to heteroscedasticity.

Our approach relies on using variation over time in the transport distance, the degree of overcapacity and whether there is a cartel. To rule out that unobserved heterogeneity between unloading points is driving the result, we do not only employ unloading point

[29] In case of shipments from multiple plants in the same year we use the quantity-weighted average rank.

[30] We consider this to be essentially without loss of precision as our controls are also observed on a year - unloading point basis. We aggregate invoices received before and after the cartel breakdown in February 2002 to separate observations.

fixed effects, but also we control for the number of plants in the neighborhood of this unloading point and the ownership concentration.This rules out that a smaller number of plants, for instance due to closures after the cartel breakdown, is driving the result. In the same vein, we also estimate the same model for the plant "rank" as this is more robust to a decrease in the number of plants (which might affect the average distance).

Endogeneity of the cartel breakdown is not a concern. As argued in Subsection 4.1, the cartel broke down due to a change in the business policy of the parent company of a cartel member, as a reaction to a different cartel case in a different product market. Additionally, the introduction of the German leniency program in the year 2000 arguably made continuing with the cartel less attractive. We therefore do not expect that other unobserved particularities in local market structures are driving the result.[31]

5 Estimation results

5.1 Main results

Table 2 contains the main regression results for both dependent variables, the distance in km between the unloading point and the delivering plant as well as the rank of the delivering plant (with the plant closest to the unloading point having rank one). The significantly positive coefficient of the *post cartel* (PC) indicator confirms that both the distance to the delivering plant and its rank are higher after the cartel breakdown.

A higher ownership concentration (HHI) of the cement plants around the unloading point is associated with a lower transport distance. Recall that the HHI measures the ownership concentration of the nearby cement plants. A possible explanation for the negative correlation with transport distance is that an owner of several plants can achieve lower transport distances by coordinating sales to customers in the area across the plants. The partial correlations of distance with the number of plants in 150km distance as well as with the customer size are not significantly different from zero.

We further analyze the time structure of the post cartel effect with the specifications in columns 2 and 4. We find no increase in rank and distance in the year before the breakdown while there is indeed a slight increase in the year the cartel ended. We observe the strongest effect in terms of magnitude and significance in the years after the breakdown. This is an indication that the rise in distances is not related to just a short-run fight of suppliers for new customers, but rather a non-transitory feature of competition.

Overall, the theoretical and empirical results point to an inefficiency that arises if firms compete with spatial differentiation and overcapacity. The cost increase can be approximately quantified as we have estimates for both the additional distance in kilometers

[31] Another reason for a deviation could be that the supply and demand balance had changed. In any case, we do control for supply and demand in our regressions (see Table 3).

Table 2: Main regression results

	Distance		Rank	
	(1)	(2)	(3)	(4)
Plants in 150km	-0.40	0.84	0.04	0.12
	(-0.10)	(0.21)	(0.14)	(0.43)
HHI (0-100)	-0.67**	-0.71**	-0.03**	-0.03**
	(-2.04)	(-2.10)	(-2.54)	(-2.48)
Customer size (year)	20.53	7.64	-2.30	-3.12
	(0.59)	(0.22)	(-1.06)	(-1.39)
Post Cartel (PC)	26.94***		1.73**	
	(3.47)		(2.56)	
Year before cartel collapse (2001)		1.02		0.06
		(0.31)		(0.23)
Year of cartel collapse (2002)		9.56*		1.08**
		(1.87)		(2.36)
Years after cartel collapse		35.17***		2.16***
		(3.63)		(2.72)
Obs.	1312	1312	1312	1312
R^2	0.63	0.63	0.49	0.49
Within R^2	0.06	0.07	0.04	0.04

t statistics in parentheses
Standard Errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. Regressions include fixed effects at the zip code level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

and the transport cost per km. As can be seen in Table 2, the point estimate for the additional transport distance under competition is close to 27km (ca. 19 miles, within a confidence interval of about 12 to 42km). Based on various sources, we consider it likely that the typical marginal transport costs per ton-km for the typical shipping by truck are in the range of 4 to 20 cents to be plausible.[32] The additional transport costs are therefore likely in the range of about 1 to 5 Euros. For comparison, estimates for the overcharge of cement customers due to the cement cartel captured in our data set are in the order of 15 Euros,[33] with average cement prices during the cartel of about 78 Euros.[34] The cartel overcharge is therefore higher than the associated transport cost inefficiency. At the same time it is noteworthy that the estimated additional average transport distance in case of competition is substantial and implies a waste of resources.

