Firms price discriminate based on suppliers' relative distances to competitors

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Abstract: We derive a theoretical model predicting that firms should mark down input prices more the longer distance a supplier has to a competitor's plant relative to their own plant. We test this prediction using contract-level data on prices of waste burned at energy plants. To the best of our knowledge, we are the first to study whether firms price discriminate based on relative distance to the closest competitor. The empirical results confirm that longer relative distances to competitors' plants lead to lower prices and show no evidence of additional effects of the distance to the chosen plant.

Keywords: auction; market power; oligopsony; price discrimination; procurement; spatial competition; transport cost; waste incineration

JEL codes: D43; D44; L11; L13; Q53

1. Introduction

Waste is costly to transport and the distances between adjacent incineration plants are often large. Therefore, owners of waste incineration plants (which produce energy by burning waste) have local market power in the waste markets. The purpose of this paper is to determine whether these plants use this market power to price discriminate between suppliers by setting lower prices the longer distance a supplier has to a competitor's plant relative to their own plant and the lower the price a supplier can be expected to be offered by a competitor. We have no reason to believe that firms' price discrimination behavior differs between the waste market and other markets, and therefore we believe that the results will enhance our understanding of how firms in general price discriminate when transport costs are important.

We have access to a unique data set containing the individual input prices that incineration companies (hereafter called plants[1]) set for different municipalities (hereafter waste supplier or suppliers) that need to dispose of the household waste disposed in their areas. The prices are constantly negative, reflecting that the value of district heating and electricity produced using a ton of waste is less than the marginal cost of burning it. More interestingly, the prices vary a great deal, from SEK –430 (USD –45) to nearly SEK –660 (USD –70) per ton during 2019.[2] Because of the large variation in distances between adjacent plants across the country and the high transportation costs (on average, SEK 1.4 per ton and kilometers (km) round trip), it is possible, a priori, that the entire difference in mill prices is explained by plants more stringently marking down input prices the longer a waste supplier has to travel to a competitor's plant relative to their own plant.

To the best of our knowledge, we are the first to study whether firms use information on how much closer suppliers or customers are to their plant compared to a competitor's plant as a way to price discriminate.[3] One reason why this has not been explored before—either in an oligopoly or oligopsony setting—is that individual prices are rarely available when contracts are privately negotiated (Miller and Osborne, 2014; Jung et al., 2021). Moreover, the theoretical models have assumed that plants are equally spaced, which implies that suppliers' distances to their second-closest plant is perfectly correlated to their distances to their closest plant. This might also go some way to explaining why empirical studies have thus far focused on how prices depend on suppliers' distances to their closest plant and neglected the importance of the suppliers' distances to competitors' plants.

The paper also contributes to the existing literature by directly estimating to what extent the oligopsonists absorb transportation costs. Previous literature (e.g., Alvarez et al., 2000; Graubner et al., 2011b) have taken as given uniform delivery (UD) pricing, i.e., that the oligopsonists absorb all the transportation costs. They then estimated the parameters of the UD pricing schedule and how the oligopsonists competed. In our setting, it is not reasonable to assume that the oligopsonists use UD pricing. Therefore, we estimate an empirical model that directly allows us to test whether they used

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[1] All but two incineration companies in Sweden own only one incineration plant each, while the other two own two each in different parts of the country (see section 3.1 for details), making the distinction between companies and plants unimportant in this paper.

[2] In 2019, the average exchange rate was 9.46 SEK per USD and 10.59 SEK per EUR.

[3] Alvarez et al. (2000) study the price effects of the sum of distances from each firm to its nearest rivals. This is an approximate summary measure of the relevant distances for oligopsonists absorbing all freight costs of suppliers by using uniform delivery pricing.

UD pricing, uniform mill pricing (also called free-on-board pricing, FOB[4]), or whether they absorb a percentage of the transportation costs.

Empirically, we find that firms price discriminate by setting lower mill prices the longer the distance a supplier has to another plant relative to its own plant. Furthermore, we find no additional effect of the distance to the chosen plant, indicating that it is the relative distance that matters. In addition, the results allow us to reject the notion that all plants fully exploit the possibility to price discriminate and that plants absorb all transportation costs. Instead, the point estimates from different specifications suggest that they absorb only 12–15% of the cost.

When firms use their market power to price discriminate, it results in inefficiencies.[5] In this context of waste markets, the implication is that suppliers face differences in waste prices that do not reflect differences in the cost of incinerating the waste. This distorts the incentives to reduce the amount of residual waste. When suppliers act on these incentives, it increases the total costs of measures taken to reduce the amount of residual waste and of transporting and burning waste, compared to what would have been the case if plants did not exploit their market power. In welfare terms, this extra cost represents an efficiency loss.[6]

The rest of this paper is structured as follows. The next section provides a brief review of previous theoretical and empirical studies on spatial price discrimination, while the third section describes the Swedish market for waste incineration. The fourth section then presents the theoretical model before the fifth section presents the data. After that, the empirical specifications are presented, which is followed by a result section and, lastly, a discussion section.

2. Previous literature about spatial price discrimination

2.1 Theoretical studies

There is an extensive theoretical literature—including the early work of Schneider (1934, 1935), Palander (1935), and Hoover (1937), as well as the later work of, among others, Greenhut and Greenhut (1977)—that shows that firms with local market power should price discriminate by charging higher prices for the customers closest to their stores. The literature also shows that a second firm constrains the possibility to price discriminate because, under some assumptions, a firm cannot charge

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[4] Refers to the case when the oligopsonists do not absorb any transport cost.

[5] Note that market power would not cause inefficiencies if plants used two-part tariffs and let the per-unit price be equal to the value of the marginal product of waste and only used their market power to mark down the lump-sum component for each supplier. However, plants are not able to do this (as explained in the third section of the paper) because the waste suppliers´ procurement designs restrict them from using two-part tariffs, i.e., the plants cannot condition the price per ton of waste on the number of tons supplied. It is in the suppliers´ interest to prevent two-part tariffs, because otherwise the plants could potentially absorb all surplus in the market.

[6] All use of market power gives lower prices of waste. Translating the results of Thisse and Vives (1988) to this setting implies that the competition would be weaker, and the input-prices of waste lower, if firms collectively could commit to FOB instead of price discriminating. Because waste generation and incineration have external effects, a detail environmental-economics analysis is required to answer if lower waste price in general increases or reduces welfare. Still, it is clear that differences in prices of waste burned at the same plant cause efficiency losses.

a higher price (including transportation costs) than the sum of the competitor´s marginal cost and transportation costs to the customer (e.g., Hoover, 1937).

Several articles have analyzed the existence of equilibria in Hotelling (1929) models. For example, Gabszewicz and Thisse (1986) showed that with FOB pricing, a pure strategy equilibrium only occurs under restrictive assumptions. However, allowing for price discrimination and entry, MacLeod et al. (1988) showed that equilibria exist under relatively general conditions.

Löfgren (1986) presented the first theoretical model of spatial monopsony. He showed that the monopsonist should pay a price to the supplier at each distance to the mill so that the derivative of the supply function times the monopsonist's profit per unit of input equals the amount supplied at that distance to the mill. In practice, this merely means that—at each location—the marginal revenue of a price increase should equal the marginal cost of it. More importantly, Löfgren showed that if the supply function is linear the monopsonist should absorb half the transportation costs of the suppliers and that the monopsonist should always absorb part of the transport cost if the logarithm of the supply curve is strictly concave. However, if the logarithm of the supply curve is strictly convex, the optimal mill price is smaller for suppliers with larger transport costs, which is referred to as phantom freight.

Alvarez et al. (2000) developed a model for duopsony and showed that if duopsonists assume that competitors will match their price changes (i.e., Löschian competition) and use uniform delivery pricing (i.e., cover all transportation costs), prices may be set above monopsony level. This can happen if space is less important so that there is an overlapping area from which both firms buy. If firm A increases its prices over the monopsony level, it has a direct negative effect on its profits, but also implies that the market area of the firm will be reduced. Suppliers at the margin add nothing to the firm's profits, but under the Löschian conjecture, firm B will also reduce their market area. Thus, firm A can capture suppliers closer to its mill that have been abandoned by firm B, which explains the incentives for setting prices above the monopsony level.

