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# Competition, Collusion, and Spatial Sales Patterns – Theory and Evidence

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# Competition, Collusion, and Spatial Sales Patterns – Theory and Evidence*

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**Abstract**

This article studies competition in markets with transport costs and capacity constraints. 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. We find that when firms compete, they more often serve more distant customers. Moreover, the transport distance also varies in the ratio of capacity relative to demand, but only if firms compete and not when they coordinate their sales. We provide a theoretical model of spatial competition with capacity constraints that rationalizes the empirical results.

**JEL classification:** K21, L11, L41, L61

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

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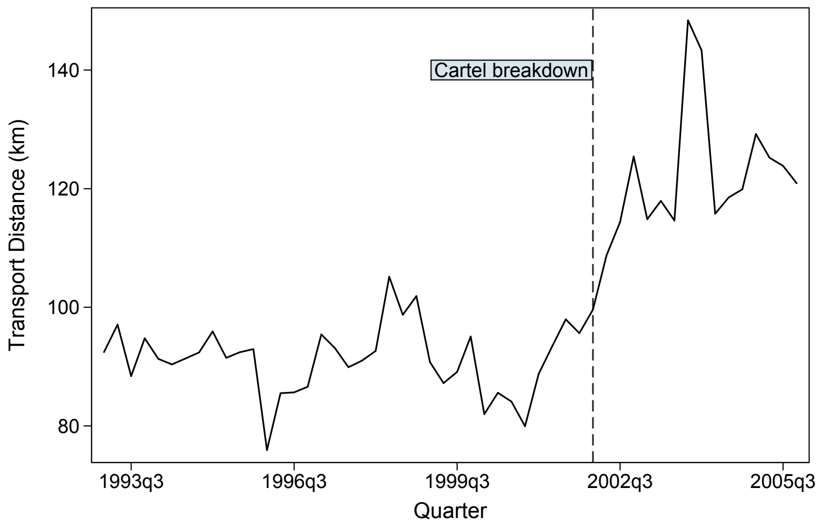
# 1 Introduction

It is well established in the literature that cartels between competitors can lead to high prices. It is also established that incentive problems in relation to the internal organization of cartels can result in excess capacities (Levenstein and Suslow [2006]; Fershtman and Gandal [1994]) and an inefficient allocation of production among cartelists (Asker [2010]; Asker et al. [2019]). We contribute to the literature by demonstrating both theoretically and empirically how competition can lead to inefficiencies that do not arise under collusion. We study how a cartel affects transport distances and costs in a market with capacity constraints and show that competition can cause an inefficiency in transport. In our empirical analysis of the cement industry, owing to competition, we find an increase of more than 25% in the average transport distance. However, the cartel's efficiency gains due to reduced transport distances appears to be much smaller than the price increase due to increased market power. Accordingly, consumers suffer from the cartel whereas the firms' profit margins increase more than the consumer prices.

Figure 1: Average distance from unloading point to cement plant




To start, we take observations from the cement industry in Germany between 1993 and 2005. The cement industry has a number of features which make the analysis of spatial competition interesting: high transport costs relative to the price, a small number of production sites, and capacity constraints. The observed time frame is interesting because it features a cartel breakdown in the year 2002, which was triggered by a policy change of one cartel member. This allows us to study the relationship between the mode of competition and spatial sales patterns.

Specifically, we compare the transport pattern in the cartel period of 1993 up to 2002 with that in the period following the cartel breakdown. Figure 1 previews one of our main results: the transport distance is distinctively lower in the cartel period.

We use a rich data set with approximately 500,000 market transactions of cement customers in Germany to substantiate the relationship between the mode of competition and transport distance using regression analyses. 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 cement suppliers and their customers were, on average, significantly lower than in the later period of competition. The point estimate for the additional transport distance under competition is close to about 26km, which amounts to an increase of more than 25% from about 90km during collusion. Moreover, we find other systematic patterns in the data. For instance, the transport distance varies in the degree of capacity utilization, but only if firms compete and not if there is a cartel. We also find that the price variation is higher post-cartel and customers switch their suppliers more often.

In order to study the possible mechanism behind these observations, we build on Hunold and Muthers [2019] and use a model where customers are located along a line between two capacity-constrained firms that sell homogeneous products.[1] Comparing the market outcomes of price competition and collusion, we find that competition can create an inefficiency in transport even when firms are symmetric and can price discriminate across customers. This inefficiency increases in the industry capacity.

[1] Hunold and Muthers [2019] use a simplified model with a fixed total capacity and discrete demand segments to study price differentiation and subcontracting when firms compete.

The customers are not always served by the closest firm as the capacity-constrained firms mix their prices in equilibrium. This leads to strategic uncertainty whereby the more distant firm sometimes makes the more attractive offer to a customer. This results in inefficient allocations. In contrast, very scarce capacity effectively leads to local monopolists and consequently minimized transport costs. Similarly, price competition with abundant capacity ensures that each customer is served by the closest supplier.

In the mixed strategy equilibrium, transport distance and inefficiency increases in the level of capacities relative to demand. Instead, a well-organized cartel minimizes transport costs at any level of capacity. The pattern that significant changes in the capacity-demand balance are not accompanied by changes in the average transport distances could therefore be indicative of coordination among the firms.

Our theoretical results and empirical evidence point to an inefficiency that arises in the case of spatial competition with capacity constraints. In industries with significant physical transport costs, such as the cement industry, this inefficiency can also cause environmental harm, for instance, due to higher carbon dioxide emissions. Our empirical evidence indicates a transport inefficiency of about 30 percent, as measured in the average transport distance. According to our analysis, the size of the harm depends on the level of excess capacities and the mode of competition. Moreover, 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 capacity points to a novel inefficiency caused by cartels, which materializes after the cartel has ended and firms are competing again.

We continue with a discussion of the related literature. In Section 3 we first describe the German cement cartel, the data, and our empirical approach. Second, we provide empirical evidence on the relationship between transport distances and competition using the data of the cement industry in Germany and discuss possible explanations. We present the theoretical model in Section 4 and develop additional hypotheses. We then test these hypotheses in Section 5. Finally, we discuss alternative explanations in Section 6 and conclude in Section 7.

## 2 Related literature

There are various economic studies of the cement industry that largely focus on investment behavior and environmental aspects (Salvo [2010a]; Ryan [2012]; Miller et al. [2017]; Perez-Saiz [2015]). More closely related to our article 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 both aggregate market data on annual regional sales and plant-specific production quantities and argue that transport costs of around $0.46 per ton-mile rationalize the data. In addition, Miller and Osborne find that isolated plants obtain higher ex-works prices from nearby customers.[2] Our study complements the study of Miller and Osborne as we can specifically test our theoretical predictions on transport distances by means of a rich customer data set that includes identified periods of collusion and competition.

The cement cartel in Germany that 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 due to elevated prices. A few other studies have also used parts of the transaction data that 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, 2018] investigate internal and external factors that 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

[2] This means prices net of transport costs.

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 excess capacity. The Finnish cement cartel agreed on an allocation that apparently minimized transport costs [Hyytinen et al., 2019].

There are a few articles which show theoretically that competition between two firms that are located in two geographically separated markets can lead to inefficient transport. Brander and Krugman [1983] show that Cournot competitors export homogeneous products to distant markets despite transport costs. This leads to higher transport costs than autarky or an agreement between the firms to not enter each others' home market. Similarly, Salvo [2010b] develops the theoretical prediction that the transport distances are lower when firms collude than when they compete in quantities. He tests the predictions with data of the cement industry in Brazil and rejects the hypothesis of quantity competition for about 2/3 of the local cement markets. Deltas et al. [2012] study suppliers that sell horizontally differentiated products. If each supplier agrees to only serve its local market, the prices can be lower and consumers better off than if the suppliers compete in both markets. Competition can reduce welfare because of costly cross-hauling (transporting goods into the distant market).

Our theoretical framework combines aspects of broadly two strands of the literature. First, there is a literature based on Bertrand [1883] – Edgeworth [1925] that analyzes price competition in the case of capacity constraints – and does so mostly for homogeneous products. This literature highlights that there are often only mixed strategy equilibria in this setting. A more recent, prominent example is Acemoglu et al. [2009]. Second, we relate to the literature on spatial differentiation in the tradition of Hotelling. In particular, our approach can be summarized as introducing capacity constraints into a model of spatial competition in the spirit of Thisse and Vives [1988]. There are a few articles which introduce product differentiation in the context of capacity-constrained price competition, notably Canoy [1996]; Somogyi [2019]; Boccard and Wauthy [2016]. However, these articles do not allow for price discrimination between customers, or for the firm bearing transport costs, and do not find a pattern of inefficient customer allocation.[3]

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 cartel in which the rents are allocated in proportion to the capacity shares. We show that existing excess capacities – which a cartel might have caused – can yield inefficiencies if firms compete (for instance, after a cartel breakdown).

# 3 Empirical set-up and main result

For our empirical analysis of transport patterns under competition and collusion we study the German cement industry where a cartel existed until 2002. We first describe the industry as well as the functioning of the cartel and its breakdown. We turn to a description of the data set in subsection 3.2. We describe the econometric model and discuss identification in subsection 3.3. In the introduction, we showed descriptively that the transport distance is distinctly lower in the cartel period. We substantiate this observation using regression analyses in subsection 3.4 where we control for other potentially confounding factors.

## 3.1 Industry background

**Production, excess capacity, and transport costs.** Cement is used for construction, mostly in the production of concrete. The production of cement consists

[3] See Hunold and Muthers [2019] for a more detailed discussion of the theoretical literature.

of two main stages. The first is the heating of the 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, particularly the capacity of clinker kilns, which constitute costly long-term investments. Substantial excess cement production capacity has 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 A1 in Annex IV). Consequently, the average utilization rate during the 1990s remained at levels below 70 percent (Friederiszick and Röller [2002]), such that excess capacity was prevalent throughout our observation period.

The costs of transporting cement from the production plant to the customer location are a significant fraction of the overall cement production costs. Friederiszick and Röller [2002] reported that the cost of transporting cement by truck over a distance of 100km amounted to more than 20 percent of the production costs.[4]

**Cartel organization and breakdown.** Since at least 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 through a regional quota system.[5] The cement producers also discussed avoiding 'advancing competition' and focusing on established market shares and customer bases.[6]

4 See Section 6 for a more detailed discussion of transport costs.

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

6 Judgment VI-2a Kart 2 - 6/08, 6 June 2009 of the OLG Düsseldorf, par. 116 and 117 (C.I.1.b), c)).

Readymix had already been a difficult and unsatisfied cement cartel member in the 1990s.[7] Finally, at the end of 2001, the firm's policy changes triggered the breakdown of the cartel. Readymix was part of the RMC group, which is a multinational building materials producer with headquarters in the United Kingdom. Possibly in reaction to the large fines for a concrete cartel that was reported in 1999 and the newly introduced leniency programs, RMC announced a new corporate policy across the group to strengthen competition policy compliance.[8]

In the context of this policy change, the German subsidiary Readymix aimed at ending its involvements in cartels. For instance, Readymix mandated an internal study on current involvements in anti-competitive conduct in the fall of 2001.[9] In addition, Readymix got a new CEO in 2002.[10]According to testimony in the public cartel case, as a result of these changes in the corporate policy, at the end of 2001 Readymix declared to the other cement producers that it would be exiting all cartel agreements. This led to the cartel breakdown and a strong price decrease.[11] 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.[12]

## 3.2 Data set and descriptive statistics

The raw data was collected by the law firm Cartel Damage Claims (CDC) to estimate damages for lawsuits against cartel members in Germany.[13] The data consists

[7] For example, Readymix did not report its true quantities between 1993 and 1997, which was detected and led to compensation measures. See judgment VI-2a Kart 2 - 6/08, 6 June 2009 of the OLG Düsseldorf, par. 266.