We now test the second hypothesis according to which an increase in demand for a

32 See Subsection 5.2 for details.

33 The estimate of Hüschelrath et al. (2016) is obtained with fixed effects regressions and expressed in terms of 2010 prices.

34 This is the quantity-weighted average of transaction prices during the cartel period in terms of 2010 prices according to our data. We did not control for different cement types and differences across regions.

Table 3: Regression results with demand proxy

	Distance			Rank		
	(1)	(2)	(3)	(4)	(5)	(6)
Plants in 150km	-7.44	-6.05	-6.80	-0.49	-0.39	-0.42
	(-1.54)	(-1.27)	(-1.45)	(-1.56)	(-1.25)	(-1.34)
HHI (0-100)	-1.35***	-1.31***	-1.13***	-0.06***	-0.06***	-0.05**
	(-3.79)	(-3.75)	(-3.29)	(-2.95)	(-2.89)	(-2.49)
Customer size (year)	62.46	43.32	38.26	-1.38	-2.80	-2.99
	(1.36)	(0.95)	(0.86)	(-0.51)	(-1.02)	(-1.10)
Post Cartel (PC)	31.58***	24.88***	179.43***	1.83**	1.33*	7.20**
	(3.53)	(3.04)	(3.15)	(2.30)	(1.67)	(2.58)
Constr. employment		-0.60	0.41		-0.04**	-0.01
		(-1.61)	(1.41)		(-2.29)	(-0.34)
PC*(Constr. Employment)			-1.77***			-0.07**
			(-2.82)			(-2.27)
Obs.	938	938	938	938	938	938
R^2	0.59	0.60	0.61	0.45	0.46	0.46
Within R^2	0.09	0.10	0.13	0.05	0.05	0.06

t statistics in parentheses
Standard Errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. Regressions include fixed effects at the zip code level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

given level of capacity decreases the average transport distance if firms compete, but has no effect on the average transport distance if firms coordinate. For this, we include in Table 3 the number of construction workers as our proxy variable for demand. As we control for the number of plants around a customer and given that the overall cement capacity does not vary much in our observation period, this variable serves as a proxy for capacity utilization: More demand corresponds to a higher level of capacity utilization. As mentioned before, this data is only available from 1996 on. To make findings comparable to prior results, we report the same specifications as in Table 2 in column (1) and (4) for the restricted data set and do not find qualitative differences. In columns (2) and (5) we include the proxy variable for demand and thus capacity utilization. With respect to the transport distance we do not find an effect that is significant at common confidence levels. We then allow for different relationships between demand and transport distance in the cartel and post cartel periods. For this we introduce an interaction term in columns (3) and (6). One can see that the *post cartel* (PC) indicator is still positively significant. However, there is no statistically significant relationship between capacity utilization (proxied with constr. employment) and the average transport distance during the cartel. Instead, the coefficient of the interaction term *post cartel* (PC) and capacity utilization (constr. employment) is significantly negative. This shows that when firms compete (post cartel), the average transport distance decreases as the capacity utilization increases. In line with the second hypothesis, the relationship between transport distance and capacity utilization is only negative when there is a cartel. When there is less overcapacity (and thus a higher level of capacity utilization), competition is less chaotic and the allocation of customers to suppliers is more efficient, while an efficient cartel simply minimizes the transport distance.

In summary, the results point to an increase in transport distance caused by competition which is in line with our theoretical analysis that predicts a somewhat chaotic form of competition. The prediction that a relative increase in capacity increases transport distances is supported by the data using a proxy for local and intertemporal demand variation as an indirect measure of capacity utilization. In the next subsections we provide further analyses to exclude alternative explanations.