Zhang and Sexton (2000) showed theoretically that exclusive contracts between duopsonists and suppliers can be used to diminish competition between duopsonists in some settings. In their 2001 paper, they analyzed the choice between FOB or UD prices in a duopsony model. They found FOB to be the dominant strategy equilibrium in markets where the freight costs are low relative to the price of the product being produced, while UD pricing is the equilibrium when the freight costs are relatively high. Graubner et al. (2011a) used an agent-based model to simulate the choice between FOB, UD, and partial freight absorption in a noncooperative duopsony market. Contrary to Zhang and Sexton (2001), they found UD pricing to be the equilibrium when the freight costs are relatively low and competition is intense. When competition is less intense, though, partial freight absorption is the equilibrium.

2.2 Empirical studies

Several theoretical studies have emphasized that distances can be in terms of product space (e.g., taste or nutritional content of breakfast cereals) as well as in terms of physical space. In empirical applications, there is a significant difference between product space and physical space because distances in product space are challenging, or even impossible, to measure accurately, while physical distances are often easily measured. For this reason, we summarize below only papers that have analyzed price discrimination in markets where physical distances are important.

Hwang (1979) found evidence of partial transport cost absorption in the coal market. On average, the sellers absorbed 63% of the transport cost. However, Hwang did not analyze how distance to competing sellers affected prices. Löfgren (1985) demonstrated that the price discrimination policy applied by cartelized pulpwood buyers was consistent with the theoretical prediction in his paper published in 1996 and, more precisely, that part of the transport cost was absorbed. Greenhut, Norman, and Hung (1987) reported that two-thirds of firms practiced price discrimination by absorbing at least part of the transport costs. Bailey et al. (1995) found that US cattle buyers absorbed a small part of the transport cost for small distances, but approximately 40% for longer distances. They did not control for distances to competitive buyers but did document a significant mark-down in counties dominated by buyers from one area and that producers located in areas where two or more markets overlap received significantly higher prices.

Taking UD pricing as given, Alvarez et al. (2000) found that transportation cost (measured as the sum of the distance to the nearest rivals multiplied by the price per liter of diesel fuel) had significant effects on milk prices paid to Spanish farmers. Graubner et al. (2011b) also took UD pricing as given and studied the pass-through of exogenous changes of the wholesale price of milk on the producer price. They found a pass-through that was close to zero and significantly smaller than one, which rejects the possibility of Hotelling-Smithies competition (i.e., the spatial version of Bertrand-Nash competition).

Miller and Osborne (2014) created a structural model to study the price discrimination of oligopolists using aggregated data from the US cement industry. Their results showed that transport cost allowed relatively isolated plants to charge higher prices from nearby customers. Using a similar model and aggregated data from the U.S. state of Indiana, Jung et al. (2021) found that market power caused by transportation costs allowed buyers to mark down prices of corn by 13%. However, they did not study price discrimination in this market.

To summarize, many previous studies have found evidence that firms price discriminate by allowing the mill price to be a function of the buyer's/seller's distance to the plant. However, no study has analyzed whether firms price discriminate by allowing the mill price be a function of the buyer's/seller's relative proximity to their plant compared to the closest competitor´s plant, which our theoretical model suggests would be profit maximizing.

3.The Swedish market for incineration of household waste

3.1 Market characteristics

The Environmental Code stipulates that any actor who generates waste is also responsible for treating that waste safely (Swedish Parliament, 2022). For non-hazardous waste, packaging exempted[7], the only disposal option allowed is incineration. Moreover, supply of waste is regulated differently depending on the type of waste generator. For instance, non-hazardous waste generated by private

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[7] Producers of packaging are responsible for the operation of a nationwide collection system for collection recycling treatment of all packaging that is put on the Swedish market (Swedish Parliament, 2018).

households, restaurants, and stores is classified as *household waste* and is the responsibility of municipalities to collect. For waste generated by industries and firms in general there is no such collection responsibility; hence, they decide themselves which waste incineration plant to sell their waste to. In 2019, industrial and firm waste accounted for 41% of all incinerated waste, municipal household waste for 36%, and imports for 21% (Swedish Waste Management Association, 2019b). Thus, municipalities are a major supplier of waste in the waste incineration market.

From the perspective of waste incineration plants, waste simply constitutes an input fuel besides others (biofuels, oil, etc.) used for energy production in the form of heat and electricity. In Sweden there are 35 energy generation plants that demand waste for incineration (Government Office of Sweden, 2017). The ownership structure is highly decentralized, with only two owners operating more than one plant.[8] The same two owners are also the only private owners; all the other plants are owned by the municipality where they are located.

Waste prices are formed differently for private waste and municipal waste. For private waste generators, incineration plants use FOB pricing. Municipal waste is instead priced through public procurements, which are organized as first-price sealed-bid auctions. The standard is that procurement excludes transport of the waste, and only these procurements are analyzed in this study.[9] A price comparison of tenders is performed by subtracting the estimated transport cost from the tender price. The transport cost is calculated as the distance between municipality and plant times a hypothetical unit transport cost that the municipality states in the procurement documents.[10] This setting makes tenderers aware of the exact transport cost that will be subtracted from its own and any other potential tenderer of the 35 waste incineration plants in Sweden. In addition to the price evaluation, procurements may also include prerequisites on quality, collective agreement, environmental standards, etc. Mostly, prerequisites are easy for tenderers to comply with. The importance of the transport cost—relative to the waste price—in the evaluation of most preferable tender varies with the geographical distribution of incineration plants. In the northern regions, distances between municipalities and plants are larger than in the south, which implies that the transportation cost makes up a larger part of the price net of transport cost.[11] For example, the median distance between a municipality and a waste incineration plant is 119 km in the northern regions and 38 km in the southern regions (Table 1). As a result of the high weight of transportation cost in the

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[8] E.ON operates installations in Norrköping and Mora. Fortum operates installations in Stockholm and Kumla. This does not affect our empirical approach because there are waste incineration installations between Norrköping and Mora and between Stockholm and Kumla, so the installations in Norrköping and Mora and Stockholm and Kumla, respectively, would not compete even if they had different owners.

[9] 77% of municipalities procure exclusive transportation. 16% of municipalities procure inclusive transportation. Remaining municipalities include collection of waste in the procurement. Procurements that include additional services (e.g., transport, waste collection) are not used in our analysis because it is not possible to disentangle the waste price. Other procurements that are excluded from our analysis are (1) when a procurement receives too few tenders, leading to the municipality to negotiate a waste price directly with a waste incineration plant, and (2) when a municipality procures its waste internally in order to let its own waste incineration plant win the procurement without competition. In neither of these cases the price is the result of market competition.

[10] An example: Assume there is a municipality that procures its waste and states in the procurement documents that it will evaluate transport costs at a unit price of€1 per ton waste and km (round trip). Two plants, A and B, which are located 10 and 30 km from the municipality put tenders at €-50 and €-35, respectively. The net price associated with plant A is then €60 (-50-10*1) and €65 (-35-30*1) for plant B, implying that the more closely located plant wins the contract.

[11] Northern regions refer to Jämtland, Västernorrland, and all regions above these.

northern regions, 91% of municipalities send their waste to the closest plant, while the same number in the south is only 67% (Table 1). The large differences in distance are illustrated in Figure 1.

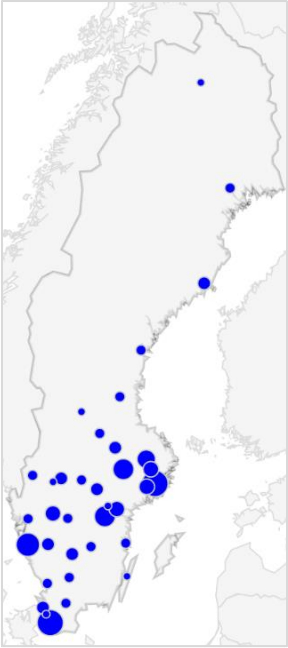

Figure 1: Location and size of waste incineration plants in Sweden. Source: CEWEP, 2022.

3.2 Technology

While the variation in the price of waste should partly be determined by the level of competition for that waste, it is the value of marginal product (VMP) of waste that constitutes the fundament in the price formation. We define VMP as the value of the heat and electricity produced by the last ton of waste at a plant, minus the marginal processing cost.

Because the waste incineration plants produce energy, the price formation is linked to prices for alternative inputs in the generation of heat and electricity. Due to the flexibility of waste incineration plants to use a mixture of fuels, the substitute technology is to switch from waste fuel to biofuels.[12] A significant switch in fuel mixture is not likely, however, since waste incineration as a technology is costly due to requirements of investments in costly flue-gas cleaning and high running costs for the treatment of hazardous ashes (Nohlgren et al., 2014). To fuel the plant with a large share of biofuels, which in contrast to waste fuels are purchased at a positive price, is therefore not likely.