[8] See Rekordstrafe gegen Betonkartell, Der Spiegel, November 3, 1999; RMC Annual Report 2001, available at Investis.com Reports, (last accessed October 2019).

[9] See judgment VI-2a Kart 2 - 6/08, 6 June 2009 of the OLG Düsseldorf, par. 122.

[10] See Readymix Webpage (In the WebArchive), (last accessed October 2019).

[11] See judgment VI-2a Kart 2 - 6/08, 6 June 2009 of OLG Düsseldorf, par. 582.

[12] A new leniency program was introduced in Germany in the year 2000, see Leniency Programme of the German competition authority (last accessed October 2019).

[13] See their website carteldamageclaims.com for more details on the lawsuits and the business model of CDC (last accessed April 2019). We were able to obtain the data for the purpose of academic research.

of about 500,000 market transactions from customers of German cement producers from January 1993 to December 2005. The 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 the locations of the cement plants and unloading points. We added information on all the cement plants located in Germany and near the German border in neighboring countries. The data contains 220 unloading points of 36 smaller and larger customers, which are either permanent (such as a concrete plant) or temporary (such as a construction site).[14] Based on the geographical information for both cement plants and unloading points, we also calculated the road distances for all possible cement plant-unloading-point relations.

Our unit of observation consists of the aggregate cement shipments to an unloading point of a customer in a year. For a part of the observations, this involves the aggregation of shipments from different cement plants to this unloading point.[15] We restrict our analysis to one specific type of cement called 'CEM I' (Standard Portland Cement), which accounts for almost 80 percent of all available transactions, and distinguish between different cement grades when appropriate.[16] We only account for shipments from plants in Germany.[17] This leaves us with almost 1,300 observations at the customer – unloading-point – year level. We obtain around 1,700 observations when we account for each delivering plant separately, and around 2,000 when we account for the different cement consistencies.

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[14] Unloading points are defined at the ZIP code level.

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

[16] These different grades correspond to different compression strengths, which do not differ significantly from the production perspective. For instance, in the assessment of a transaction, the European Commission considered that the market of gray cement should not be further segmented according to grades or classes. See para. 49 in M.7252 HOLCIM / LAFARGE (last accessed October 2019).

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

Table 1 shows the 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.[18] The indicator *post-cartel* is defined accordingly.

The demise of the cartel was clearly associated with a strong decrease in price (71 euros during the cartel period and 50 euros post-cartel, expressed in 2005 prices). For a specific unloading point and cement consistency, we calculated the variation coefficient of the annual average prices across suppliers. 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. Finally, our data set is complemented by a regional diesel price index, which takes the value 100 in the year 2000.[19]

In order to capture changes in supply relationships, we calculate the average shipment distance (in road km) between the supplying cement plants 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, the rank is also higher in the period after the cartel breaks down.[20] To control for the size of the customers, we calculate the total quantity shipped to the respective customer by aggregating across locations and purchases of all cement consistencies. The average of this variable in the data set is 106,330 tons per year.[21]

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

[19] Regional diesel price indices were not readily available for all regions. We describe the construction of this variable in Annex VI.

[20] Average distance and rank evolve similarly over time, suggesting that changes in the location of unloading points or closures of cement plants, which should affect the rank less than the average transport distance, are unlikely to drive the results. Indeed, plotting the rank yields a graph similar to Figure 1.

[21] As some of the 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.

Clinker is the most important intermediate product of cement and its production capacity is crucial for the cement production capacity. However, capacity data at the plant level is unfortunately unavailable. Yet the clinker kiln capacities are relatively stable during the observation period (cf Figure A1 in Annex IV). Based on this insight, our empirical approach has two elements: First, we control for the number of cement plants located around an unloading point within a road distance radius of 150km and approximate variations in capacity utilization by variations in the local cement demand in the county of the unloading point in a given year.[22] Second, we use the local number of workers in the construction industry as a proxy variable for local demand (because we do not have data on cement demand 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 that the annual cement consumption and the number of workers in construction are highly correlated, with a correlation coefficient of 0.93 (Figure A2 in Annex IV). In order to eliminate county size effects, we normalize the number of workers by the respective value in 1996 and multiply it by 100. There is substantial variation reflected by the high standard deviation of 12 percent.

To obtain measures of local supply, we calculated the number of plants and independent cement producers located within a 150km road distance radius for each of the unloading points in each year. To obtain a measure of ownership concentration, we calculate HHIs as the sum of squared shares of plants by distinct owners ('local ownership concentration').[23] The number of cement plants around the unloading points after the cartel breakdown is 0.3 lower while the local ownership concentration increased by less than 3 percent. Similarly, the number of firms in a

22 County refers to the German 'Landkreise und kreisfreie Städte', which corresponds to the NUTS3-level in the European Union.

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

road distance radius of 150km around the unloading point decreased by 0.5.[24] This average increase in the concentration is partly due to plant closures and mergers. Moreover, the locations of unloading points also vary over time, for instance, due to temporary construction sites.[25]

As a robustness check, we 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. Specifically, we use the RMC indicator, which takes the value of one if a plant of this supplier is within a 150km distance of the unloading point (which is the case in 27 percent of the cases), and zero otherwise. Finally, we also report the location of the unloading point within Germany (which is captured by the indicators East, West, North, South).[26] The price levels for the different consistencies of cement differ. When analyzing the price variation, we therefore distinguish between the different cement consistencies, of which 42.5 is the most frequent one.

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24 The comparison is between the average of the cartel and post-cartel period, while decreases usually take place within both periods. Decreases in the number of plants, year on year, are always only in the magnitude of one plant, and refer in all cases to areas with at least four plants. If the number of firms decreases in the 150km neighborhood of an unloading point, it is in over 90 percent of cases by one firm and in areas with at least four firms.

25 The distance between an unloading point and the nearest cement plant decreased from, on average, 54 to 52km (not reported in the table). Other things equal, this suggests that transport distances should have decreased rather than increased.

26 Regions are defined in the same way as it was done by the colluding cement producers in Germany, see judgment VI-2a Kart 2 - 6/08, 6 June 2009 of the OLG Düsseldorf.

Table 1: Descriptive statistics

| | Cartel period | | Post-Cartel Period | | Overall | |
|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Post-Cartel (PC) | 0.00 | 0.00 | 1.00 | 0.00 | 0.22 | 0.42 |
| *Outcomes* | | | | | | |
| Price (FOB, 2005 EUR) | 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 EUR) | 8.05 | 3.88 | 7.70 | 4.38 | 7.98 | 3.99 |
| Freight cost (p.t.km. 2005 EUR) | 0.13 | 0.19 | 0.14 | 0.32 | 0.13 | 0.23 |
| Diesel price index (regional) | 83.36 | 12.28 | 114.14 | 8.95 | 90.22 | 17.29 |
| *Distance measures* | | | | | | |
| Shipment distance (km) | 91.43 | 58.06 | 122.89 | 103.48 | 98.44 | 71.95 |
| Rank of 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 |
| Firms in 150km | 5.19 | 2.72 | 4.73 | 2.31 | 5.08 | 2.64 |
| Local ownership concentration | 28.68 | 15.29 | 31.17 | 16.93 | 29.23 | 15.70 |
| 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 | |

Notes: Quantity-weighted averages. The number of observations refers to the aggregates at the annual, customer unloading point, and cement-consistency level.

## 3.3 Empirical model and identification

We now explain our strategy for identifying econometrically how the mode of competition affects the transport distance. Our approach relies on using variation over time in the transport distance to different unloading points ($y$) and in the state of competition ($Post - Cartel = 1$ means post-cartel, 0 means cartel). We estimate a linear model with observations at the level of the customer ($c$), unloading point ($u$), and year ($t$):

$$y_{c,u,t} = \beta_1' X_{c,u,t} + \beta_2 \textit{Post-Cartel}_t + \beta_3 \textit{Post-Cartel}_t \cdot Z_{c,u,t} + \varepsilon_u + \epsilon_{c,u,t}. \quad (1)$$

Equation 1 can be conceptualized as a reduced-form equation that comes out of the equilibrium model which we develop in Section 4. The post-cartel indicator is supposed to measure the difference in the transport distance when there is competition instead of collusion in the market. To identify the effect of different firm conduct, we control for other factors which might also affect the transport distance.

One potential factor is the market structure around a customer's unloading point. To deal with this concern, our approach is threefold. First, to account for unobserved time-constant heterogeneity between unloading points, we employ unloading point fixed effects ($\varepsilon_u$). By this, we essentially compare the transport distance over time for unloading points which existed both during and after the cartel. Second, we also control for changes in local supply by 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, is driving the result. Third, we also estimate the same model for the *rank* of the supplying plant as this is more robust to a decrease in the number of plants (which might affect the average distance).

The transport distance might be affected by the cost for transportation, which could change over time. We include the regional diesel price index as a control variable. Demand for cement largely depends on the demand of the construction industry. To control for demand, we use the number of construction workers at the county level, which is highly correlated with measures for cement demand. It is reasonable to assume that construction demand is exogenous to moderate changes in the cement markets. As cement constitutes only a small fraction of the cost of construction projects, the demand for cement is generally viewed as being inelastic with respect to the cement price. Only for significant price changes does a considerable degree of substitution between cement and other building materials (such as wood) appear to be possible in the long term. However, looking at shorter periods of a few years, as in our analysis, it is reasonable to assume that the demand is exogenous.[27]

The error term captures determinants of distance that are not accounted for in the controls. Getting an unbiased estimate of the cartel impact ($\beta_2$) requires the cartel period to be uncorrelated with those determinants. As argued in subsection 3.1, the cartel broke down due to a change in the corporate 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 might have increased the incentives to report illegal cartel activities. Hence, we do not expect that there are other unobserved changes that coincide with the end of the cartel and additionally affect our outcome variables. We therefore do not expect that the unobserved part of the determinants, e.g., measurement errors in the transport costs, are correlated with the cartel end. The standard errors are clustered at the unloading-point level and are robust to heteroscedasticity.[28]

**Additional (robustness) specifications.** We use two different specifications of the dependent variable $y_{c,u,t}$: The distance between the delivering cement plant and

[27] See judgment VI-2a Kart 2 - 6/08, 6 June 2009 of the higher regional court (OLG) Düsseldorf, par. 599 to 603 (G. II. 2. bb). The court's view that demand has a low price elasticity is based on a consensus of industry insiders and academic economic experts.

[28] Clustering at a narrower level, e.g. customer unloading point, leaves the results qualitatively unaffected.

the unloading point of the customer as well as the rank of the delivering plant (with rank 1 for the plant closest to the customer or its delivery point).[29]

Moreover, we investigate the timing of events more closely to rule out that our findings are driven by idiosyncratic events in relation to the breakdown of the cartel. More specifically, we analyze the evolution of the distance and rank of the supplying plant by adding indicators for the year before the cartel breakdown, the year of the breakdown, and the years after the breakdown. This allows us to assess whether the increase in distance and rank occurred even before the cartel ended and might have therefore been driven by other factors. It also allows us to distinguish whether the increase in distance is a temporary or a permanent phenomenon.

## 3.4 Main regressions on distance and rank

Table 2 contains the main regression results for both dependent variables, the distance in km between the unloading point and the delivering plant, and the rank of the delivering plant (where rank one relates to the plant closest to the unloading point).

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. In the distance regression, this coefficient can be interpreted as the average increase in distance per ton of cement post-cartel as distances are weighted by the cement quantity for each unloading point.

Furthermore, a higher local ownership concentration of the cement plants around the unloading point yields a lower transport distance.[30] A possible explanation for this result 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

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

[30] Recall that there is variation in the local ownership concentration over time due to plant closures and mergers, see subsection 3.2.

of distance with the number of plants in a 150km radius 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. However, 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.[31]

Overall, our first empirical results point to a potential inefficiency that arises if spatially differentiated and capacity-constrained firms compete. We quantify and discuss the cost increase using our estimates for both the additional distance in kilometers and the transport cost per km in Section 7.