5.2 Transport costs

One might be concerned that higher transport distances in the period starting in 2002 could be due to lower marginal costs of transport and not (only) the cartel breakdown. However, we do not observe a decrease in transport costs in these years. To see this, we first study the transport costs as stated in the customer bills. As the transport costs indicated in the customer bills might differ from the actual costs and thus results should be taken with a grain of salt, we also study a diesel price index of the German statistical office.

We aggregate the billing data annually at the unloading point - production plant level and deflate it to the year 2005. We then regress this measure of per-ton transport cost in various ways. The results are in Table 4. In columns (1) to (3), we include fixed effects of the customer unloading point (zip code) and the cement production plants. This allows to control for time-constant differences of unloading-point or plant-specific fixed costs of transport, such as the simplicity of loading and unloading. Across all three specifications, there is no indication that the deflated marginal transport costs were lower post cartel (see the virtually zero coefficients of the interaction terms of post cartel and distance, both in the linear and quadratic specifications). In column (4) we include relation specific fixed effects, with a relation being the combination of production point and unloading point. This lets us compare the total transport cost for the same supply relation over time.[35] Also here, one cannot observe a statistically significant decrease in relation specific transport costs post cartel.

[35] Note that as the distance between production plants and unloading point of customer does not change over time, the distance regressor is omitted here.

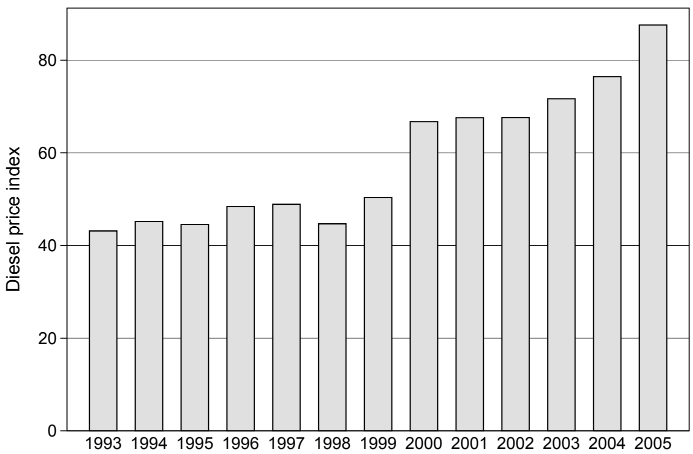
Table 4: Robustness check: Transport cost

	Zip and Plant FE			Relation FE
	(1)	(2)	(3)	(4)
	All	Only <150km	All	All
Ordered Quantity	-0.02	0.01	-0.02	-0.00
	(-1.38)	(0.79)	(-1.19)	(-0.29)
Post Cartel (PC)	-0.89*	-0.48*	-0.74*	-0.34
	(-1.68)	(-1.89)	(-1.67)	(-1.62)
Shipment distance (km)	0.02***	0.04***	0.05***	
	(2.78)	(7.04)	(7.11)	
PC*(Ship. dist.(km))	0.00	0.00	0.00	
	(0.85)	(0.71)	(0.27)	
Shipment distance (km) - squared			-0.00***	
			(-4.10)	
PC*(Ship. dist.(km) - squared)			0.00	
			(0.33)	
Obs.	1672	1199	1672	1669
R^2	0.68	0.79	0.70	0.83
Within R^2	0.11	0.08	0.17	0.00

t statistics in parentheses
Standard Errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. Regressions include fixed effects at the client zip code and plant level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As most cement in Germany is shipped by truck, the diesel price is an important, and at the same time possibly volatile, part of the marginal costs of transporting cement. Consistent with the previous regression results, the times series of the diesel price in Germany does not exhibit a drop in the post cartel period, but instead increases monotonically over the years since 1998 (Figure 4). In summary, we do not find support for the alternative explanation that higher transport distances are caused by lower transport costs.