Although substitution between fuels is limited within a specific plant unit, substitution between a waste incineration unit and biofuel incineration unit at the same plant is present. Therefore, if the capacity constraints for waste incineration are not binding, a higher price of the substitute biofuel should lead to larger demand for waste, and, hence, a higher (less negative) price of waste. Moreover,

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[12] The reverse, i.e., that a biofuel installation uses waste fuels, is neither possible nor allowed. Also, oil is used in some installations, for example, when starting up installations and in old installations that are primarily used during the coldest weeks. We do not include oil prices in the empirical analysis because there is almost no variation in oil prices across plants in Sweden and variation over time is captured by year dummies.

if the capacity constraints of the waste incineration plants are not binding, the demand for waste, and hence its price, should be higher the higher the demand for the outputs electricity and district heating are.

4. Theoretical model

In this section we mathematically and graphically illustrate how discriminatory prices should optimally be set by profit-maximizing oligopsonists. The model is inspired by Hoover (1937) and by later work, e.g., research by MacLeod et al. (1988) and Thisse and Vives (1988) for oligopolies, but adjusted to reflect an oligopsony.

We assume that there are J oligopsonists owning one plant each, and we call the oligopsonists "plants". Because we observe no entry or exit of plants in the data analyzed in this paper, we do not derive a model that explains entry and exit. Instead, the number of plants is assumed to be exogenously given and readers interested in entry and exit choices are referred to MacLeod et al. (1988). Also, the waste suppliers and the plants are assumed to be exogenously distributed in a linear market.

First, the suppliers declare that they will sell their waste to the plant whose price gives them the highest price per ton of waste net of transportation costs. For any mill price per ton, P_i^j, offered by plant j to supplier i, the net price N_i^j equals $P_i^j - t_i D_i^j$, where t_i is supplier i's valuation per ton and km of the distance to a plant, and D_i^j is the distance in km between supplier i and plant j. Note that $t_i D_i^j$ equals the transportation cost per ton for a round trip to the plant if t_i equals actual transportation cost per ton and km roundtrip, but we assume that suppliers can commit to any value of t_i. This assumption resembles the situation in Sweden where municipalities procure waste incineration in public procurement and commit in the procurement documents to supply the waste to the firm that offers them the highest net price, $P_i^j - t_i D_i^j$, for the value of t_i declared in the documents.[13] We assume that all values of t_i and D_i^j are common knowledge.

For simplicity, we assume that the supply of waste is exogenous and normalize it to 1 for each supplier. However, to which plant each supplier delivers its waste is endogenous.

Following Löfgren (1986), we assume that the value of the marginal product (VMP^j) does not depend on the quantity of the input, but we allow it to vary between plants. More specifically, we assume that each unit of the output energy is sold at an exogenous price, R^j, and produced by one unit of waste and one unit of a composite second input bought at the exogenous price w^j, implying that $VMP^j = R^j - w^j$. The profit of plant j is written as

$$\pi^j = I^j\left(R^j - w^j - P_i^j\right), \tag{1}$$

where I^j is the number of suppliers that ultimately sell their waste to plant j.

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[13] The procurement documents support the notion that municipalities use constant t_i when calculating the net price, even though there can be scale economics in the length of transportations. The average value of t_i is SEK 1.4 (USD 0.15) per ton and km round trip, which is also a reasonable approximation of the average true transportation cost per ton and km round trip.

We assume that the plants maximize their profits and engage in Bertrand-Nash competition at each location of suppliers. Moreover, for given profits, the plants are assumed to prefer larger outputs, implying that their maximal willingness to pay for waste exactly equals VMP^j. We assume that plants' bidding strategies and VMP^j are common knowledge. The latter is a simplification motivated by the fact that firms in the empirical application have good knowledge of competitors' technology, can observe the prices of energy and alternative fuel in the regions of the competitors, and that firms have full information regarding suppliers' valuations of transport costs to different plants, which is the key explanatory variable.

Super index *C* denotes the plant that supplier *i* chooses, and super index *S* denotes the plant that is the chosen plant's toughest competitor for supplier *i*´s waste. At equal net prices, we assume that suppliers deliver to the plant with the highest value of $VMP^j - t_i D_i^j$. This assumption can be justified by this plant having a cost advantage so that in reality it can offer the supplier ε higher mill price. Also, for notational and analytical convenience we assume that no waste suppliers are located at a point where two plants have the same value of $VMP^j - t_i D_i^j$. Then it follows that the profit maximizing strategy for a plant that has the highest value of $VMP^j - t_i D_i^j$ is to offer supplier *i* a price (P_i^j) that makes its net price equal to its competitor´s highest possible net price[14]:

$$P_i^C - t_i D_i^C = VMP_i^S - t_i D_i^S \tag{2}$$

or simply:

$$P_i^C = VMP_i^S - t_i\left(D_i^S - D_i^C\right) \tag{3}$$

The price P_i^C can also be expressed as $VMP^C + \gamma_i^C$, where γ_i^C is the markdown the chosen plant can set given the VMP at the two plants and the difference in transport cost associated with choosing between the two plants. When plants price discriminate in this way, suppliers will end up selling to the plant with the highest value of $VMP^j - t_i D_i^j$, and plant *S* will be the plant with the second-highest value of $VMP^j - t_i D_i^j$ for supplier *i*.[15]

Figure 2 illustrates the oligopsonistic price discrimination results for a simple example where plants and suppliers are located on a straight road, suppliers have the same *t*, which also equals the true transportation cost per ton and km, and plants have the same VMP.[16] The latter assumption, together with the assumptions above, implies that suppliers will sell to the closest plant.

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[14] Similar results have been derived from earlier research by, among others, Thisse and Vives (1988). They studied sellers facing endogenous demand, which also resulted in segments where sellers had monopoly positions.

[15] The chosen plant is the same as would be the case if all plants set $P_i^j = VMP^j$. This implies that this form of price discrimination will not cause any efficiency losses if the quantities supplied are exogenous, but, as discussed in the concluding section, it will cause efficiency losses when the quantities supplied are endogenous.

[16] Figure 2 differs from Figure 1a in MacLeod et al. (1988) primarily in the sense that it is for an oligopsony instead of an oligopoly and because we have chosen to locate the plants at different distances from each other to imitate the situation in Sweden. We take the locations as exogenously given.

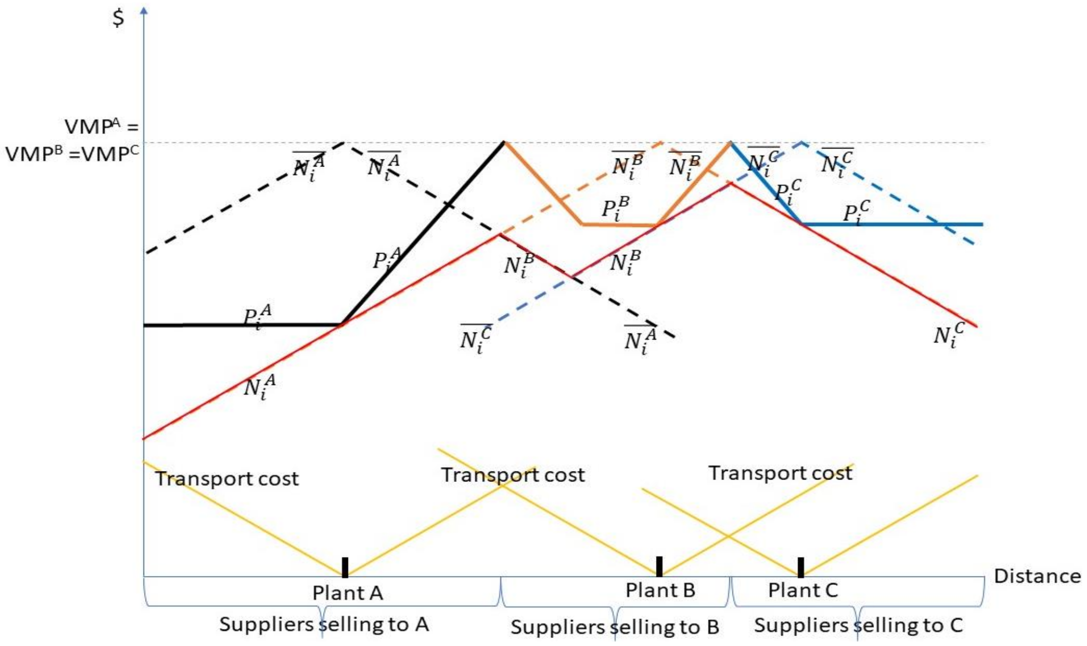

Figure 2: Illustration of oligopsonistic price discrimination.