*Summary.* The point estimate for the additional average transport distance per ton of cement under competition relative to collusion is close to 26km (within a confidence interval of about 11 to 40km).

One can illustrate the magnitude of the possible aggregate effect by applying the transport distance of 26km per ton to the total German cement consumption of about 30 million tons in 2003. The additional transport, owing to competition instead of collusion, could amount to a fully loaded cement truck driving more than 700 times around the globe.[32]

[31] Separate regressions with subsamples according to the different cement strength classes reveal that our findings are not driven by composition effects, i.e., changes in the share of distinct cement consistencies delivered before versus after the end of the cartel.

[32] This assumes a truck with a capacity of 27 tons. Please note that this is a rough out-of-sample approximation that extrapolates the results from our data set to illustrate the order of magnitude of the possible aggregate effect. Clearly, various means of transport are used and such an extrapolation has a large degree of uncertainty.

Table 2: Main regression results

| | Distance | | Rank | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Diesel price index (regional) | 0.06 | -0.14 | 0.01 | 0.01 |
| | (0.13) | (0.18) | (0.01) | (0.01) |
| Plants in 150km | -0.10 | 0.54 | 0.12 | 0.14 |
| | (3.98) | (3.95) | (0.28) | (0.28) |
| Local ownership concentration | -0.67** | -0.71** | -0.03** | -0.03** |
| | (0.33) | (0.34) | (0.01) | (0.01) |
| Customer size (year) | 17.89 | 11.42 | -3.01 | -3.32 |
| | (37.14) | (36.94) | (2.34) | (2.41) |
| Post-Cartel | 25.72*** | | 1.39** | |
| | (7.40) | | (0.61) | |
| Year before cartel collapse (2001) | | 3.59 | | -0.08 |
| | | (3.95) | | (0.30) |
| Year of cartel collapse (2002) | | 12.53** | | 0.92** |
| | | (5.57) | | (0.45) |
| Years after cartel collapse | | 39.67*** | | 1.91*** |
| | | (10.32) | | (0.73) |
| Constant | 117.54*** | 130.36*** | 2.99 | 3.51 |
| | (31.95) | (32.09) | (2.26) | (2.30) |
| 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 |
| Mean Dep. Var. | 110.22 | 110.22 | 4.19 | 4.19 |

Notes: Dependent variable: distance between the buyer and the producer (columns (1) and (2)); rank of the supplying plant from the viewpoint of the buyer (columns (3) and (4)). Unit of observation: aggregated purchases at a customer's unloading point in a specific year (1993–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# 4 Theory

In this section we set up a spatial model where capacity-constrained firms set prices. We first study the competitive equilibria and then examine the market outcome when firms coordinate their sales activities.The resulting theoretical predictions are consistent with the increase in the average transport distance post-cartel that we discovered in the cement data. Moreover, we develop additional theoretical predictions which we then test empirically in Section 5. We argue in Section 6 that this model provides a better explanation of the empirical findings than alternative theories. There are two symmetric firms. Firm $L$ is located at the left end of a line, and firm $R$ at the right end. In-between, customers of mass $M$ 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 the firm and customer location on a line of length 1. Transport 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. The transport costs equal $C(x) = t \cdot x$, with $t > 0$. The contestability assumption $v > C(1)$ becomes $v > t$. Please see Figure 2 for an illustration.

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. A decrease in the mass of demand $M$ and an increase in the capacity per firm $K$ have identical effects in the model. For the analysis, the *ratio of capacity relative to demand* is therefore the relevant measure: $k \equiv K/M$. The capacity parameter $k$ equals the share of demand that one firm can serve.

Firms set prices simultaneously. To simplify, we assume that each firm charges the same price at each location (uniform pricing): $p^i(x) = p^i$.[33] In Annex I, we show

[33] This means that prices including transport costs are uniform. The ex-works prices consequently decrease in the distance between supplier and customer.

that firms, depending on the transport costs, may still only charge uniform prices in equilibrium even when location-based price discrimination is possible. Moreover, we show that the increase in transport distance with competition generalizes to location-based price discrimination.

The resulting market allocation depends not only on the prices but also on the capacity relative to demand, as a firm may be unable to serve all customers for which it has charged the lowest price with its capacity. One can divide the market into three segments. We call the customers close to a firm the firm's *home market*. The home market of one firm ends with the customer that will be served by the other firms if the latter serves all customers closest to its location up to its capacity limit. Hence, the share of the home market is $1-k$. Between the two *home markets*, there is a segment of *intermediate customers*. This segment in the middle will turn out to be switching suppliers and has a share of $2k-1$. Figure 2 depicts the transport costs and the market segments of the model for linear transport costs.

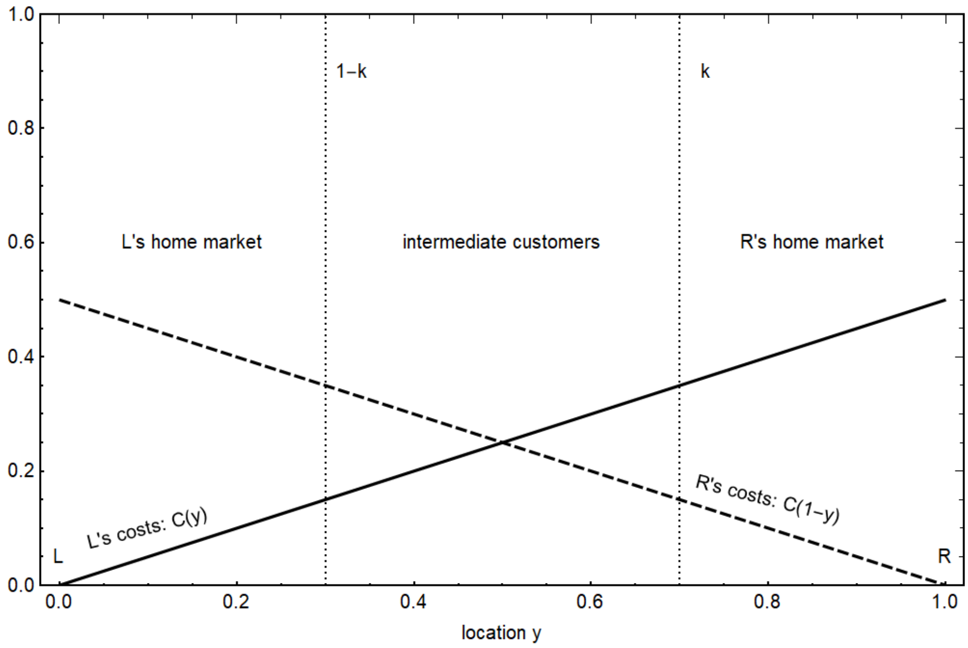


Figure 2: Model with linear costs ($t = 0.5$); per-firm capacity-demand-ratio: $k = 0.7$.

**Rationing.** Each customer attempts to buy from the firm with the lowest price if that price is not above the valuation of $v$. If there is demand for a firm's good by more customers 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.

2. If point 1. does not yield a unique allocation, the profit of the firm which has the binding capacity constraint is maximized (this 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.[34] While this is not the only possible rationing rule, we consider this rule appropriate for several reasons.[35] Arguably, what is most important for the purpose of the present paper is that the rationing rule aims at achieving efficiencies, but inefficiencies nevertheless arise in the competitive equilibrium.

We solve the price game for symmetric Nash equilibria, taking the rationing rule into account. We start by characterizing symmetric Nash equilibria for the case of competition 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 analyze the game when firms coordinate their sales activities.

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

[35] See Hunold and Muthers [2019] for a further discussion of rationing rules in a related model.

## 4.1 Competition without capacity constraints

Suppose that each firm has the capacity to serve all customers. Absent capacity constraints, the logic of Bertrand competition implies that in equilibrium no firm can make any additional profit by marginally undercutting its competitor. Hence, it is an equilibrium that both firms' prices are equal to the marginal cost of serving a customer in the middle, i.e., the marginal customer for both firms: $p^i = C(0.5)$.[36] Each firm serves customers from its location up to the location of the customer at 0.5. Both firms make a profit equal to $M \int_0^{0.5} C(0.5) - C(x)dx$. Consumer surplus is given by $M\,(v - C(0.5))$. 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 are equal to the marginal cost of serving a customer in the middle: C(0.5).*

## 4.2 Competition with capacity constraints

**Non-existence of a pure strategy equilibrium.** Suppose each firm can only serve a share $k$ of the 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? The competitive equilibrium characterized above is the symmetric Nash equilibrium in pure strategies with the highest profit for each firm. If this is not an equilibrium with price discrimination, then there is no symmetric pure strategy equilibrium of the game. There cannot exist a pure strategy equilibrium with higher profits as this would imply higher prices which could be profitably undercut by the competitor.

Each firm has a profit of $M \int_0^{0.5} C(0.5) - C(x)dx$ in the candidate pure strategy equilibrium. A firm could instead charge a higher price, which would result in

[36] There are additional symmetric pure strategy equilibria with even lower prices. In the following we focus on the pure strategy equilibrium with the highest sustainable price, which maximizes the parameter region for pure strategy equilibria.

the firm serving its home market as residual demand. For firm $L$ this would be the customers between location 0 and $1-k$. The optimal price is $v$ in this case as demand is not elastic to prices up to $v$. This would result in a profit of $M\int_0^{1-k} v - C(x)dx$.

Hence, the pure strategy equilibrium does not exist if

$$M\int_0^{1-k} v - C(x)dx > M\int_0^{0.5} C(0.5) - C(x)dx,$$

or equivalently

$$v > \frac{C(0.5)0.5 - \int_{1-k}^{0.5} C(x)dx}{1-k} \equiv \tilde{v}. \tag{2}$$

**Lemma 1.** *A pure strategy equilibrium does not exist if the valuation, $v$, is sufficiently large for a given cost structure $C(x)$ and capacity $k \in (0,5;1)$. The critical valuation above which there exist no pure strategy equilibrium, $\tilde{v}$, increases in the costs of serving customers at location 0.5 and the ratio of capacity relative to demand ($k$), but decreases in the cost difference between firms for serving intermediate customers.*

**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 distribution functions over the prices of each firm.

**Proposition 2.** *If firms are restricted to playing uniform prices, in the symmetric mixed strategy equilibrium both firms play prices according to the atomless distribution function defined in Equation (9) and mix over the interval $\underline{p}$ to $v$ with*

$$\underline{p} = \frac{v \cdot (1-k) + \int_{1-k}^{k} C(x)dx}{k}. \tag{3}$$

*In equilibrium, almost surely either one of the two firms sets a lower price than the other firm and serves customers up to its capacity limit, starting with the closest customers.*

*Proof.* See Annex II. □

In the symmetric mixed strategy equilibrium the *home market* customers, located in a distance of up to $(1-k)$ to each firm, will always be served by that firm. The *intermediate customers,* located at a distance higher than $|1-k|$ to any of the firms, are always served by the firm with the lowest price.

Let us now analyze how the average transport distance depends on the capacity in the market. The size of the two home markets as a fraction of total demand is given by $2 \cdot (1-k)$. The group of intermediate customers has a share $2k-1$ in total demand. The average transport distance for intermediate customers depends on the capacities. Either of the two firms has the lowest price with equal probability. The transport distance for a specific intermediate customer is its average distance to the two firms, which is 0.5 for any customer on the line between the two firms. The average transport distance across all customers is thus

$$2\int_0^{1-k} x \cdot dx + 0.5(1-2(1-k)) = 0.5 - k + k^2, \tag{4}$$

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 assumption. We summarize in

**Proposition 3.** *In the symmetric mixed strategy equilibrium (Proposition 2), the average transport distance increases in the ratio of capacity relative to demand* $k = K/M$.