Figure 4: Diesel price index



Source: German Statistical Office

The positive and significant coefficients of the distance measures indicate positive marginal transport costs. For large distances it is plausible that the cement was shipped by train or ship, as this is often more economical, and these large values can drive the ordinary least square results. Pooling all observations therefore leads to lower marginal cost estimates (as can be seen in column (1) and column (3) with the negative coefficient on the quadratic distance term). We find significantly higher marginal transport costs when including only the observations with transport distances below 150 in the regression (column (2)). For these observations the truck is the likely means of transport.[36] Compared to the results of column (1), we consider these estimates of 0.04 Euro-cents in 2005 prices as more plausible measure for the typical transport distance observed in the data – the average distance is approximately 100km (Table 1). Still, the estimates are about half the size of those we obtained from an older industry study. More precisely, Friederiszick and Röller (2002) report incremental freight costs of 0.16 Deutsche Mark per ton-km.[37] This amounts to about 0.10 Euro (in prices of 2010), which is broadly in line with our back-of-the-envelope calculations for a 27 ton silo truck where we consider the costs for a driver, diesel and truck abrasion. Potential reasons for the lower estimates obtained from the billing data are incomplete reports of transport costs as a separate item in the bills, wrong allocations of costs across the items cement price and freight costs, as well as our imprecise measures of distance on the right hand side (attenuation bias).

It is interesting that Miller and Osborne (2014) obtain relatively high transportation cost estimates of around $0.46 per tonne-mile by means of a structural model which uses aggregate market data on annual regional sales and production in the United States.[38] Miller and Osborne also report an average transport distance of 122 miles for cement in the US Southwest and ex-works prices of about $ 77. This implies a relatively high share of transport cost, whereas our billing data for Germany is more in line with the statement of Friederiszick and Röller (2002) that transport costs amount to about 20% of total cement costs in case of shipments per truck at a distance of about 100km.

In summary, we consider marginal transport costs in the range of about 4 to 20 Euro-cents per ton-km in 2010 prices as plausible for the observed post cartel period in Germany.

5.3 Price variation

Our theory predicts a mixed strategy equilibrium in prices in case of competition which implies an increase in price variation for price offers and also realized prices compared

[36] For these observations we have also not find decreasing marginal transport costs (regression results not reported).

[37] Friederiszick and Röller (2002) report transport cost figures of Fiederer et al (1994) on p. 88.

[38] Page 222 in Miller and Osborne (2014).

to the case of coordination. Our understanding of the contracting in this market is that pricing in a supplier customer relationship is usually for a period of a year. This can for example be gathered from the billing data, which indicates retroactive rebates for the supplies in a given year. We also observe in the data that 65 percent of the quantity is transacted with one supplier over the whole time span of the data set and around 60 percent of the quantity after the cartel broke down.

To test the prediction that price variation increases after the cartel, we use the billing data and compute yearly net prices per ton of cement for combinations of a production-plant, the customers unloading point and the cement type. We distinguish here between cement types as they have different price levels in general and we want to rule out that our results are driven by potential composition effects.[39] Subsequently, we calculated (as described in subsection 4.3) the variation coefficient over these plant-customer-type specific average prices.

Table 5: Robustness check: Variation coefficient

	All	At least two suppliers		
	(1)	(2)	(3)	(4)
	Zip and Type FE	Zip-Type FE	Zip and Type FE	Zip-Type FE
Plants in 150km	-0.13	-0.18	-0.32	-0.40
	(-0.90)	(-0.95)	(-0.68)	(-0.71)
HHI (0-100)	-0.00	-0.00	-0.00	0.00
	(-0.73)	(-0.76)	(-0.01)	(0.14)
Customer size (year)	-0.28	-0.29	-1.87	-1.68
	(-0.74)	(-0.67)	(-1.03)	(-0.88)
Post Cartel (PC)	0.32**	0.33**	1.28*	1.33*
	(2.05)	(2.07)	(1.89)	(1.73)
Obs.	2014	2013	498	469
R^2	0.09	0.14	0.18	0.19
Within R^2	0.01	0.02	0.04	0.04

t statistics in parentheses
Standard Errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. Regressions include fixed effects at the zip code and cement type level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The regressions of the variation coefficient on the post cartel indicator and various controls are in Table 5. In columns 1 and 2 we use all shippings for our regression analysis. Controlling for unloading point and cement type fixed effects, we observe a significant increase in the variation coefficient. This is also the case when using a combined fixed