The $\overline{N_i^j}$-lines ($j = A, B, C$) show the net price per ton that suppliers at different locations could receive from the different plants if plants set their mill prices equal to their VMP, that is, $\overline{N_i^j} = VMP_i^j - t_i D_i^j$. The slopes of the $\overline{N_i^j}$-lines are determined by the marginal transportation costs per ton and km (t_i). At each location, the highest $\overline{N_i^j}$-line of a competitor imposes a restriction on the mill price (P_i^j) that a plant can offer its suppliers without them choosing to sell to another plant. Specifically, for supplier *i* to choose to sell to plant *j*, the net price $N_i^j = P_i^j - t_i D_i^j$ must weakly exceed the highest $\overline{N_i^j}$ of a competing plant. Therefore, the price of plant *j* should be set such that the price minus the transport cost from *i* to *j* equals the highest possible net price of the hardest competitor. The equilibrium net prices N_i^j received by suppliers are in red. For suppliers to plant A and C, $N_i^j = \overline{N_i^B}$ because if A and C offer them a lower price than this, plant B could outbid them. Similarly, $N_i^B = \max\left\{\overline{N_i^A}, \overline{N_i^C}\right\}$, which means that the net price received by suppliers to B equals the net price that A or C, whichever is closest to them, could offer by setting their mill price equal to their VMP.

To the left of plant B, there is a flat segment of the mill price P_i^B. The reason for this is that $D_i^S - D_i^C$ is constant in the interval to the left of B when C is still the second-closest plant. For the plants A and C, there are also flat segments on the sides at which they do not have any competitor. Such flat segments would not arise if we had a model with equal distances between plants, which is the equilibrium if suppliers are evenly spaced, but this is far from the reality in the market we study. That we do not assume equal distances between plants makes it clear that the equilibrium prices are not only a function of how close the suppliers are to the chosen plant but rather of how much closer different suppliers are to their chosen plant compared to the closest plant operated by a competitor.

When all plants and suppliers are located on a straight road as in Figure 2, the mill price set by plant B increases twice as fast as the transportation cost to the right of this plant. The logic behind the "twice as fast" result, is that—for given mill prices and as one moves from B towards C—the net price of selling to B is increased by t_i per km while the net price of selling to C is reduced by t_i per km. Because actual space is three-dimensional, rather than one-dimensional, and all points in space are not connected by straight roads, the "twice as fast" result is not a general result. However, whenever D_i^S is a negative function of D_i^C, optimally discriminatory mill prices will increase faster than transportation costs as one moves away from the closest plant.[17]

To summarize, the theoretical model stipulates that profit-maximizing oligopsonists will set their mill prices P_i^C equal to $\mathrm{VMP}_i^S - t_i\left(D_i^S - D_i^C\right)$. They will differentiate the prices based on $t_i\left(D_i^S - D_i^C\right)$ as emphasized above but also based on variation in $\mathrm{VMP}_i^S = R_i^S - w_i^S$. In the empirical application, we use electricity price as well as a proxy for demand for district heating to measure variation in R_i^S. Also, we use fixed effects for plant S to capture time-invariant differences in VMP_i^S across plants, e.g., in marginal processing cost, and include year-specific fixed effects to control for variation in *VMP* over time.

5. Data

To study whether plants price discriminate among their waste suppliers, we asked all Swedish municipalities for procurement documents on waste incineration in the period 2010–2019. From the documents, we receive information about the name and location of suppliers[18] and plants, the number of tenders in each procurement, the mill price of the winning tenderer (P_{iy}), and the unit transport price (t_i) at which procuring municipalities evaluate the transportation cost of each tender. The documents also contain information regarding over which years the contract spans. Distances between suppliers and plants are measured with Google Maps.

A municipality will not procure waste incineration under the following circumstances: (a) it owns a waste incineration plant, (b) it cooperates with a municipality that owns a waste incineration plant, or (c) its supply of waste is too low. In cases where municipalities have procured waste incineration jointly with other services (e.g., waste collection, transport to the incineration plant), it is not possible to distinguish the price of waste; hence, such observations are excluded, which leaves us with 219 unique contracts.

The value of electricity is assumed to be the electricity spot price (NordPool, 2022) in the electricity trading area where the incineration plant is located[19]. For the value of heat, we do not proxy it with the price of district heating. The reason for this is that the level of the district heating price, in contrast to electricity, is determined locally by the monopolistic waste incineration plant. Instead, we use data on Heating Degree Days (HDD) (Eurostat, 2022) in the area of an incineration plant as a proxy of

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[17] To our knowledge, the previous studies of oligopsony pricing have not studied optimal discriminatory pricing where prices can change faster than transport costs in distances to the mills. Instead, theoretical analyses have studied the choice between FOB and UD pricing (Zhang and Sexton, 2001) or between FOB, UD, and partial freight absorption (Graubner et al., 2011a). Alvarez et al.'s work (2000) is an example of an empirical study that analyzed the importance of distance to competitors, but they performed their research in a setting with UD-pricing. In most oligopoly markets, lack of data on individual prices for customers hinders empirical studies of optimal discriminatory pricing.

[18] Procurement contracts can cover waste from multiple municipalities that have procured incineration jointly.

[19] Since 2012, Sweden has been divided into four electricity trading regions with individual spot prices (NordPool, 2022).

demand for district heating in the same area. Biofuels, which is the most important substitute for waste in district heating production, is valued with the price of biofuels (Swedish Energy Agency, 2022). All prices are adjusted with the consumer price index to the 2019 price level. Table 1 presents variable definitions and descriptive statistics. In addition to what Table 1 shows, an important point to note about the variables $Elec\_P_{iy}^{S-C}$, $DH\_P_{iy}^{S-C}$, and $Bio\_P_{iy}^{S-C}$ is that they only differ from zero in 8, 118, and 31 of the observations. In the specifications where these variables are included, the coefficients for especially $Elec\_P_{iy}^{S-C}$ and $Bio\_P_{iy}^{S-C}$ should be interpreted with caution.

Table 1: Variable description and descriptive statistics.

Variable	Description	Mean	Median	Min	Max	Source
P_{iy}	Waste price (SEK/ton) for supplier *i* in year *y*.	-489	-490	-717	-256	Proc.
D^C_{iy}	Distance (km) between supplier *i* and its chosen plant *C,* in year *y*.	73	56	1	364	Proc.; Google Maps
D^S_{iy}	Distance between supplier *i* and its closest plant except the chosen plant *C,* in year *y*.	103	78	1	304	Proc.; Google Maps
D^F_{iy}	Distance (km) between supplier *i* and closest plant (F) in year *y*.	58	44	1	291	Proc.; Google Maps
D^{Sec}_{iy}	Distance (km) between supplier *i* and second closest plant (Sec) in year *y*.	110	87	20	304	Proc.; Google Maps
t_{iy}	Unit transport cost (SEK/ton/km) specified in procurement of supplier *i* in year *y.*	1.4	1.3	0.7	5	Proc.
$t_{iy}\left(D^S_{iy} - D^C_{iy}\right)$	Difference in transport cost that supplier *i* would face if selling to plant *S* instead for plant *C.*	45	47	-420	357	Proc: Google Maps
$Elec\_P^S_{iy}$	Electricity spot price (SEK/MWh) in area of the plant closest to supplier *i* except plant *C*, in year *y*. *	422	406	212	600	NordPool (2022)
$Elec\_P^C_{iy}$	Electricity spot price (SEK/MWh) in area of the chosen plant *C*, in year *y*. *	422	406	212	600	NordPool (2022)
$DH\_D^S_{iy}$	Heat demand (HDD) in area of the plant closest to supplier *i* except the chosen plant *C*, in year *y*.	4523	4508	2976	7161	Eurostat (2022)
$DH\_D^C_{iy}$	Heat demand (HDD) in area of the chosen plant *C*, in year *y*.	4503	4369	2976	7161	Eurostat (2022)
$Bio\_P^S_{iy}$	Biofuel price (SEK/MWh) in area of the plant closest to supplier *i* except the chosen plant *C*, in year *y*.	209	208	179	239	Swedish Energy Agency (2022)
$Bio\_P^C_{iy}$	Biofuel price (SEK/MWh) in area of the chosen plant *C*, in year *y*.	209	208	179	239	Swedish Energy Agency (2022)
$Elec\_P^{S-C}_{iy}$	Difference in electricity spot price (SEK/MWh) in area of plant *S* and plant *C*.	0.3	0	-19	15	NordPool (2022)
$DH\_P^{S-C}_{iy}$	Difference in heat demand (HDD) in area of plant *S* and plant *C*.	19	0	-801	1228	Eurostat (2022)
$Bio\_P^{S-C}_{iy}$	Difference in biofuel price (SEK/xx) in area of plant *S* and plant *C*.	0.1	0	-18	18	
$year_i$	Start year of a procured contract.	2013.7	2014	2010	2019	Proc.
η_y	Year fixed effects.	-	-	-	-	
θ^C_{iy}	Fixed effects for the chosen plant of supplier *i* year *y*.	-	-	-	-	
θ^S_{iy}	Fixed effects for the plant that is closest to supplier *i* except for its chosen plant year *y*.	-	-	-	-	
D^{North}_i	Dummy taking value of 1 if supplier *i* is located in the north.	0.4	0	0	1	Proc.
D^{South}_i	Dummy taking value of 1 if supplier *i* is located in the south.	0.6	1	0	1	Proc.
$Var\left\{t_{iy}\left(D^S_{iy} - D^C_{iy}\right)\right\}^C$	The chosen plant´s variance in $t_{iy}\left(D^S_{iy} - D^C_{iy}\right)$ across its contracts.	6161	3514	5	45899	Proc.