Each of the *intermediate customers* is served by the more distant firm with a 50 percent probability. In expected terms, the aggregate transport inefficiency thus amounts to

$$\frac{1}{2}M\int_{1-k}^{0.5}\left[C\left(1-x\right)-C\left(x\right)\right]dx+\frac{1}{2}M\int_{0.5}^{k}\left[C\left(x\right)-C\left(1-x\right)\right]dx,$$

which due to symmetry reduces to $M \int_{0.5}^{k} \left[C\left(x\right) - C\left(1-x\right)\right] dx$.

## 4.3 Market outcome when firms collude

If firms coordinate and maximize joint profits, they can achieve prices above the competitive level. It turns out that the firms also optimally coordinate on minimizing costs when serving customers – different from the competitive equilibrium when firms are capacity constrained. Cost minimization follows from the rationing rule when firms collude with symmetric uniform prices. Below, we show that cost minimization extends to the case of price discrimination.

Suppose that firms use grim-trigger strategies to implement the collusive outcome in an infinitely repeated game. Let us study the usual stability condition of collusion:

$$\pi^{C} \frac{1}{1-\delta} \geq \pi^{D} + \frac{\delta}{1-\delta} \pi^{N}, \tag{5}$$

where $\delta$ denotes the common discount factor, $\pi^C$ the collusive profit in each period, $\pi^D$ the period profits of the deviating firm and $\pi^N$ the per-period profit a deviating firm makes in the punishment phase. The punishment consists of the firms playing the competitive equilibrium of the stage game infinitely. The important point is that $\pi^N$ is independent of how customers are allocated during successful coordination.

**Proposition 4.** *For any collusive pricing scheme, firms optimally allocate customers in a way that minimizes costs.*

*Proof.* See Annex II. □

The proposition means that, for any collusive pricing scheme, the cost-efficient customer allocation maximizes the collusive per-period profit. The reason is that there are sufficient instruments, in particular, the price levels for each customer, which the firms can use to reduce the profit of a deviating firm without any need to alter the collusive customer allocation. Improving the efficiency of the collusive customer allocation facilitates cooperation as it increases the range of discount factors which satisfy the incentive-compatibility condition (5). A cost-minimizing approach appears to be reflected in various actual cartels.[37]

## 4.4 Hypotheses for the empirical analysis

Our model with only two suppliers is necessarily stylized and we do not expect all stylized results to materialize 1:1 in real-world markets. We derive the hypotheses from the mixed strategy equilibria of our model. These equilibria feature an endogenous variation in prices and supplier relationships as well as an increase in transport distance with competition.[38] We discuss how our model parameters relate to the empirical estimates in Annex III and explain why mixed strategy equilibria with (endogenously) uniform pricing are plausible outcomes.

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

***H2.*** *An increase in the mass of 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.*

***H3.*** *Customers switch their supplier more often when there is competition compared to coordination.*

***H4.*** *The variation in prices is larger under competition than under coordination.*

Hypothesis H1 follows directly from propositions 2 and 4. While competition yields strategic uncertainty that results in inefficiently long transport distances, optimal collusion among firms, instead, implies transport cost minimization. Our

[37] For instance, one strategy of the cement cartel in Germany was that firms focused on their customer bases and avoided 'advancing' competition for customers of other firms (see subsection 3.1). With respect to the former legal cement cartel in Finland, Hyytinen et al. [2019] 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.

[38] Depending on the transport cost, on the customers' willingness to pay, and on the capacity-demand-ratios, our model can also predict local monopolies or perfect competition outcomes.

interpretation of the theory is that the market outcome is more volatile with competition, which accordingly leads to more volatile prices and more switching of suppliers. Hypothesis H3 directly follows from this comparison. Moreover, changing prices are a natural feature of our competitive equilibrium, whereas such changes do not arise endogenously under coordination. This yields hypothesis H4.

Hypothesis H2 follows from propositions 3 and 4. The extent of the coordination failure when firms compete decreases in demand relative to capacities. Under collusion, the transport distances are unaffected by demand changes relative to capacity.

# 5 Additional empirical evidence

## 5.1 Demand and transport distance (H2)

In subsection 3.4 we found that the average transport distances increases post-cartel, which is in line with our first hypothesis (H1). We now test the second hypothesis according to which 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. For this, we include the number of construction workers as our proxy variable for demand. Recall that construction demand is largely exogenous to the cement price and highly correlated with the number of construction workers (see subsection 3.3 and Figure A2 in Annex IV). The overall cement capacity does not vary much in our observation period. Moreover, we control for the number of plants around a customer's unloading point. Consequently, a larger number of construction workers serves as a proxy for a decrease in the capacity-to-demand ratio.

To make our findings comparable to prior results, in Table 3 we report the same specifications as in Table 2 in columns (1) and (4) for the restricted data set (the demand data is only available from 1996 onward) and do not find qualitative differences. In columns (2) and (5), we include the proxy variable for demand and thus the capacity utilization. We only find a weakly significant effect of our proxy variable on the transport distance. This weak significance disappears once we 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* indicator is still positively significant. However, there is no statistically significant relationship between the capacity utilization (proxied with construction employment) and the average transport distance during the cartel anymore. Instead, the coefficient of the interaction term *post-cartel* and capacity utilization (construction employment) is significantly negative. This shows that when firms compete, a higher degree of capacity utilization makes the allocation of customers to suppliers more efficient, while an efficient cartel simply minimizes the transport distance at any degree of capacity utilization.

Moreover, we have also regressed the absolute values of the residuals on the post-cartel indicator, the demand-interaction with post-cartel as well as other control variables. Table 6 in Annex V contains the results. The unexplained component of distance as well as rank is significantly higher post-cartel (columns 1 and 3). This is consistent with our theory whereby the randomness in the allocation results from the strategic uncertainty post-cartel. Also, the estimated coefficient of the interaction of post-cartel and demand is significantly negative, which means that more demand relative to capacity is associated with less randomness in the allocation (see columns 2 and 4). This is again consistent with our theory as the fraction of intermediate customers for which strategic uncertainty arises in equilibrium is smaller when demand is larger.

*Summary.* The regression analyses are consistent with H2 whereby an increase in the ratio of capacity and demand increases the average transport distance, but only if the firms compete. For this analysis we use a proxy for local and inter-temporal demand variation as an indirect measure of the variation in capacity utilization.

Table 3: Regression results with demand proxy

| | Distance | | | Rank | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Diesel price index (regional) | 0.02 | -0.26 | -0.10 | 0.01 | -0.00 | 0.00 |
| | (0.19) | (0.26) | (0.25) | (0.01) | (0.02) | (0.02) |
| Plants in 150km | -7.34 | -6.66 | -7.03 | -0.44 | -0.40 | -0.41 |
| | (4.82) | (4.73) | (4.67) | (0.33) | (0.32) | (0.32) |
| Local ownership concentration | -1.36*** | -1.22*** | -1.10*** | -0.06*** | -0.05*** | -0.05** |
| | (0.36) | (0.36) | (0.36) | (0.02) | (0.02) | (0.02) |
| Customer size (year) | 61.72 | 44.48 | 38.79 | -1.77 | -2.78 | -3.00 |
| | (47.75) | (46.02) | (44.66) | (2.82) | (2.76) | (2.75) |
| Post-Cartel | 31.11*** | 27.58*** | 178.68*** | 1.58** | 1.38* | 7.21** |
| | (7.92) | (7.64) | (57.00) | (0.67) | (0.70) | (2.84) |
| Construction Employment (CE) | | -0.81* | 0.31 | | -0.05* | -0.00 |
| | | (0.49) | (0.40) | | (0.03) | (0.03) |
| Post-Cartel*CE | | | -1.75*** | | | -0.07** |
| | | | (0.63) | | | (0.03) |
| Constant | 178.62*** | 272.76*** | 153.87** | 8.13*** | 13.67** | 9.08 |
| | (43.17) | (74.05) | (67.29) | (3.08) | (5.26) | (5.56) |
| Obs. | 938 | 938 | 938 | 938 | 938 | 938 |
| $R^2$ | 0.59 | 0.60 | 0.61 | 0.46 | 0.46 | 0.46 |
| Within $R^2$ | 0.09 | 0.10 | 0.13 | 0.05 | 0.05 | 0.06 |
| Mean Dep. Var. | 103.65 | 103.65 | 103.65 | 4.47 | 4.47 | 4.47 |

Notes: Dependent variable: distance between the buyer and the producer (columns (1) to (3)); rank of the supplying plant from the view point of the buyer (columns (4) to (6)). Unit of observation: aggregated purchases at a customer's unloading point in a specific year (1996–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

## 5.2 Supply dynamics (H3)

Our theory predicts that customers switch suppliers more frequently when there is competition than when there is collusion. As the capacity to demand ratio ($k$) determines the size of the intermediate market segment, the model also predicts that, for a given capacity, an decrease in demand increases supplier switching (Figure 2 illustrates this). We now test these predictions. To do so, we compute several additional measures, which we summarize in Table A.V in Annex IX. We calculate the number of distinct plants shipping to a customer's unloading point in that year ('#Plants') and the share of the 'main' delivering plant in all supplies of that year ('%Main plant'). On average, customers source more than 90 percent from their largest (and in many cases only) supplier for a given year and unloading point both during and after the cartel. Whereas the descriptive statistics suggest a slight increase in the number of supplying plants post-cartel (which is, however, not significant in regressions), the share of the main delivering plant and the concentration of the supplies are not higher post-cartel.[39]

To measure supply dynamics, the indicator 'Change main plant' takes the value 1 if the main delivering plant is not the same as in the previous year, and the value 0 otherwise. Indeed, the average value increases from 0.18 during the cartel period to 0.23 in the post-cartel period (a 27% increase). To better capture dynamics in the case of multi-sourcing, the variable '$\sum$SSC' sums the squared differences in the supply shares of all plants supplying a customer's unloading point between two years. For instance, suppose that in year 1 plants A and B each supplied 50 percent of all quantities, whereas in year 2 plant A supplied all quantities (100%). The measure thus equals $\left[(1 - 1/2)^2 + (0 - 1/2)^2\right] = [1/4 + 1/4] = 1/2$, whereas it equals 0 if the shares of both plants are constant across the years. As these measures might

[39] We have performed additional regression analyses (similar to the ones presented in Table 4) which show that – controlling for changes in market structure – there is no significant relationship between the post-cartel indicator and the number of shipping plants and the supply share of the main plant.

be flawed by drastic changes in demand – for instance, an unloading point had been a temporary construction site – the measure '$\sum$Sq. share changes, strict' excludes all customer unloading point-year combinations where the total demanded quantity was less than 25 percent or more than 200 percent of the total supplied quantity of the previous year. All these measures indicate increases in supplier dynamics post-cartel.

To avoid that composition effects or changes in the local market structure drive changes in supply dynamics, we run regressions similar to the ones in Table 2, but with the new measures as dependent variables. Table 4 shows the results.[40]

The regression analyses reveal that supplier changes occur significantly more often post-cartel. The likelihood of a change of the main plant increases by 11 percentage points (from a sample average of 24 percent), and the sum of squared plant share changes increases by 18 (from a sample average of 29). The result is even slightly stronger when excluding observations with drastic changes in the sourced quantity (an increase of 23 from a sample average of 25).

In Table 4, we additionally control for the level of cement demand during and after the cartel in specification 2, 4, and 6 by applying a similar specification as in Table 3. We find that an increase in demand (measured by construction employment) has no effect on the likelihood of a customer changing its main supplying plant during the cartel. However, we find a weakly significant negative effect after the end of the cartel. Similarly, we observe that post-cartel an increase in demand (for a given capacity) has a significant negative effect on the sum of squared plant share changes. The results are in line with the theory prediction. Less excess capacity means that the fraction of 'intermediate customers,' where supplier changes occur in the mixed strategy equilibrium, is smaller.