[39] We understand that these subtypes of CEM I differ in price and certain characteristics such as the hardness, but can be produced by virtually all cement plants that produce CEM I. We present the other regression results without subtype controls as this should not matter with respect to the their dependent variables. We have checked, however, that qualitatively the same results are obtained when controlling for the subtype.

effect for the unloading point and cement type, as in column 2. Note that when shipments for one customer came only from one plant, this yields a variation coefficient of zero. As single-sourcing was much more regular in the cartel period, one could be concerned that the result is solely driven by the rise of a higher number of suppliers. Therefore we re-run the same set of regressions as in column 1 and 2 in column 3 and 4, but only for unloading points with at least two suppliers. We find that still the variation coefficient increases, with the coefficient being higher in magnitude but more volatile.

Across all specifications, the post cartel indicator has a significantly negative coefficient (at least at the 10% level). This indicates that the price variation is indeed larger when firms compete than in case of cartel, which is consistent with our theory.

5.4 Readymix

A potential robustness concern might be that an increase in the transport distance after the cartel breakdown could be due to retaliatory measures against the defecting cement supplier called Readymix. The other suppliers could punish Readymix by supplying customers of Readymix at lower prices. This might result in shipping cement over longer distances than is usually economically sensible. Given the high transport costs of cement and reinforced by the cartel agreement, the customers of Readymix should mainly be within the typical shipment distance around the cement plants of Readymix. As a consequence, retaliatory measures against Readymix should, if at all, mainly increase the transport distance at unloading points near the cement plants of Readymix. In order to investigate this potential explanation, we additionally estimate the model

$$y_{c,u,t} = \beta_1' X_{c,u,t} + \beta_2 post\,cartel_t + \beta_3 post\,cartel_t \cdot Readymix_{c,u,t} + \varepsilon_u + \epsilon_{c,u,t}, \qquad (10)$$

where *Readymix* is an indicator which takes on the value of one when there is a cement plant of the supplier Readymix in 150km road distance to the respective unloading point, and is zero otherwise.

The respective regression results can be found in Table 6. The regressions show that the presence of the deviating firm is not a good predictor for the the increase in distances, as the interaction term is not significantly different from zero. In other words, significant increases in distance post cartel materialize irrespective of whether there is a cement plant of Readymix in the area. We have thus not found empirical support for the alternative hypothesis that retaliatory measures in relation to the firm that deviated from the cartel agreement explain the increase in distance.

Table 6: Robustness check: Readymix AG (RMC) plant near customer

	Distance		Rank	
	(1)	(2)	(3)	(4)
Plants in 150km	-0.40	1.22	0.04	0.02
	(-0.10)	(0.30)	(0.14)	(0.06)
HHI (0-100)	-0.67**	-0.51	-0.03**	-0.03**
	(-2.04)	(-1.54)	(-2.54)	(-2.25)
Customer size (year)	20.53	19.17	-2.30	-2.28
	(0.59)	(0.58)	(-1.06)	(-1.06)
Post Cartel (PC)	26.94***	20.31**	1.73**	1.80**
	(3.47)	(2.27)	(2.56)	(2.22)
RMC plant in 150km		-10.10*		0.37
		(-1.87)		(0.46)
PC*(RMC plant in 150km)		25.81		-0.27
		(1.33)		(-0.23)
Obs.	1312	1312	1312	1312
R^2	0.63	0.63	0.49	0.49
Within R^2	0.06	0.07	0.04	0.04

t statistics in parentheses
Standard Errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. Regressions include fixed effects at the zip code level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6 Conclusion

We have studied the spatial pattern of sales in an industry with significant transport costs and capacity constraints. When firms compete, there can be an inefficiency in transport that increases in the degree of excess capacity. Overall, there is a non-monotonic relationship between the average transport distance in case of competition and the degree of excess capacity. When firms are highly capacity constrained, they are effectively local monopolists and minimize the average transport distance. For intermediate capacities, instead, the average transport distance increases in the degree of overcapacity, until there are no effective capacity constraints. Absent capacity constraints, price competition yields marginal cost based pricing for each customer, such that again the cheapest supplier wins the contract. A result of this analysis is that the average transport distance should vary in the degree of overcapacity if there is capacity constrained competition, but not if there is a well-organized cartel. When firms are capacity constrained at an intermediate level, the pattern that significant changes in the supply-demand balance are not accompanied by changes in the average transport distance is therefore indicative of coordination among the firms.