Table 2 shows that distances between municipalities and waste incineration plants vary across the country, with larger distances in the north and smaller distances in the south. In 72% of cases, the municipality has a contract with the closest waste incineration plant.

Table 2: Descriptive statistics on geographical and contract relations between municipalities and incineration plants. Distances refer to median values in kilometers.

	Dist. to closest plant	Dist. to 2nd-closest plant	Dist. to 3rd-closest plant	Dist. to chosen plant	Obs.
Country	44	87	109	56	223
South[1]	38	79	100	50	180
North[2]	119	229	327	119	43
	% where closest plant is contracted	% where 2nd-closest plant is contracted	% where 3rd-closest plant is contracted	% where >3rd-closest plant is contracted	
Country	72	9	10	9	

1. The counties of Dalarna and Gävleborg are the most northern counties in the southern region.
2. The counties of Jämtland and Västernorrland are the most southern counties in the northern region.

Municipalities may choose to contract another waste incineration plant instead of the plant closest to them because another plant, despite being further away, can offer a higher price net of transport costs. Figure 3 shows that the likelihood for a municipality to sign a contract with the closest plant increases if the difference in distance between the first- and second-closest plant increases. This is intuitive as shorter differences in distance increases the probability that a plant other than the closest plant can place the most economically advantageous bid, e.g., because its VMP is higher.

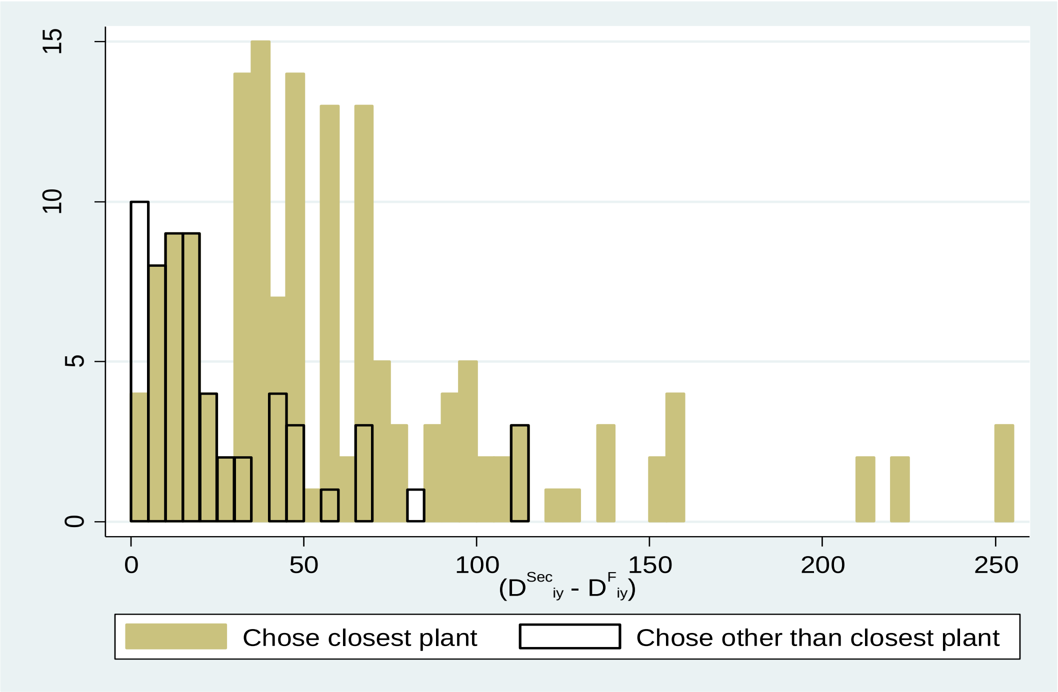

Figure 3: Histogram over distance between closest and second-closest plant to a municipality, $D_{iy}^{Sec} - D_{iy}^{F}$. Presented for subgroups of municipalities that have/have not chosen to contract the closest plant.

The price of waste varies both in time and geographical space. Figure 4 **Figure 4**shows that the average price increased in the first half of the period and thereafter it decreased again to levels around SEK -500. Disaggregation of prices across regions also shows that waste prices are lower in northern regions, which is a trend that holds over the whole period of 2010–2019 (results not presented in the paper). This may be an indication that plants in the north take advantage of the situation when municipalities in the north are stationed further away from competing plants.

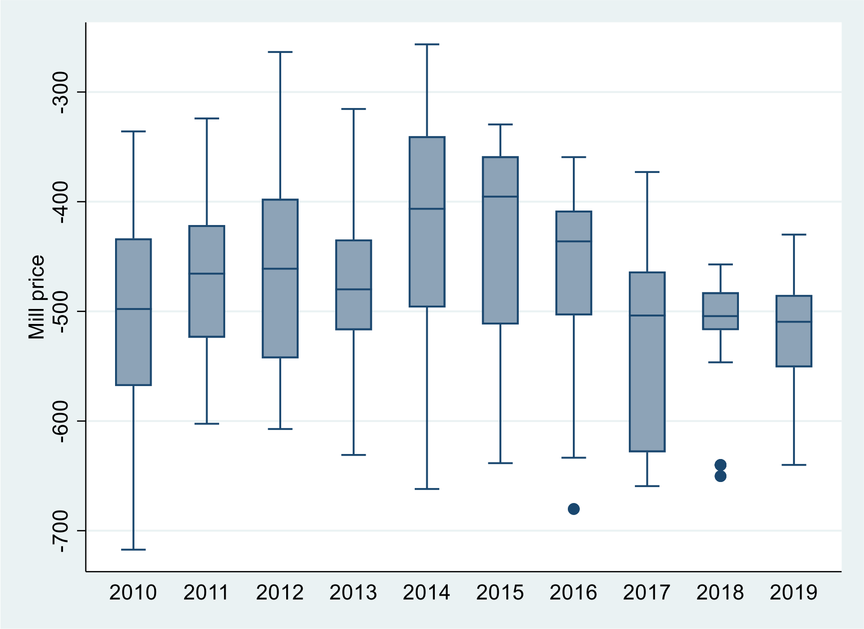

Figure 4: Boxplots over yearly mill prices for waste (SEK/ton).

6. Empirical model

Adding a year index to Equation 3 of the theoretical model implies that the price at the chosen plant, P_{iy}^{C}, equals $\mathrm{VMP}_{iy}^{S} - t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$, where VMP_{iy}^{S} is determined by output prices and the marginal processing cost. Superindex C denotes the chosen plant and S denotes the plant that is the chosen plant's toughest competitor for supplier *i*´s waste in year *y*. Below we assume that plant S is the plant closest to supplier i except of the chosen plant.

To capture variation in the value of outputs for plant *S*, we include the price of electricity $(Elec\_P_{iy}^{S})$ and heating degree days $(DH\_D_{iy}^{S})$ in the area of plant *S*.[20] Fixed effects for plant *S* (θ_{iy}^{S}) are used to capture time-invariant differences in VMP_{iy}^{S}, for example, variation in marginal processing costs or regional variation in demand of district heating which is not captured by $DH\_D_{iy}^{S}$.[21] We also include the price of biofuel $(Bio\_P_{iy}^{S})$, as this is an alternative fuel that can be used in a waste incineration plant

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[20] Since district heating markets are local monopolies, the district heat price is not an exogenous value of demand for district heating. Therefore, we use the number of heating degree days as a proxy for the demand for heat.