[40] Note that the sample is restricted to observations starting in 1996 to ease comparison, as in Table 3. Results using the full sample can be found in Table A.VI in Annex IX. Please also note that the number of observations is lower when studying changes over years and even more so when using the strict change measure (which excludes certain observations, as explained in the text).

*Summary.* In line with H3, customers change their main supplying plant between years significantly more often post-cartel. Similarly, when there are several supplying plants, their supply shares are more volatile post-cartel. This is consistent with our theory, according to which in the case of competition customers more frequently obtain the best offer from different suppliers at different points in time. Also consistent with our theory, post-cartel these increases in switching can partly be explained by increases in the capacity-demand-ratio.

Table 4: Regression results for supply dynamics

| | Ch. main pl. | | $\sum$ SSC | | $\sum$ SSC, (strict) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Plants in 150km | -3.02 | -2.99 | -2.37 | -2.02 | -0.81 | -1.79 |
| | (3.74) | (3.80) | (5.03) | (5.02) | (5.22) | (5.20) |
| Local ownership concentration | -1.02*** | -0.95** | -1.18*** | -1.06*** | -0.91** | -0.86** |
| | (0.37) | (0.38) | (0.38) | (0.39) | (0.41) | (0.42) |
| Customer size (year) | -16.84 | -22.41 | -13.26 | -28.70 | 25.47 | 6.27 |
| | (25.44) | (26.87) | (31.02) | (32.59) | (38.85) | (39.76) |
| Post-Cartel | 10.52** | 67.69** | 18.97*** | 114.93*** | 25.87*** | 145.37*** |
| | (4.34) | (31.52) | (6.04) | (35.51) | (5.99) | (35.98) |
| Construction Employment (CE) | | 0.32 | | 0.36 | | 0.81* |
| | | (0.39) | | (0.40) | | (0.47) |
| Post-Cartel*CE | | -0.66* | | -1.13*** | | -1.36*** |
| | | (0.34) | | (0.38) | | (0.39) |
| Constant | 75.69** | 43.52 | 77.25* | 39.17 | 47.21 | -21.33 |
| | (34.30) | (52.22) | (42.99) | (62.38) | (46.36) | (64.92) |
| Obs. | 750 | 750 | 750 | 750 | 554 | 554 |
| $R^2$ | 0.30 | 0.30 | 0.28 | 0.29 | 0.34 | 0.36 |
| Within $R^2$ | 0.03 | 0.04 | 0.03 | 0.05 | 0.07 | 0.09 |
| Mean Dep. Var. | 24.40 | 24.40 | 29.41 | 29.41 | 25.49 | 25.49 |

Notes: Dependent variables: Change in the main plant (measuring whether the main delivering plant is not the same as in the previous year (columns (1) and (2)); Sum of the squared changes in supply shares of all plants supplying a customers' unloading point between two years (columns (3) and (4)); Sum of squared changes in supply shares, excluding all customer unloading point-year combinations where the total demanded quantity was less than 25% or more than 200% of the total supplied quantity of the previous year (columns (5) and (6)). Unit of observation: aggregated purchases for all consistencies of cement at a customer's unloading point in a specific year (1996–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

## 5.3 Price variation (H4)

Our theory predicts a mixed strategy equilibrium in the case of price competition. To test whether the price variation is higher post-cartel, we use the invoice data and compute annual net prices per ton of cement for each combination of the unloading point, production plant, customer, and cement consistency.[41] We distinguish here between cement consistencies as they may have different prices and we want to rule out that our results are driven by potential composition effects.[42] Subsequently, we calculated the variation coefficient over these annual prices for each unloading point. The variation is thus across different production plants and customers[43]

Table 5 contains the results of the regressions of the variation coefficient (multiplied by 100 to make the coefficients more readable) on the post-cartel indicator and various controls. Controlling for the unloading point and cement consistency fixed effects, we observe a significant increase in the price variation post-cartel. This is also the case when using a combined fixed effect for the unloading point and cement consistency (column (2)).

Further analyses show that the increase in price variation is not significantly correlated to increases in demand (see in Annex IX).

*Summary.* Across all specifications of the price variation, the post-cartel indicator has a significantly positive coefficient. This indicates that the price variation is larger when firms compete than when they collude. These findings are consistent with our theoretical prediction (H4).

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41 In the German cement industry, suppliers and customers often agree on contract terms for a period of a year. One can, for instance, find indications of this practice in the invoice data, which in various cases contains retroactive rebates for the supplies in a given year.

42 These consistencies are subtypes of CEM I and differ in certain characteristics (in particular strength), but can be produced by virtually all plants that produce CEM I (see subsection 3.1). We present the other regression results without subtype controls as this should not matter with respect to their dependent variables. We obtain qualitatively the same results when controlling for the subtype.

43 Instead of using the variation of prices for each customer's unloading point, we also ran regressions with variation coefficients based on each unloading point (sometimes across different customers which use the same unloading point) and obtained qualitatively the same results.

Table 5: Regression results for variation coefficient

| | (1) Zip and Type FE | (2) Zip-Type FE |
|---|---|---|
| Plants in 150km | -0.12 | -0.80 |
| | (3.40) | (3.89) |
| Local ownership concentration | 0.00 | 0.01 |
| | (0.20) | (0.21) |
| Customer size (year) | -0.75 | 3.53 |
| | (18.17) | (18.53) |
| Post-Cartel | 20.88*** | 21.33*** |
| | (7.14) | (7.25) |
| Constant | 4.58 | 7.94 |
| | (24.54) | (28.13) |
| Obs. | 1986 | 1986 |
| $R^2$ | 0.11 | 0.15 |
| Within $R^2$ | 0.02 | 0.02 |
| Mean Dep. Var. | 9.30 | 9.30 |

Notes: Dependent variable: variation coefficient (multiplied by 100) of prices charged at for specific unloading point. Unit of observation: aggregated purchases for a specific cement consistency (strength 32.5, 42.5 and 52.5) at an unloading point in a specific year (1993–2005) for all customers. Regressions include fixed effects at the zip code and cement consistency level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

# 6 Alternative explanations

**Other theories predicting that the transport distance is higher with competition.** The theoretical foundation for our predictions is that, in the intermediate parameter regions of our model, only mixed strategy equilibria exist under competition. We interpret the mixed strategy equilibria as a form of strategic uncertainty about the individual price offers of the competitors. This uncertainty leads to inefficient allocations of customers to suppliers. Firms serve demand in a larger radius under competition than under collusion. A standard model of competition, such as the well-known Hotelling model without capacity constraints and two symmetric firms, would not predict that transport distances change with the mode of competition: both under competition and under collusion the market is shared equally – in line with transport cost minimization. This holds irrespective of whether firms price discriminate.

There are other theories which predict that firms supply more distant customers under competition than under collusion [Deltas et al., 2012; Salvo, 2010b]. However, these models do not match important features of the cement industry under investigation. In particular, they do not take capacity constraints into account and the results do not hold if price discrimination is possible. Consequently, these models make no prediction on the change in transport distance if the capacity-demand ratio changes. Moreover, they do not predict any change in the price variation or the supply dynamics due to competition.

**Inefficient production during the cartel.** One could alternatively consider that firms do not serve markets efficiently when they collude. For example, this might be because a cartel agreement permanently allocates customers to the different firms on the basis of transport distances and average production costs, but does not take short-term production cost differences into account. In contrast, under competition, abstracting from capacity constraints, the most cost efficient firm at a particular point in time would serve each customer. Competition could thus yield an increase in the average transportation distance if there are sufficient short-term differences in costs that do not depend on the transport distance. However, we would not expect large short-term efficiency changes on a regular basis as the production technology in the cement industry is rather well developed and stable over time. The data also shows that in the years with competition, the customers switched suppliers more and prices varied more than in the cartel years. This suggests that there would have to be substantial cost volatility if this result were not driven by the strategic uncertainty of the competitive mixed strategy equilibrium. Moreover, we observe that demand decreases (relative to capacity) are correlated with larger transport distances, but only if firms compete. This can be explained in our model with capacity constraints. Without capacity constraints, a model with significant volatility in the individual plant's costs would not predict increased transport distances.

**Changes in transport cost.** One might be concerned that higher transport distances in the post-cartel period starting in 2002 could be due to lower marginal costs of transport and not (only) the cartel breakdown. The regressions in Table 2 and Table 3 account for these possible changes through the inclusion of the regional diesel price index. In Annex VI, we further show that (marginal) transport costs did not decrease post-cartel. There, in addition to this robustness check, we derive an interval of plausible marginal transport costs.

**Retaliatory measures.** A potential robustness concern might be that an increase in the transport distance after the cartel breakdown could be due to retaliatory measures against Readymix, the defecting cement supplier. The other suppliers could have punished Readymix by supplying customers of Readymix at lower prices. This might have resulted in exceptionally high shipping distances that would not occur in the case of short-term profit-maximization. Given the high transport costs of cement and reinforced by the cartel agreement, the customers of Readymix should have mainly been within the typical shipment distance around the cement plants of Readymix. Consequently, retaliatory measures against Readymix should, if at all, have predominantly increased the transport distance at unloading points near the Readymix cement plants. We therefore investigate in Annex VII the alternative hypothesis that retaliatory measures in relation to the firm that deviated from the cartel agreement explain the increase in distance. We do not find empirical support for such a claim.

# 7 Conclusion

We study the spatial sales patterns in an industry with significant transport costs and capacity constraints. For this, we investigate the allocation of customers to suppliers in the cement industry in Germany from 1993 to 2005, where a cartel existed in part of the observation period. We show that the transport distances between suppliers and customers were, on average, significantly lower during the cartel period than in the later period of competition. We control for other potentially confounding factors, such as the number of production plants, plant ownership, diesel costs, and retaliatory actions.

Consistent with the above-mentioned finding, we present a theory based on a Bertrand-Edgeworth model that predicts inefficiently long transport distances when firms compete, but not if they collude. We identify a competitive equilibrium where capacity-constrained firms mix their prices. The conditions for this equilibrium are arguably fulfilled in the cement industry under investigation. In equilibrium, the average transport distance increases when the capacity-demand ratio increases. The prediction is thus that the average transport distance varies in the degree of capacity utilization if there is capacity-constrained competition, but not if there is a well-organized cartel. Hence, changes in the capacity-demand ratio that are not accompanied by changes in the average transport distance can be an indication of coordination among capacity-constrained competitors.

We find support in the data for the theory: for a given level of capacity, an increase in demand leads to a lower average transport post-cartel, but has no significant effect on the transport distance during the cartel period. Consistent with a competitive mixed strategy equilibrium in prices and the notion of strategic uncertainty, we also find that the price variation as well as the variation in transport distance are higher post-cartel and customers switch their suppliers more often.

The results of our study help to better understand the competitive process and provide hints for distinguishing competition and coordination when analyzing market data. For instance, when assessing the merger M.7009 HOLCIM/CEMEX WEST in 2014, the European Commission took past cartel behavior in the German and European cement industry into account and investigated whether the relevant cement markets exhibited signs of coordinated behavior between the cement producers. 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.[44] A result of the present article is that, in such a case, one could also analyze average transport distances as well as measures of volatility. For instance, one could study whether – other things equal – average transport distances decreased again in the years up to the merger control assessment. This could indicate (though not prove) a return to the coordination of the cement producers' behavior. Besides merger control, our results can also be used for cartel prosecution.