We have empirically investigated the allocation of customers to suppliers in the cement industry in Germany from 1993 to 2005, which had been cartelized in part of our observation period. Controlling for other potentially confounding factors, such as the number of production plants and demand, we have shown that during the cartel period the average transport distances between suppliers and customers were on average significantly lower than in the later period of competition. This provides strong empirical support of our theoretical finding that competing firms serve more distant customers in areas that are closer to their competitors' production sites. Moreover, in line with our theory, for a given level of capacity an increase in demand leads to a lower average transport distance when firms compete, but has no significant effect on the transport distance during the cartel period.

The results of this exercise help to better understand the competitive process and provides hints for distinguishing competition and coordination when analyzing market data. For instance, in the assessment of the merger M.7009 HOLCIM / CEMEX WEST in 2014 the European Commission took the past cartel behavior in the German and European cement industry into account and investigated whether the relevant cement markets exhibited signs of coordinated behavior of the cement producers. In its analysis, the European Commission even referred to a Bertrand-Edgeworth model, which – given the economic literature of that time – did not take both capacity constraints and location specific costs into account.[40] The result of the present article is that in such a case one could also analyze average transport distances. For instance, one could study whether – other things equal – average transport distances have again decreased in the years up to the merger control assessment. This would indicate a return to coordinated behavior of the cement producers. Besides merger control, our results can naturally also be used for cartel prosecution.

It is noteworthy that this model applies to various industries where capacity constraints and a form of spatial differentiation or adaption costs exist, and where location or customer based price discrimination may be relevant. Besides cement, these include other heavy building materials and commodities, but also specialized consulting services and customer specific intermediate products, as supplied for example to the automobile industry.

There is plenty of scope for further analyses. For instance, a more structural estimation approach that takes the Bertrand-Edgeworth model framework into account seems desirable. Moreover, reformulating the model to allow for more than two and also for asymmetric firms, and simulating the effects of mergers in such a setting appears to be of competition policy interest.

[40] See the European Commission decision M.7009 HOLCIM / CEMEX WEST, fn. 195 on page 44.

References

Acemoglu, D., Bimpikis, K., and Ozdaglar, A., "Price and capacity competition." *Games and Economic Behavior*, Vol. 66 (2009), pp. 1–26.

Asker, J., "A Study of the Internal Organization of a Bidding Cartel." *The American Economic Review*, Vol. 100 (2010), pp. 724–762.

Bejger, S., "Polish cement industry cartel-preliminary examination of collusion existence." *Business & Economic Horizons*, Vol. 4 (2011).

Benoit, J.-P. and Krishna, V., "Dynamic duopoly: Prices and quantities." *The Review of Economic Studies*, Vol. 54 (1987), pp. 23–35.

Bertrand, J., "Théorie des richesses: revue des théories mathématiques de la richesse sociale par Léon Walras et reserches sur les principes mathématiques de la richesses par Augustin Cournot." *Journal des Savantes*, (1883), pp. 499–508.

Blum, U., "The East German Cement Cartel: Cartel Efficiency and Cartel Policy after Economic Transformation." *Eastern European Economics*, Vol. 45 (2007), pp. 5–28.

Boccard, N. and Wauthy, X., "On the Nature of Equilibria when Bertrand meets Edgeworth on Hotelling's Main Street." (2016), mimeo.

Canoy, M., "Product differentiation in a Bertrand–Edgeworth duopoly." *Journal of Economic Theory*, Vol. 70 (1996), pp. 158–179.

Davidson, C. and Deneckere, R. J., "Excess Capacity and Collusion." *International Economic Review*, Vol. 31 (1990), pp. 521–41.

Edgeworth, F. Y., "The pure theory of monopoly." *Edgeworth, Papers relating to Political Economy*, Vol. 1 (1925), pp. 111–142.

Fershtman, C. and Gandal, N., "Disadvantageous semicollusion." *International Journal of Industrial Organization*, Vol. 12 (1994), pp. 141–154.