[21] Note that, although θ_{iy}^{S} is fixed for each plant, it varies over time for suppliers that do not sell to the closest plant during all years, which explains the sub index *y*.

to produce electricity and district heating. Lastly, we include year-specific fixed effects (η_y) to control for variation in *VMP* over time. Specification 1 is written as

$$P_{iy}^{C} = \beta_1 t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right) + \beta_2 Elec\_P_{iy}^{S} + \beta_3 DH\_D_{iy}^{S} + \beta_4 Bio\_P_{iy}^{S} + \eta_y + \theta_{iy}^{S} + \varepsilon_{iy} \qquad \text{(Spec. 1)},$$

where the dependent variable is the mill price municipality *i* received per ton of waste in year *y*.

If plants exercise spatial price discrimination as much as possible, the theoretical model suggests $\beta_1 = -1$. In such a scenario, all plants fully exploit the option to mark down their prices by the amount of the additional transport cost the supplier would face by selling to a competitor. A value between –1 and 0 can either indicate that only some plants price discriminate as the theoretical model predicts and/or that the ones that price discriminate do not do so to the extent suggested by the model. Moreover, significant positive effects for $Elec\_P_{iy}^{S}$, $DH\_D_{iy}^{S}$ or $Bio\_P_{iy}^{S}$ could in principle also be indications of price discrimination as it can suggest that the price a plant offers supplier *i* is also determined by the highest possible price its competitor can offer the same supplier. For example, a positive effect of $Elec\_P_{iy}^{S}$ could indicate that plants pay more to suppliers that can be offered a high price from plant *S* due to a high demand for the output electricity at plant *S.* However, due to high correlation in output and input prices in nearby regions, it is likely that the variables $Elec\_P_{iy}^{S}$, $DH\_D_{iy}^{S}$, and $Bio\_P_{iy}^{S}$ in specification 1 capture part of the price effects of $Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$. Therefore, the estimated coefficients for the former should be interpreted with caution.

In specification 2, we also include fixed effects for the chosen plant of municipality i in year *y*, θ_i^{C}, as well as input and output prices at plant *C* ($Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$). These variables should capture variation in prices that could also exist without any type of price discrimination. For example, the positive effects of these variables imply that plants pay more for waste when the demand for an output, or the price of the alternative input, increases, which indicates that their capacity constraints are not binding or that substitution possibilities exist, respectively. Specification 2 is written as

$$\begin{aligned} P_{iy}^{C} = {} & \beta_{21} t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right) + \beta_{22} Elec\_P_{iy}^{S-C} + \beta_{23} DH\_P_{iy}^{S-C} + \beta_{24} Bio\_P_{iy}^{S-C} + \beta_{25} Elec\_P_{iy}^{C} \qquad \text{(Spec. 2)}, \\ & + \beta_{26} DH\_D_{iy}^{C} + \beta_{27} Bio\_P_{iy}^{C} + \eta_{2y} + \theta_{2iy}^{S} + \theta_{2iy}^{C} + \varepsilon_{2iy} \end{aligned}$$

where sub index 2 is used to distinguish the fixed effects and error terms from corresponding terms in other specifications. We use difference variables $Elec\_P_{iy}^{S-C}$, $DH\_P_{iy}^{S-C}$, and $Bio\_P_{iy}^{S-C}$ instead of $Elec\_P_{iy}^{S}$, $DH\_P_{iy}^{S}$, and $Bio\_P_{iy}^{S}$, because the prices of electricity and biofuels and the demand for district heating are highly correlated across regions.

Note that θ_i^{C}, $Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$ should not affect prices according to the theoretical model, as plants should price as low as they possibly can without losing suppliers to competitors. However, we include these variables in specification 2 (and specification 3) to allow data to be explained by price setting behavior other than price discrimination.

Another purpose of specification 2 is to determine whether the estimate of β_1 for the baseline specification only reflects that firms that face less competition use their market power to mark down their prices to all suppliers but do not discriminate among them. For example, plants might abstain from price discrimination, or reduce the degree of price discrimination, because of the risk of arbitrage, because of legal concerns, or because they consider it to be unfair.[22]

Note that, when we include θ_{iy}^{C}, significant values of θ_{iy}^{S} are also an indication of price discrimination; more precisely, they are an indication that the prices plants offer depend on the price individual suppliers can secure from their alternative plant *S*. We will therefore test whether the parameters θ_{iy}^{S} are jointly significant.

Simultaneously including fixed effects for both the chosen plant *C* and the alternative plant *S* partial out a large share of the variation in distance between suppliers and plants, which can reduce the power of the tests of price discrimination that relate to these distances. Therefore, we also estimate specification 3, which includes θ_{iy}^{C}, and $Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$, but excludes θ_{iy}^{S} and $Elec\_P_{iy}^{S-C}$, $DH\_P_{iy}^{S-C}$, and $Bio\_P_{iy}^{S-C}$. Specification 3 is written as

$$P_{iy}^{C} = \beta_{31} t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right) + \beta_{32} Elec\_P_{iy}^{C} + \beta_{33} DH\_D_{iy}^{C} + \beta_{34} Bio\_P_{iy}^{C} + \eta_{3y} + \theta_{3iy}^{C} + \varepsilon_{3iy} \quad \text{(Spec. 3)}.$$

In specification 3, the only test for price discrimination is whether the effect of $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ is negative or not. This makes it convenient to use variations of this specification to study heterogeneity in price discrimination. We perform three tests of heterogeneity in price discrimination. In the first, we explore whether plants price discriminate more if they have more to benefit from price discrimination because the differences in $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ across its suppliers are large. This is done by including interaction terms between $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ and $Var\left\{t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)\right\}^{C}$, where the latter is defined as the variance of $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ for contracts signed with plant *C*. Second, we test whether plants in the sparsely populated north part of Sweden, where the distances between plants are larger, price discriminate more than plants in the south. Lastly, we test whether plants price discriminate more for larger values of $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ by including the square of this variable. This test is inspired by Bailey et al. (1995), who found that plants absorbed a larger part of the transportation costs for more distant suppliers.

In accordance with the theoretical results, specifications 1–3 assume that the effect of D_{iy}^{C} is equal to the negative of the effect of D_{iy}^{S}. We relax this assumption in specifications 1b, 2b, and 3b by adding the term $t_{iy} D_{iy}^{C}$. In these specifications, the estimates for $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$, $\widehat{\beta_{s1}}$ for specifications s = 1b, 2b, 3b, inform how prices are set with respect to the relative distance, while the estimates for $t_{iy} D_{iy}^{C}$, ($\widehat{\beta_{s2}}$), tells us whether plants in addition adjust their prices with respect to the distance to the supplier, keeping the relative distance fixed. A reason for adjusting price, although spatial competition is unaffected, could be to account for the risk that lower prices may affect the quantity that suppliers generate and deliver. The total effect on price with respect to transportation cost from the supplier to the chosen plant is thus $\frac{\partial P_{iy}^{C}}{\partial t_{iy} D_{iy}^{C}} = \beta_{s2} - \beta_{s1}$ for specifications s = 1b, 2b, 3b. If plants (partially) absorb

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[22] The fixed effects θ_{i}^{C} can also control for the possibility that the prices at some plants might be lower because of superior quality that suppliers value, for example, higher environmental standards and adherence to collective agreements. However, the procurement documents reveal that the winning tenderer almost exclusively is chosen based on prices net of transportation costs. The fixed effects can also control for if some firms for some reason do not attempt to extract all supplier surplus.

freight costs, the difference $\beta_{s2} - \beta_{s1}$ should be strictly positive, and if $(\beta_{s2} - \beta_{s1}) < 1$, it indicates that plants do not absorb all transportation costs.[23]