Furthermore, our results point to a transport inefficiency that occurs under competition. The point estimate for the additional transport distance of cement under competition is close to 26km (from an average transport distance during the cartel of about 90km). Based on various sources, we consider it likely that the typical

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

marginal transport costs per ton-km for the typical shipping by truck are in the range of 4 to 20 euro-cents. The additional transport costs are therefore likely to be in the range of about 1 to 5 euros per ton of cement.[45] For comparison, estimates of the overcharge of cement customers due to the cement cartel are in the order of 15 euros per ton and thus much higher than the estimated cost-savings due to the cartel.[46] This indicates that the cartelists benefited mainly from raising prices, and to a lesser extent, from transport cost savings. Interestingly, the cartelists' profit margin for each ton of sold cement potentially increased more than the estimated price-overcharge, as the cartel apparently also lead to lower costs. Furthermore, it is noteworthy that the estimated additional average transport distance in the case of competition is substantial and implies a waste of resources.

Besides cement, our model applies to various other products and industries where capacity constraints and a form of spatial differentiation or adaption costs exist. These include not only 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, it appears to be of competition policy interest if one could extend the model to allow for more than two possibly asymmetric firms and simulate the effects of mergers in such a setting. Finally, to further support the theory, it would be valuable to observe the pattern of lower transport costs during a phase of collusion also in other industries.

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45 This approximation results from multiplying the additional 26 km respectively with 4 and 20 euro-cents per km.

46 The estimate of Hüschelrath et al. [2016] is obtained with fixed effects regressions and expressed in terms of 2010 prices. It is based on the data set that we also use in the present paper. For reference, average cement prices during the cartel amounted to about 78 euros.

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# Annex I: Price Discrimination

So far we have assumed that the firms (have to) set uniform prices across customers. In general, price discrimination tends to increase efficiency. For example Deltas et al. [2012] show in a model without capacity constraints that price discrimination results in a cost-minimizing customer allocation under competition and collusion. In contrast, we show that inefficiencies arise under competition even when perfect price discrimination is feasible if there are capacity constraints.

We only deviate from our previous assumptions by allowing each firm $i$ to set a different price $p^i(x)$ for each location $x \in [0, 1]$. For cement, this is plausible as cement suppliers can set prices individually for the different industrial customers and their location is typically known.[47] Whenever capacities bind, we employ the same rationing rule as before.

We first establish a symmetric pure strategy equilibrium, which features an efficient allocation of customers to firms. We show that if there is no pure strategy equilibrium, there is an allocative inefficiency. We also show that a symmetric mixed strategy equilibrium with uniform prices exists for a range of transport costs.

Let us first characterize the case without capacity constraints. This also establishes the candidate pure strategy equilibrium for the case of capacity constraints.

**Lemma 2.** *If firms compete without capacity constraints, transport costs are minimized and each firm serves its closest customers up to a distance of* 0.5*. Prices decrease from both ends of the unit line toward the center.*

*Proof.* See Annex II. □

Let us turn to the case of competition with capacity constraints. There exists no pure strategy equilibrium if $v$ is relatively large compared to transport costs. The condition differs from the case of the uniform-pricing restriction above because the profits in the pure strategy equilibria are larger with price discrimination.

[47] Note that due to customer-specific pricing this model could be equivalently expressed in terms of customers bearing the transport costs.

**Lemma 3.** *If firms can price discriminate, a pure strategy equilibrium does not exist if the valuation is sufficiently large for a given cost structure $C(x)$ and capacity level $k \in (0,5;1)$, that is,*

$$v > \frac{\int_{0.5}^{1} C(x)dx - \int_{1-k}^{0.5} C(x)dx}{1-k} \equiv \hat{v}. \tag{6}$$

*Proof.* See Annex II. □

The threshold $\hat{v}$ increases in the costs of serving the home market, and in the degree of excess capacity $k$, but decreases in the cost difference between the firms of serving intermediate customers.

We now turn to the case that $v > \hat{v}$, such that no pure strategy equilibria exist, and study symmetric mixed strategy Nash equilibria. Such an equilibrium is defined by a symmetric pair of joint distribution functions over the prices of each firm.

**Proposition 5.** *If a pure strategy equilibrium does not exist, any mixed strategy equilibrium features a strictly inefficient customer allocation with positive probability.*

*Proof.* See Annex II. □

We now derive conditions under which firms charge only uniform prices in equilibrium, albeit they could charge different prices for each customer.

**Proposition 6.** *The symmetric mixed equilibrium in uniform prices exists even when firms can price discriminate if the valuation of the product is sufficiently high for a given cost structure:*

$$v \geq C(k) + \frac{\int_{1-k}^{k} C(k) - C(x)dx}{(1-k)^2}. \tag{7}$$

*Proof.* See Annex II. □

The proposition establishes that mixed strategy equilibria with endogenously uniform prices exist for a certain parameter range with a sufficiently large $v$.[48] Compared to other models of competition among symmetric firms where perfect price discrimination is feasible, a surprising consequence of the uncertainty in the mixed strategy equilibrium is that competition does not yield cost minimization. In equilibrium, some of the *intermediate customers* are almost certainly served by the more distant firm. The size of this transport inefficiency increases in the ratio of capacity relative to demand (that is $k$, see Proposition 3).

With higher transport costs, there is no equilibrium with only uniform prices because firms have an incentive to increase prices for more distant customers above the price level for close customers. If both firms play a mixed strategy equilibrium with sometimes larger prices for more distant customers, each firm faces lower prices of its competitor for its more distant customers. This makes it easier to satisfy the indifference over prices in the mixed strategy equilibrium. In a less general setting with linear costs and only four customers, we obtain such a mixed strategy equilibrium with increasing prices for relatively high transport costs [Hunold and Muthers, 2019]. In that setting, however, it is not possible to analyze how the average transport distance changes in the level of capacity relative to demand. Based on the previous results, we conjecture that similar equilibria with strictly increasing prices also exist in this more general setting with a continuum of customers and a general cost function.

It is noteworthy that the parameter range for which the derived equilibrium with endogenously uniform prices arises can be large. For instance, condition (7) becomes

$$v \geq t \, \frac{1 - 2k + 2k^3}{2(1-k)^2} \tag{8}$$

[48] To be precise, the condition holds for a given $v$ 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 $x \in (1-k, k)$.

with linear transport costs. 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 (6). When total capacity exceeds demand by up to approximately 25 percent, there is always a mixed strategy equilibrium where firms play only uniform prices, i.e., condition (8) holds if condition (6) holds.[49]

In Annex VII we discuss how the parameter regions of the linear model match the empirical conditions of the cement industry.

## Annex II: Proofs

*Proof of Proposition 2.* 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 maximum 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 almost surely the latter outcome does not occur, 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

49 This can be seen when setting the right-hand sides of equations (8) and (2) equal and solving for $k$.

demand (customers) uniformly distributed on the line. As a consequence, the mass of demand 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 $L$:

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

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

$$F^R(p^L) = \frac{p^L k - v\,(1-k) - \int_{1-k}^k C(x)dx}{p^L(2k-1) - \int_{1-k}^k C(x)dx}. \tag{9}$$

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 1:

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

$$\implies \underline{p} = \frac{v \cdot (1-k) + \int_{1-k}^k C(x)dx}{k}. \tag{10}$$

□

*Proof to Proposition 2.* Suppose that each firm has the 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 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 $\int_0^1 \{v - \min[C(x), C(1-x)]\} dx$. □

*Proof to Lemma 3.* 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 pricing with asymmetric costs). Hence, there is no incentive to undercut these prices. Similarly, there is no incentive to reduce the prices for those customers at a distance of less than 0.5 as they are already buying from the firm. In view of the other firm's capacity constraint, it is now potentially profitable to charge the highest possible price to all those customers that the firm wants to serve, that is, their valuation of $v$. All customers prefer to buy from the other firm at the lower prices which range from $C(1/2)$ to $C(1)$. 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 of $\int_0^{0.5} C(1-x) - C(x)dx$ if

$$v \cdot (1-k) - \int_0^{1-k} C(x)dx > \int_0^{0.5} C(1-x) - C(x)dx$$
$$\Leftrightarrow v > \frac{\int_{0.5}^{1} C(x)dx - \int_{1-k}^{0.5} C(x)dx}{1-k}. \tag{11}$$

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 simplifies to

$$v > t\left[\frac{1}{4(1-k)} + \frac{1-k}{2}\right]. \tag{12}$$

The condition holds for sufficiently small transport costs. There are potentially equilibria with even lower prices, in which firms set prices below costs for customers that are closer to the competitor. 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. □

*Proof to Proposition 5.* An inefficiency occurs if the capacity is binding for any firm in a mixed strategy equilibrium with positive probability. A binding capacity means that a firm serves a fraction $k > 0.5$ of the market. This implies that the firm serves customers at the more distant half of the market for which it is not the most efficient supplier.

Suppose there was a symmetric mixed strategy equilibrium in which the capacity would never be binding for any firm. If there is a mixed strategy equilibrium in which the price support of the two firms strictly overlaps at any location, there is an inefficiency because the less efficient firm will sometimes win customers in that location. Thus, the only possible efficient mixed strategy equilibria are equilibria in which the firm that is cost efficient for a customer charges that customer only weakly lower prices than its competitor. If that was the case, the competitor, however, would have a strict incentive to lower its prices unless the efficient firm only charges prices below the marginal cost of the competitor. Recall that in the equilibrium which we construct the capacity does not bind for any firm, such that the pure Bertrand-pricing logic holds for an individual location. For a given location, this logic rules out equilibrium prices that are larger than the marginal cost of the less efficient firm in that location. This leaves only price distributions with prices that are equal to the larger marginal costs at a particular location, or between the two levels of marginal costs in this location. However, those prices are dominated by serving only the residual fraction of the market, $1-k$, with a price equal to $v$ for all customers (see Lemma 3). Hence, there cannot be a mixed strategy equilibrium without an inefficiency whenever there is no pure strategy equilibrium. □

*Proof of Proposition 6.* Consider that firm $R$ plays uniform price functions according to the distribution function $F_R$ stated in Equation (9) in Annex I. The distribution function $F_R$ is defined such that firm $L$ is indifferent between all uniform prices on the support $[\underline{p}, v]$.

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 (9). Consider prices for two customers with locations $x$ and $y$, where $y > x$. Suppose in contrast to weakly increasing prices that $p^L(y) < p^L(x)$, 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 does switching the prices have an effect on profits and is strictly profitable. By switching 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 (9). 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 customers 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 (9) is derived such that there is no incentive to increase or decrease a uniform price function, 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 Equation (9)), one can show that this condition is monotonically increasing in $p^L$, such that it is most critical for $p^L(k) = \underline{p}$:

$$\begin{aligned} &\left[1 - F^R(\underline{p})\right] - f^R(\underline{p}) \left[p^L(k) - C(k)\right] \leq 0 \\ \Longleftrightarrow\ &v \geq C(k) + \frac{\int_{1-k}^{k} C(k) - C(x)dx}{(1-k)^2}. \end{aligned} \tag{13}$$

□

*Proof of Proposition 4.* Suppose the firms' symmetric collusive strategy consists of a price $p^C(x)$ which customers at location $x \in [0, 1]$ should pay and the allocation of the customer to one or the other firm: $Z(x) \in \{L, R\}$. The firms can implement this strategy in the following ways: Firm $Z(x)$ charges customers at location $x$ a price of $p(x)$. The other firm charges the customers at location $x$ a price of $p(x) + \epsilon$, where $\epsilon$ is strictly positive but arbitrarily close to 0. This ensures that firms serve the customers according to the collusive allocation rule $Z(x)$. Any allocation that is compatible with the capacity levels can be implemented with any price level in 0 to $v$.

For given price levels, the incentive to deviate is minimized, as the firm that does not get a customer in the collusive equilibrium charges the lowest possible price compatible with these price levels.

The choice of the price levels $p(x)$ is independent of the allocation $Z(x)$ as a switch between the collusive prices of the two firms has no effect on the effective price levels but changes only the allocation of customers between the two firms.