Friederiszick, H. and Röller, L.-H., "Lokale Märkte unter Gobalisierungsdruck. Eine industrieökonomische Studie zur deutschen Zementindustrie." *RACR Studie 01*, (2002), on behalf of the German Ministry of Economics and Labour.

Friederiszick, H. and Röller, L.-H., "Quantification of Harm in Damages Actions for Antitrust Infringements: Insights from German Cartel Cases." *Journal of Competition Law and Economics*, Vol. 6 (2010), pp. 595–618.

Harrington, J. E., Hüschelrath, K., and Laitenberger, U., "Rent sharing to control non-cartel supply in the German cement market." *ZEW Discussion Paper No. 16-025, Mannheim.*, (2016).

Harrington, J. E., Hüschelrath, K., Laitenberger, U., and Smuda, F., "The discontent cartel member and cartel collapse: The case of the German cement cartel." *International Journal of Industrial Organization*, Vol. 42 (2015), pp. 106–119.

Hüschelrath, K. and Veith, T., "Cartel Detection in Procurement Markets." *Managerial and Decision Economics*, Vol. 35 (2014), pp. 404–422.

Hunold, M. and Muthers, J., "Capacity constraints, price discrimination, inefficient competition and subcontracting." *DICE Discussion Paper*, (2017).

Hüschelrath, K., Leheyda, N., Müller, K., and Veith, T., "Schadensermittlung und Schadensersatz bei Hardcore-Kartellen - Ökonomische Methoden und rechtlicher Rahmen." *ZEW Wirtschaftsanalysen, Bd. 102, Nomos, Baden-Baden*, (2012).

Hüschelrath, K., Müller, K., and Veith, T., "Estimating damages from price-fixing: the value of transaction data." *European Journal of Law and Economics*, Vol. 41 (2016), pp. 509–535.

Hüschelrath, K. and Veith, T., "Cartelization, Cartel Breakdown, and Price Behavior: Evidence from the German Cement Industry." *Journal of Industry, Competition and Trade*, Vol. 16 (2016), pp. 81–100.

Hyytinen, A., Steen, F., and Toivanen, O., "Anatomy of Cartel Contracts." *Katholieke Universiteit Leuven, FEB Research Report MSI_1231*, (2014).

Kreps, D. M. and Scheinkman, J. A., "Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes." *Bell Journal of Economics*, Vol. 14 (1983), pp. 326–337.

Miller, N. H. and Osborne, M., "Spatial differentiation and price discrimination in the cement industry: evidence from a structural model." *The RAND Journal of Economics*, Vol. 45 (2014), pp. 221–247.

Miller, N. H., Osborne, M., and Sheu, G., "Pass-through in a concentrated industry: empirical evidence and regulatory implications." *The RAND Journal of Economics*, Vol. 48 (2017), pp. 69–93.

Perez-Saiz, H., "Building new plants or entering by acquisition? Firm heterogeneity and entry barriers in the US cement industry." *The RAND Journal of Economics*, Vol. 46 (2015), pp. 625–649.

Röller, L.-H. and Steen, F., "On the workings of a cartel: Evidence from the Norwegian cement industry." *The American Economic Review*, Vol. 96 (2006), pp. 321–338.

Ryan, S. P., "The costs of environmental regulation in a concentrated industry." *Econometrica*, Vol. 80 (2012), pp. 1019–1061.

Salvo, A., "Inferring market power under the threat of entry: The case of the Brazilian cement industry." *The RAND Journal of Economics*, Vol. 41 (2010), pp. 326–350.

Sinitsyn, M., "Equilibria in a Capacity-Constrained Differentiated Duopoly." Tech. rep., McGill University, Montréal (2007).

Somogyi, R., "Bertrand-Edgeworth competition with substantial horizontal product differentiation." (2016), mimeo.

Thisse, J. and Vives, X., "On the Strategic Choice of Spatial Price Policy." *American Economic Review*, Vol. 78 (1988), pp. 122–37.