We estimate all specifications with two-stage least squares where $t_{iy}\left(D_{iy}^S - D_{iy}^C\right)$ and $t_{iy}D_{iy}^C$ are instrumented. The reason for this is that suppliers are more likely to sell to a plant other than the closest plant the lower the closest plant´s VMP is, and if this variation in VMP is not fully captured by our explanatory variables and (partly) known by the competing plants, this can make the distance variables become correlated with the error terms, resulting in bias. For example, if the VMP of the closest plant is low for the contract period, this increases the probability that another plant is contracted, which in turn increases the value of D_i^C and decreases the value of $t_{iy}\left(D_{iy}^S - D_{iy}^C\right)$. At the same time, the value of ε_{iy} can be decreased if the contracted plant knows that it faces unusually weak competition from its toughest competitor and if this variation is not captured by the explanatory variables. For comparison, we also report OLS estimates in the Appendix. As instruments excluded from the second stage we use $t_{iy}\left(D_i^{Sec} - D_i^F\right)$ and $t_{iy}D_i^F$. The variables D_i^F and D_i^{Sec} are the distances between municipality i and its two closest plants. These variables are constant over time, as there is no entry or exit of plants during the study period, and they do not depend on the choice of plant to sell to. In 72% of the contracts, we observe that municipalities sell to the closest plant, i.e., $D_i^F = D_{iy}^C$ and $D_i^{Sec} = D_{iy}^S$.[24]

Based on our hypotheses on expected signs for $t_{iy}\left(D_{iy}^S - D_{iy}^C\right), \partial P_{iy}^C / \partial D_{iy}^C$, $Elec\_P_{iy}^S$, $DH\_D_{iy}^S$, $Bio\_P_{iy}^S$, $Elec\_P_{iy}^{S-C}$, $DH\_P_{iy}^{S-C}$, $Bio\_P_{iy}^{S-C}$, $Elec\_P_{iy}^C$, $DH\_D_{iy}^C$, and $Bio\_P_{iy}^C$, we perform and report one-sided significance tests. For the effect of $t_{iy}D_{iy}^C$ we report two-sided tests because the null hypothesis is that this variable has no independent effect.

7. Results

Results for specifications 1–3 are presented in Table 3, while those for 1b–3b (which include $t_{iy}D_{iy}^C$) are presented in Table 4. Results from OLS regressions are presented in the Appendix, and results for the heterogeneity analyses are presented in Table 5.

In accordance with the theoretical predictions, we can reject the null hypothesis that there is either no effect or a positive effect of $t_{iy}\left(D_{iy}^S - D_{iy}^C\right)$ on mill prices in specifications 1–3 and 1b–3b. That is, the offered price of waste is significantly lower the farther away a supplier is located from a competitor's plant relative to the contracted plant. The point estimate for specification 1 indicates that prices are marked down by 28.2% of the increase in transportation costs that suppliers would face if they had chosen plant S instead of plant C. The estimate for specification 1b is similar, but those for

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[23] Note that $\beta_{s2} - \beta_{s1}$ is not an exact measure of the share of transportation costs that are absorbed by the plants because the real transportation costs can differ from how transportation costs are valued in the procurements (t_{iy}). However, we find the values of t_{iy} to be reasonable approximations of the real transportation costs.

[24] In the heterogeneity analyses, the interaction terms with $t_{iy}\left(D_{iy}^S - D_{iy}^C\right)$ are also instrumented, and $t_{iy}(D_i^{Sec} - D_i^F)Var\left(D_{iy}^S - D_{iy}^C\right)_{iy}^C$, $t_{iy}(D_i^{Sec} - D_i^F)North_{iy}^C$, and $\left[t_{iy}(D_i^{Sec} - D_i^F)\right]^2$, respectively, are added as additional instruments.

specifications 2–3 and 1b–3b are closer to zero, ranging from 11.0% to 16.7%. Still, the estimates are significantly below zero at the 10% level, except that for specification 1b. This difference between specifications 1 and 1b on the one hand and 2–3 and 2b–3b on the other hand suggests that the estimates for specifications 1 and 1b are partly driven by the fact that some plants that face little competition, because of long distances, mark down prices to all suppliers. Such behavior should not affect the estimates for $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ in specifications 2–3 and 2b–3b, where we control for fixed effects of the chosen plant. In specifications 2–3 and 2b–3b we also address that VMP at the chosen plant can vary over time by controlling for variation in the demand for the outputs and the price of the alternative fuel at the chosen plant.[25]

Table 4 shows that when we control for fixed effects of the chosen plant (θ_{iy}^{C}), the effect on price due to a marginal change in transportation cost to the chosen plant ($\partial P_{iy}^{C}/\,\partial t_{iy}D_{iy}^{C}$) is 12–13% and significant at the 10% level. In other words, plants absorb 12–13% of transport costs. This is similar to the results from specifications 2 and 3, where the negative of the estimates for $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ suggests that 12% and 15%, respectively, of the transport cost is absorbed by the plants. Furthermore, the point estimates for the separate effect of $t_{iy}D_{iy}^{C}$ are close to zero; only a fourth to a tenth of the estimates for $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$, and throughout not significantly different from zero. This is consistent with the theoretical prediction that it is the relative distance that should matter for prices, rather than just the distance to the chosen plant.[26]

Besides price discrimination in the spatial dimension through the effect of $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$, there are other channels for price discrimination. First, in specification 2–3 and 2b–3b, where we control for fixed effects at the chosen plant (θ_{iy}^{C}), the fixed effects of the competing plants (θ_{iy}^{S}) are jointly significant at the 1% level.[27] This means that suppliers selling to the same plant receive different prices based on where their alternative plant is. For example, the same plant can pay less to a supplier who is relatively close to another plant with a low VMP than it pays to a supplier whose alternative plant is one with a higher VMP.

Second, the estimates for $DH\_D_{iy}^{S-C}$ in specifications 2 and 2b provide some degree of support for price discrimination. More precisely, the significantly positive estimate indicates that (for a given value of $DH\_D_{iy}^{C}$) a plant will offer a higher price to a supplier if its alternative plant faces a high demand for district heating and therefore can be expected to offer higher prices for waste to increase its energy

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[25] Results not presented in tables suggest that approximately half of the change in the estimated effect of $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ between specification 1, on the one hand, and specifications 2 and 3, on the other hand, are explained by the inclusion of $Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$ and, in specification 2, the difference variables $Elec\_P_{iy}^{S-C}$, $DH\_P_{iy}^{S-C}$, and $Bio\_P_{iy}^{S-C}$.

[26] We have also estimated specification where we allowed the effect of $t_{iy}D_{iy}^{C}$ to depend on whether $t_{iy}D_{iy}^{S}$ exceeds different threshold values. The idea here is that monopsonists might have an incentive to let prices depend on $t_{iy}D_{iy}^{C}$, but that they are more likely to act in such a way in respect to a supplier the farther away the supplier is from a competitor. However, we have not found significant effects of the separate variable for $t_{iy}D_{iy}^{C}$ in any of these specifications that control for plant-specific fixed effects. This might indicate that all plants act as oligopsonists rather than monopsonists in respect to all suppliers. Another possibility is that the logarithm of the supply curve for waste is neither strictly concave nor strictly convex, which would make the optimal monopsonistic mill price indifferent to transport costs (Löfgren, 1986).

[27] The tests are performed based on 203 observations that have more than one observation for each fixed effect unit.

production. However, we believe that the estimates for $DH\_D_{iy}^{S-C}$ should be interpreted with caution because we find no positive effect of $DH\_D_{iy}^{C}$. Also, note that the parameter for $DH\_D_{iy}^{S-C}$ is only identified by the 56% of the observations in which $DH\_D_{iy}^{S-C}$ differs from zero. As reported in the data section, the variables $Elec\_P_{iy}^{S-C}$ and $DH\_D_{iy}^{S-C}$ differ from zero even less often—only for 4% and 15% of the observation—which can explain the non-significant estimates for them. We do not consider the positive estimate for $Elec\_P_{iy}^{S}$ in specification 1 and 1b as supporting evidence for price discrimination because it certainly captures the effect of the omitted variable $Elec\_P_{iy}^{C}$ due to the high correlation between the variables (0.99).

Table 3: Effects on mill prices (P_{iy}^{C}) from IV estimation of specifications 1–3.