Thus, the price level for each customer, which determines the deviation profit, is independent of the allocation of customers in the collusive equilibrium. As the collusive allocation does not affect the deviation profit, the only objective of the customer allocation is thus to maximize collusive profit $\pi^C$. Any allocation that does not minimize transport costs cannot maximize the collusive profits as then there exists a price switch between the two firms that discretely reduces costs without affecting the price level. □

# Annex III: Estimates for model parameters

In this annex we relate the parameters of the theory model to the empirical values. We first argue that the assumption of linear transport costs is a reasonable approximation. Under this assumption, we highlight that there appears to be a large parameter area in the model where uniform mixed strategy equilibria exist. We illustrate that the empirical values are consistent with mixed strategy equilibria that feature uniform pricing. A caveat applies as the theory model is a stark abstraction of the market – it does not include the geography and restricts attention to two suppliers. Moreover, the empirical values are only rough estimates.

Our theory model predicts different outcomes, from local monopolies to perfect price competition, with the interesting area of mixed strategy equilibria in-between.

The assumption of linear transport cost seems reasonable for the cement industry in Germany where most shipments are made by truck. The predicted outcomes of the model depend on the valuation $v$, the transport cost parameter $t$, and the ratio of capacity relative to demand, $k$. The monopoly outcome only occurs if $k \leq 1/2$, i.e., total capacity does not exceed demand. Data provided by the German cement association as well as the analysis in the competition policy cases suggests that there has been significant excess capacity. Moreover, there would be limited need for a cartel in such a situation of local monopolies.

The more interesting distinction is between the pure strategy and the mixed strategy equilibrium. Condition (6) distinguishes between these cases. Condition (7) distinguishes between the cases under which uniform price equilibria occur and where such equilibria do not exist. Figure 3 shows these two conditions in a diagram with $v/t$ on the vertical axis and $k$ on the horizontal axis. Uniform, mixed strategy equilibria result if $v/t$ is large and $k$ is not too large. The parameter area for mixed strategy equilibria in uniform prices is a subset of a general area where no pure strategy equilibria exist. From the graph one can note that uniform price equilibria can be sustained over a rather large parameter area.

With more capacity relative to demand, the uniform price equilibria only exist if the transport costs are not too large. For instance, if total capacity exceeds demand by 50 percent ($k = 0.75$), the valuation $v$ must be at least twice as large as the costs of serving the most distant customer for which each firm has capacity. As the model is specified in a duopoly context with a uniform distribution of consumers, there are clear limitations when trying to match the parameter regions to the data of the cement industry. With this caveat in mind, let us elaborate what could be reasonable estimates for the parameters $v$, $t$ and $k$ that describe the theoretical parameter regions.

Let us start with $v$. As a rough approximation, it seems reasonable to consider demand as price inelastic up to some point. In our model, the cartel price depends

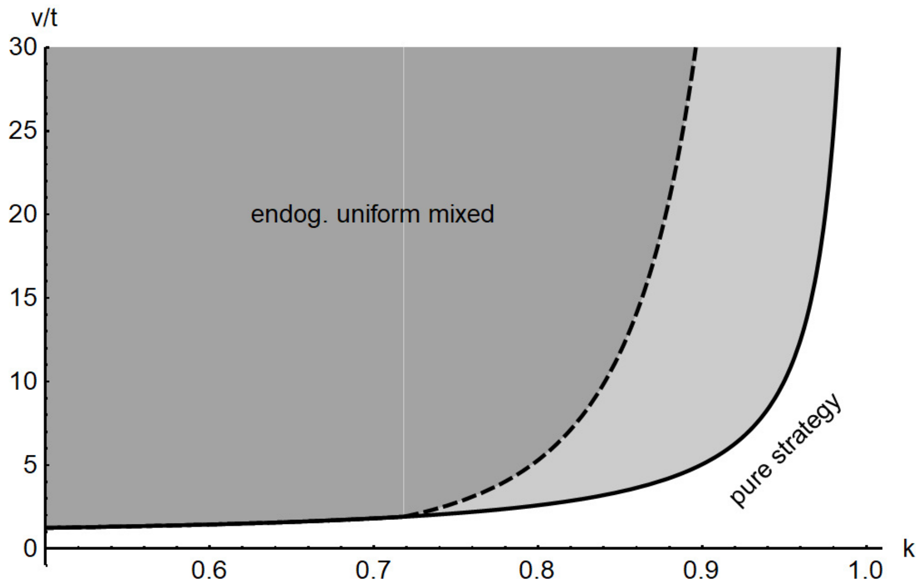



Figure 3: Parameter conditions – assuming linear transport costs – for the mixed strategy equilibrium and uniform prices. No pure strategy equilibrium exists for parameters above the solid line, while a uniform price mixed strategy equilibrium exists for parameters above the dashed and above the solid line.

on how patient the firms are, and equals $v$ if the firms are sufficiently patient. Given that there were several asymmetric cement producers in Germany during the time of the cartel, and considering that according to industry sources the price level in Germany is rather low compared to other various Western-European countries, we conjecture that the cartel price level of about 71€ per ton during the cartel phase was well below the valuation $v$ (see the descriptive statistics in Table 1).

The parameter $t$ in the model describes the linear transport cost for the total distance (a length normalized to one) between the firms. One rough estimate of $t$ can be derived from the average distance in the cartel phase and the per-km costs of transport under the assumption that markets are allocated efficiently during the cartel. This corresponds to an average transport distance in the model of 1/4 during the cartel. In our data, during the cartel phase, on average, firms serve customers at a distance of 91km. An estimate for $t$ can thus be calculated using the costs of transporting to a distance of four times the average of 91km.

We have looked at different sources to derive a rough estimate of the per km transport costs empirically. Using the freight costs indicated in the invoices, the average freight cost per km, albeit including fixed transport cost like loading and unloading, is 0.13€ (see Table 1 for the freight cost descriptives). Our regression gives us an estimate of the marginal transport costs of 0.04€ per km (see Appendix IV). With an average distance of about 91km, this gives us a transport cost estimate for $t = C(1) = 0.04\,\text{euro-cents/km} \cdot 4 \cdot 91\text{km} \approx 14.6$ euro-cents and $v/t$ of just below 5. As one can see in Figure 3, at $v/t = 5$ there is a large range of $k$ for which uniform price equilibria exist, that is, up to $k$ of about 0.8 and other non-mixed strategy equilibria up to $k$ of about 0.9. As we do not have capacity measures in our data set, we need to rely on external sources. Friederiszick and Röller [2002] state that capacity utilization was below 70 percent during the early cartel years. In the model, 70 percent capacity utilization when serving half of the market would translate into $k = 0.5/0.7 \approx 0.71$. For an excess capacity $k = 0.71$ only uniform price mixed strategy equilibria exist.

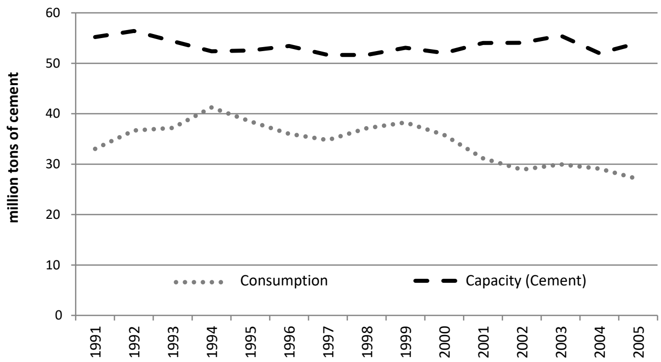
Overall, relating the parameters of the theoretical model to empirical estimates shows that it is plausible that the parameters are in a range where mixed strategy equilibria result, and, moreover, even endogenously uniform prices.

## Annex IV - Annex IX

**Supplemental Materials for Hunold, Matthias, Hüschelrath, Kai Laitenberger, Ulrich, and Muthers, Johannes 'Competition, Collusion, and Spatial Sales Patterns – Theory and Evidence,'**

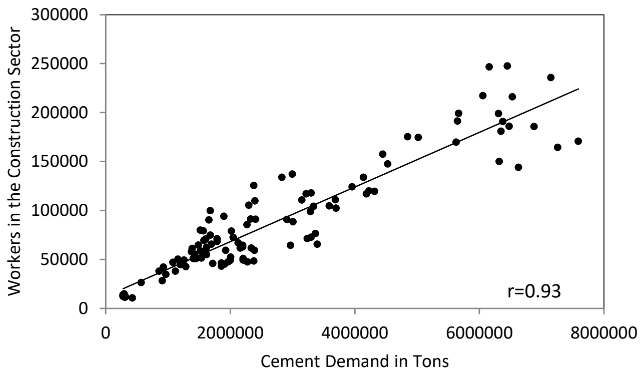
# Annex IV: Additional graphs

Figure A1: Cement capacity, production, demand, and capacity utilization




The figure shows the evolution of domestic cement consumption in Germany between 1991 and 2005 and the capacity utilization of the domestic plants. Source: German Cement Association, Friederiszick and Röller [2002] and own calculations.

Figure A2: Cement consumption and construction employment for the German Bundesländer (states) 1993–2005




The figure shows combinations of annual cement demand in tons and the corresponding number of workers in the construction sector in a German Bundesland for the years 1993 and 2005. Sources: German Statistical Office, Regional Statistical Offices and own calculations.

# Annex V: Variance of the residuals from the distance-regressions

Tabelle A.I: Analysis of residuals from the regressions in Table 2 and 3

| | Distance | | Rank | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Diesel price index (regional) | 0.05 | -0.11 | 0.00 | -0.00 |
| | (0.06) | (0.10) | (0.00) | (0.01) |
| Plants in 150km | 0.15 | -1.73 | 0.13 | -0.08 |
| | (2.15) | (1.83) | (0.18) | (0.13) |
| Local ownership concentration | -0.30 | -0.35** | -0.01 | 0.00 |
| | (0.20) | (0.16) | (0.01) | (0.01) |
| Customer size (year) | -11.77 | -13.53 | -2.61** | -3.43*** |
| | (17.29) | (16.80) | (1.08) | (1.25) |
| Post-Cartel | 18.28*** | 94.93*** | 1.04*** | 4.80*** |
| | (3.09) | (19.16) | (0.24) | (0.94) |
| Construction Employment (CE) | | -0.16 | | -0.02 |
| | | (0.19) | | (0.02) |
| Post-Cartel*CE | | -0.94*** | | -0.05*** |
| | | (0.21) | | (0.01) |
| Constant | 27.14 | 73.04** | 0.76 | 4.47* |
| | (16.48) | (28.71) | (1.31) | (2.33) |
| Obs. | 1312 | 938 | 1312 | 938 |
| $R^2$ | 0.56 | 0.64 | 0.65 | 0.71 |
| Within $R^2$ | 0.09 | 0.17 | 0.06 | 0.11 |
| Mean Dep. Var. | 26.73 | 28.79 | 1.75 | 1.96 |

Notes: Dependent variable: (absolute) residuals of a regression of distance (columns (1) and (2) and rank of the supplying plant from the viewpoint of the buyer (columns (3) and (4)). Unit of observation: aggregated purchases at a customer's unloading point in a specific year (1996–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters.

$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

# Annex VI: Transport costs

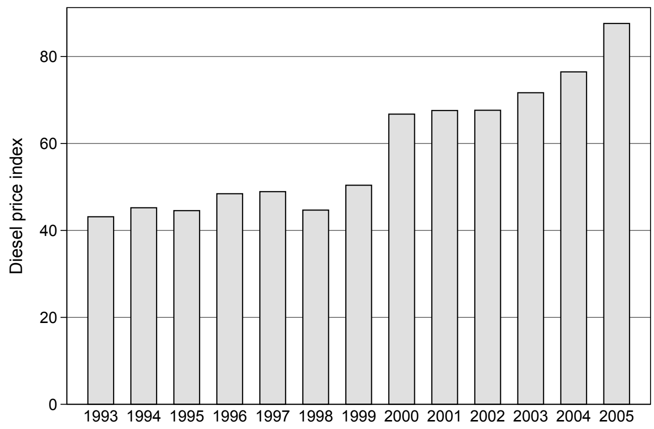
In this annex, we show both descriptively and by means of a regression analysis that marginal transport costs did not decrease post-cartel. Furthermore, we derive an interval of plausible marginal transport costs, which we use to roughly quantify the possible additional transport costs when firms compete.