Annex I: Proof of Proposition 4

Proof. We proceed in two steps. In the first step we show that weakly increasing prices are best responses to uniform prices in the second step we show that no firm has an incentive to deviate with a single price at any location while maintaining the order of weakly increasing prices. For the first step, let us consider the best response of firm L when R plays uniform prices according to the equilibrium distribution defined in (3). Consider prices for two customers with locations x and y, where $y > x$. Suppose to the contrary of weakly increasing prices that $p^L(x) > p^L(y)$, while the uniform price of R is p^R. We show that L either strictly prefers to switch the prices for x and y or is indifferent. The case that x is served but not y cannot emerge, because as R plays uniform prices it cannot be that $p^R(x) = p^R > p^L(x)$ and $p^R(y) = p^R < p^L(y)$. Three other cases are conceivable: first, L serves both x and y, second, L servers neither x nor y, third, L serves only y but not x. Only in the third case switching the prices has an effect on profits and is strictly profitable. By switching prices to increasing prices, L can ensure that revenues are identical but costs are strictly lower. This establishes that it is always a best-response to uniform prices to play non-decreasing price functions.

In the second step we derive the conditions under which uniform prices are best-responses to uniform prices. For this let us consider the marginal incentive to change prices given that the price order has weakly increasing prices before and after the change. Again, consider that R plays uniform prices p^R with the equilibrium price distribution for uniform prices defined in (3). As L plays weakly increasing prices and the price distribution of R is atomless, the realized price functions almost surely cross once or not at all. This means that either p^R is above or below all prices of L, or L has lower prices for all customers starting at the location of L up to a threshold customer right of whom all customers face higher prices from L than from R . Note that given the rationing rules all customers between 0 and $1-k$ will always be served by L . Either the threshold customer lies in the interval $[0, 1-k)$, then R is at its capacity limit and by the rationing rule all customer in that interval are served by L as this maximizes consumer surplus and minimizes costs. If the threshold customer is in the interval $[1-k, 1]$, then L always serves at least all customers in the interval $[0, 1-k)$, even if R is at its capacity limit. As L serves customers in $[0, 1-k)$ independent of the price level, as long as the weakly increasing price order is maintained, L has a strict incentive to increase prices in that interval up to the price level at the border of that interval at $1-k$. Hence, all-best responses in weakly increasing prices have uniform prices in $[0, 1-k)$. Furthermore, as there is a marginal incentive to increase prices in that interval, but the price distribution in equation (3) is derived such that there is no incentive to increase or decrease a uniform price function, thus by construction the average marginal profit of changing a uniform price is zero. Hence, the marginal incentive to change prices, neglecting that this can change the customer allocation through rationing, must be negative for at least some prices in the interval $[1-k, 1]$, starting from any weakly increasing price function. Thus, if the marginal profit from increasing the price $p^L(k)$ is negative, which is the price for the most distant customer that is ever served by firm L in this context, then it is optimal to lower all prices in $[1-k, k]$ such that the order of increasing prices is just maintained. This implies that if there is no incentive to increase $p^L(k)$, it is optimal to set a single uniform price in the whole interval $[0, k]$. Note that, given weakly increasing prices, customers in $(k, 1]$ are never served by L such that it is also a best response to charge the identical uniform price p^L in $[k, 1]$. A sufficient and necessary condition for an equilibrium in uniform prices is thus that there is no marginal incentive to increase $p^L(k)$ individually for any $p^L(k) \in [\underline{p}, v]$:

$$\begin{aligned}\frac{\partial}{\partial p^L(k)}\left[p^L(k)-C(k)\right]\left[1-F^R(p^L(k))\right] &\leq 0\\ \Leftrightarrow \left[1-F^R(p^L(k))\right]-f^R(p^L(k))\left[p^L(k)-C(k)\right] &\leq 0\end{aligned}$$

Substituting f^R (derived from (3)) it can be shown that this condition is monotonically increasing in p^L such that it is most critical for $p^L(k)=\underline{p}$:

$$\begin{aligned}\left[1-F^R(\underline{p})\right]-f^R(\underline{p})\left[p^L(k)-C(k)\right] &\leq 0\\ \leftrightarrow v \geq C(k)+\frac{\int_{1-k}^{k} C(k)-C(x)dx}{(1-k)^2}&.\end{aligned}$$

$\square$