**Descriptive analysis.** One might be concerned that higher transport distances in the post-cartel period starting in 2002 could be due to lower marginal costs of transport and not (only) the cartel breakdown. To investigate this claim, we retrieved data on the development of the diesel price in Germany.[50] However, as revealed by Figure A3, we do not observe a decrease in transport costs in these years in the diesel price. 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. 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.

**Regression results.** We study the transport costs as stated in the customer invoices. As we do not suspect the transport costs of different cement consistencies to be different, we aggregate the invoice 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 costs in various ways, as shown in Table A.II. In columns (1)

[50] Note that in the regressions in the main part, we used information on the regional development of diesel prices. This data was unfortunately not readily available. We therefore approached all regional statistical offices in Germany. We got partially positive responses from six states (Baden-Württemberg, Bavaria, Hesse, Rhineland-Palatinate, Berlin and Brandenburg), for the others there was no data available. If a time series started later, we backcasted the values of the series assuming the same development as on the national level. For the states where no data was available, we imputed the series by the following procedure. We first used indices of neighboring states, i.e., 1) the index of state Brandenburg to fill in values for the remaining north-eastern states Mecklenburg Western Pommerania, Saxony, Saxony-Anhalt, and Thuringia, and 2) the index of Rhineland Palatinate for Northrhine-Westphalia. For the north-western states Lower-Saxony, Bremen, and Schleswig-Holstein we used the national index as there was no data for any neighboring state available.

Figure A3: Evolution of the German diesel price index




Source: German Statistical Office

to (3), we include fixed effects of the customer unloading point (zip code) and the cement production plants. This allows us to control for time-constant differences of the unloading-point or plant-specific fixed costs of transport, such as the simplicity of loading and unloading. For 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 the production point and the unloading point. This allows us to compare the total transport cost for the same supply relation over time.[51] Again, we are unable to find a statistically significant decrease in relation to specific transport costs post-cartel.

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)

[51] Note that as the distance between production plants and the unloading points of customers do not change over time, the distance regressor is omitted here.

with the negative coefficient of the quadratic distance term). We find significantly higher marginal transport costs when including only the observations with transport distances below 150km in the regression (column (2)). For these observations, the truck is the likely means of transport.[52] Compared to the results of column (1), we consider these estimates of 0.04 euro-cents per km in 2005 prices as a more plausible measure for the typical transport distance observed in the data – the average distance is approximately 100km (Table 1).

*Summary.* We do not find support for the alternative explanation that higher transport distances post-cartel are caused by lower transport costs.

**Transport cost estimate.** The positive and significant coefficients of the distance measures in the previous regressions indicate positive marginal transport costs. The arguably most plausible estimate amounts to 0.04 euro-cents in 2005 prices for the typical transport distance of around 100km (Table 1). Still, the estimates are about half the size of those derived in an older industry study. Friederiszick and Röller [2002] report incremental freight costs of 0.16 Deutsche Mark per ton-km.[53] This amounts to about 0.10 euro (in 2010 prices). This number is in line with our back-of-the-envelope calculation for a 27 ton silo truck where we consider the costs for a driver, diesel, and truck wear and tear. Depending on the parameters in this calculation, such as the truck's typical capacity utilization, one can also rationalize costs of up to about 0.20 euro.

Our lower regression estimates might be explained by the fact that we do not necessarily measure the true costs accurately, but only the transport costs reported in the customer invoices. Potential reasons for our lower estimates are incomplete reports of transport costs as a separate item in the invoices, wrong allocations of costs

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

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

across the items cement price and freight costs, as well as our imprecise measures of distance on the right-hand side (attenuation bias).[54]

*Summary.* We find marginal transport costs in the range of about 4 to 20 euro-cents per ton-km in 2010 prices to be most plausible for the observed post-cartel period in Germany.

[54] It is interesting to note that Miller and Osborne [2014] obtain relatively high transport cost estimates of around $0.46 per ton-mile by means of a structural model which uses aggregate market data on annual regional sales and production in the United States. Miller and Osborne (see p. 222) 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 percent of total cement costs for shipments per truck at a distance of about 100km.

Table A.II: 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) | |
| Post-Cartel*(Dist.(km)) | 0.00 | 0.00 | 0.00 | |
| | (0.85) | (0.71) | (0.27) | |
| Shipment distance (km) - squared | | | -0.00*** | |
| | | | (-4.10) | |
| Post-Cartel*(Dist.(km) - squared) | | | 0.00 | |
| | | | (0.33) | |
| Constant | 6.90*** | 4.44*** | 4.58*** | 8.62*** |
| | (10.67) | (10.92) | (9.17) | (113.74) |
| 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 |
| Mean Dep. Var. | 8.52 | 7.32 | 8.52 | 8.52 |

Notes: Dependent variable: Transport cost per ton as stated in the customer invoice deflated to the year 2005. Unit of observation: aggregated purchases by a customer at an unloading point from a specific plant in a specific year (1993–2005) for all shippings (columns (1), (3) and (4)) and for shippings below 150km in distance (column (2)). Regressions include fixed effects at the zip code of the unloading point and cement plant level (columns (1) to (3)) or at the combination of those ('relation,' column (4)). Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Annex VII: Deviating cartel member (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 have punished Readymix by supplying customers of Readymix at lower prices. This might result in higher transport distances than in the case of competition where firms maximize their individual short-term profits. 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 Readymix cement plants. 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

$$y_{c,u,t} = \beta_1' X_{c,u,t} + \beta_2 \textit{Post-Cartel}_t + \beta_3 \textit{Post-Cartel}_t \cdot \textit{Readymix}_{c,u,t} + \varepsilon_u + \epsilon_{c,u,t}, \quad (14)$$

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 radius to the respective unloading point, and is zero otherwise.

The respective regression results can be found in Table A.III. The regressions show that the presence of the deviating firm is not a good predictor of 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 Readymix cement plant in the area or not.

*Summary.* We are unable to find 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 A.III: Robustness check: Readymix AG (RMC) plant near customer

| | Distance | | Rank | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Diesel price index (regional) | 0.06 | 0.06 | 0.01 | 0.02 |
| | (0.13) | (0.14) | (0.01) | (0.01) |
| Plants in 150km | -0.10 | 1.54 | 0.12 | 0.09 |
| | (3.98) | (4.08) | (0.28) | (0.28) |
| Local ownership concentration | -0.67** | -0.51 | -0.03** | -0.03** |
| | (0.33) | (0.34) | (0.01) | (0.01) |
| Customer size (year) | 17.89 | 16.22 | -3.01 | -3.00 |
| | (37.14) | (35.26) | (2.34) | (2.32) |
| Post-Cartel | 25.72*** | 18.93** | 1.39** | 1.46** |
| | (7.40) | (8.32) | (0.61) | (0.72) |
| RMC plant in 150km | | -9.74* | | 0.46 |
| | | (5.58) | | (0.81) |
| Post-Cartel*(RMC plant in 150km) | | 25.89 | | -0.25 |
| | | (19.42) | | (1.18) |
| Constant | 117.54*** | 103.43*** | 2.99 | 3.05 |
| | (31.95) | (33.09) | (2.26) | (2.17) |
| 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 |
| Mean Dep. Var. | 110.22 | 110.22 | 4.19 | 4.19 |

Notes: Dependent variable: distance between the buyer and the producer (columns (1) and (2)); rank of the supplying plant from the viewpoint of the buyer (columns (3) and (4)). Unit of observation: aggregated purchases at a customer's unloading point in a specific year (1993–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Annex VIII: Price variation and varying demand

Table A.IV: Robustness check: Variation coefficient with demand proxy

| | (1)<br>Zip and Type FE | (2)<br>Zip-Type FE |
|---|---|---|
| Plants in 150km | 1.13 | -0.81 |
| | (3.73) | (4.77) |
| Local ownership concentration | -0.25 | -0.19 |
| | (0.19) | (0.19) |
| Customer size (year) | -8.58 | -13.05 |
| | (22.71) | (24.17) |
| Post-Cartel | 23.96*** | 23.65*** |
| | (8.87) | (8.65) |
| Construction Employment (CE) | -0.10 | -0.12 |
| | (0.21) | (0.21) |
| Constant | 12.65 | 27.11 |
| | (36.84) | (43.14) |
| Obs. | 1370 | 1361 |
| $R^2$ | 0.14 | 0.20 |
| Within $R^2$ | 0.02 | 0.02 |
| Mean Dep. Var. | 10.56 | 10.63 |

Notes: Dependent variable: variation coefficient of prices charged at a specific unloading point, calculated over different customers (columns (1) and (2)) or for the same customer (columns (3) and (4)). Unit of observation: aggregated purchases for a specific cement consistency (strength 32.5, 42.5 and 52.5) at an unloading point in a specific year (1996–2005) for all customers (columns (1) and (2)) or for customers separately (columns (3) and (4)). Regressions include fixed effects at the zip code and cement consistency level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Annex IX: Supply dynamics

Table A.V: Descriptive statistics for supply dynamics

| | Cartel period | | Post-Cartel Period | | Overall | |
|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| # Plants | 1.47 | 0.68 | 1.62 | 0.78 | 1.50 | 0.71 |
| % Main plant | 0.92 | 0.15 | 0.92 | 0.13 | 0.92 | 0.15 |
| Change main plant | 0.18 | 0.38 | 0.23 | 0.42 | 0.19 | 0.39 |
| $\sum$ sq. share changes | 0.18 | 0.44 | 0.29 | 0.57 | 0.20 | 0.47 |
| $\sum$ sq. share changes, strict | 0.14 | 0.37 | 0.31 | 0.60 | 0.17 | 0.43 |
| Observations | 939 | | 373 | | 1312 | |

Notes: quantity-weighted averages. The number of observations refers to the aggregates at the annual customer unloading-point level.

Table A.VI: Regression results for supply dynamics (full sample)

| | (1) Ch. main pl. | (2) $\sum$ SSC | (3) $\sum$ SSC, (strict) |
|---|---|---|---|
| Plants in 150km | -4.51 | -3.37 | -1.22 |
| | (3.47) | (5.22) | (5.69) |
| Local ownership concentration | -0.50* | -0.54 | -0.36 |
| | (0.29) | (0.38) | (0.31) |
| Customer size (year) | 4.40 | 0.61 | 61.13** |
| | (18.99) | (24.56) | (28.67) |
| Post-Cartel | 11.31*** | 18.66*** | 21.90*** |
| | (3.72) | (5.36) | (5.60) |
| Constant | 66.25** | 62.91 | 29.68 |
| | (28.08) | (40.22) | (45.20) |
| Obs. | 994 | 994 | 729 |
| $R^2$ | 0.26 | 0.24 | 0.30 |
| Within $R^2$ | 0.02 | 0.03 | 0.06 |
| Mean Dep. Var. | 23.64 | 28.53 | 23.47 |

Notes: Dependent variables: Change in the main plant (measuring whether the main delivering plant is not the same as in the previous year (column (1)); Sum of the squared changes in supply shares of all plants supplying a customer's unloading point between two years (column (2)); Sum of squared changes in supply shares, excluding all customer unloading point-year combinations where the total demanded quantity was less than 25% or more than 200% of the total supplied quantity of the previous year (column (3)). Unit of observation: aggregated purchases for all cement consistencies at a customer's unloading point in a specific year (1993–2005). Regressions include fixed effects at the zip code level. Standard errors are robust to heteroscedasticity and adjusted for serial correlation inside clusters. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$