	1	2	3
$t_{iy}(D_{iy}^{S} - D_{iy}^{C})$	-0.282^{+++}	-0.117^{+}	-0.147^{+}
	(0.1000)	(0.0856)	(0.0902)
$Elec\_P_{iy}^{S}$	1.955^{+}		
	(1.473)		
$DH\_D_{iy}^{S}$	0.0280		
	(0.0532)		
$Bio\_P_{iy}^{S}$	-0.912		
	(2.743)		
$Elec\_P_{iy}^{S-C}$		-0.980	
		(2.477)	
$DH\_P_{iy}^{S-C}$		0.279^{++}	
		(0.135)	
$Bio\_P_{iy}^{S-C}$		8.216	
		(8.280)	
$Elec\_P_{iy}^{C}$		2.409^{++}	1.077
		(1.175)	(1.245)
$DH\_D_{iy}^{C}$		0.0557	-0.00797
		(0.0573)	(0.0539)
$Bio\_P_{iy}^{C}$		2.153	-0.241
		(2.031)	(1.980)
N	219	219	219
Year F.E. (η_y)	yes*	yes***	yes***
Plant *C* F.E. (θ_{iy}^{C})	no	yes***	yes***
Plant *S* F.E. (θ_{iy}^{S})	yes***	yes***	no
R^2	0.179	0.270	0.228
Underidentification	20.23	26.18	17.38
Weak identification	59.61	268.6	39.19

Notes: *(i)* The dependent variable is P_{iy}^{C}; see Table 1 for variable definitions. *(ii)* Standard errors are reported within parentheses. *(iii)* *, **, and *** indicate statistical significance at the 10%, 5%, and 1% significance level for two-sided tests, while $^{+}$, $^{++}$, and $^{+++}$ indicate statistical significance at the 10%, 5%, and 1% significance level for one-sided tests. *(iv)* Test for underidentification reports the Kleibergen-Paap rk LM statistic. Test for weak identification reports the Kleibergen-Paap rk Wald F statistic.

Table 4: Effects on mill prices (P_{iy}^{C}) from IV estimation of specifications 1b, 2b, and 3b.

	1b	2b	3b
$t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$	-0.310^{+++}	-0.110	-0.167^{+}
	(0.118)	(0.109)	(0.118)
$t_{iy}D_{iy}^{C}$	-0.0632	0.00987	-0.0371
	(0.0971)	(0.0840)	(0.0896)
$Elec\_P_{iy}^{S}$	1.982^{+}		
	(1.453)		
$DH\_D_{iy}^{S}$	0.0262		
	(0.0530)		
$Bio\_P_{iy}^{S}$	-0.883		
	(2.718)		
$Elec\_P_{iy}^{S-C}$		-1.012	
		(2.479)	
$DH\_P_{iy}^{S-C}$		0.282^{++}	
		(0.141)	
$Bio\_P_{iy}^{S-C}$		8.291	
		(8.280)	
$Elec\_P_{iy}^{C}$		2.394^{++}	1.140
		(1.180)	(1.247)
$\mathrm{DH\_D}_{iy}^{C}$		0.0559	-0.00649
		(0.0574)	(0.0538)
$Bio\_P_{iy}^{C}$		2.146	-0.165
		(2.037)	(1.990)
$\partial P_{iy}^{C}/\,\partial t_{iy}D_{iy}^{C}$	0.247^{+++}	0.120^{+}	0.130^{+}
	(0.0986)	(0.0857)	(0.0804)
N	219	219	219
Year F.E. (η_y)	yes*	yes***	yes***
Plant *C* F.E. (θ_{iy}^{C})	no	yes***	yes***
Plant *S* F.E. (θ_{iy}^{S})	yes***	yes***	no
R^2	0.186	0.270	0.229
Underidentification	22.39	26.37	18.74
Weak identification	43.92	122.3	27.79

Notes: *(i)* The dependent variable is P_{iy}^{C}; see Table 1 for variable definitions. *(ii)* Standard errors are reported within parentheses. *(iii)* *, **, and *** indicate statistical significance at the 10%, 5%, and 1% significance level for two-sided tests, while $^{+}$, $^{++}$, and $^{+++}$ indicate statistical significance at the 10%, 5%, and 1% significance level for one-sided tests. *(iv)* Test for underidentification reports the Kleibergen-Paap rk LM statistic. Test for weak identification reports the Kleibergen-Paap rk Wald F statistic.

To summarize, all specifications provide some support for the notion that spatial price discrimination exists. It is also noteworthy that all estimates for $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ are significantly different from -1, which means that we can rule out that all plants fully exploit the possibility to price discriminate. Regarding other variables, it should be noted that the total effect of $Elec\_P_{iy}^{C}$ in specification 2 (2.409 + 0.980 = 3.390) is not statistically different from zero at any conventional significance level, even though the partial effect for a given price difference to plant *S* (2.409) is significant. This is also true for specification 2b. Moreover, note that the estimates for $Elec\_P_{iy}^{C}$, $DH\_D_{iy}^{C}$, and $Bio\_P_{iy}^{C}$ in specifications 3 and 3b likely capture part of the effects of the corresponding variables at plant *S*. The estimates for the year fixed effects (not reported in tables) are largest for 2014–2016, which was expected given the descriptive statistics presented in Figure 4. The plant fixed effects are on average more negative in the north of Sweden than in the south.

Results from the heterogeneity analysis are presented in Table 5. We find no significant effect of the interaction variable between variance in $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ and $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$. Nor is the quadratic term of $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ significantly different from zero, and we find no significant difference in the effect of $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ between the south and north. That is, we find no statistically significant evidence for heterogeneity in the degree of price discrimination. Still, it should be noted that the point estimate for both the linear and quadratic terms of $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ are negative in the quadratic specification and that the marginal effect of $t_{iy}D_{iy}^{C}$ is only significantly negative when the distance to the chosen plant is large. Also, the point estimate for $t_{iy}\left(D_{iy}^{S}-D_{iy}^{C}\right)$ is significantly negative for plants in the northern part of the country but not in the southern part of the country, where the distances between plants are smaller.

Table 5: Heterogeneity tests based on specification 3.

	Variance	Quadratic	North
$t_{iy}\left(D^{S}_{iy}-D^{C}_{iy}\right)$	-0.165	-0.0852	
	(0.155)	(0.262)	
$t_{iy}\left(D^{S}_{iy}-D^{C}_{iy}\right)*Variance$	0.00000155		
	(0.00000785)		
$\left\{t_{iy}\left(D^{S}_{iy}-D^{C}_{iy}\right)\right\}^{2}$		-0.000208	
		(0.000723)	
$t_{iy}\left(D^{S}_{iy}-D^{C}_{iy}\right)*D^{South}$			-0.0432
			(0.208)
$t_{iy}\left(D^{S}_{iy}-D^{C}_{iy}\right)*D^{North}$			-0.177^{++}
			(0.107)
$Elec\_P^{C}_{iy}$	1.099	1.103	1.198
	(1.259)	(1.237)	(1.277)
$DH\_D^{C}_{iy}$	-0.00688	-0.00220	0.000276
	(0.0537)	(0.0549)	(0.0555)
$Bio\_P^{C}_{iy}$	-0.314	-0.126	-0.0352
	(1.951)	(1.972)	(2.040)
N	218	219	219
Year F.E. (η_y)	yes	yes	yes
Plant *C* F.E. (θ^{C}_{iy})	yes	yes	yes
Plant *S* F.E. (θ^{S}_{iy})	no	no	no
Underidentification	7.795	22.12	8.821
Weak identification	19.15	10.78	4.888
R^2	0.229	0.227	0.216
$\partial P^{C}_{iy} / \partial t_{iy} D^{C}_{iy}$			
50th percentile	0.160	0.105	
	(0.13)	(0.20)	
75th percentile	0.155^{+}	0.126	
	(0.11)	(0.14)	
90th percentile	0.139^{++}	0.156^{++}	
	(0.08)	(0.08)	
99th percentile	0.0937	0.234	
	(0.24)	(0.28)	

Notes: *(i)* The dependent variable is P^{C}_{iy}; see Table 1 for variable definitions. *(ii)* Standard errors are reported within parentheses. *(iii)* *, **, and *** indicate statistical significance at the 10%, 5%, and 1% significance level for two-sided tests, while $^{+}$, $^{++}$, and $^{+++}$ indicate statistical significance at the 10%, 5%, and 1% significance level for one-sided tests. *(iv)* Test for underidentification reports the Kleibergen-Paap rk LM statistic. Test for weak identification reports the Kleibergen-Paap rk Wald F statistic. *(iv)* The last rows of the table report estimates of $\partial P^{C}_{iy} / \partial t_{iy} D^{C}_{iy}$ at the 50th, 75th, 90th, and 99th percentile of the distribution of $t_{iy} D^{C}_{iy}$.

8. Summary and discussion

The purpose of this research is to determine whether owners of waste incineration plants use their local market power to price discriminate among suppliers. We derive a theoretical model for an oligopsony, which builds on existing oligopoly models (Hoover, 1937; MacLeod et al., 1988; Thisse and Vives, 1988). In contrast to many oligopoly models, we do not assume plants to be equally spaced, and therefore the suppliers' distances to the second-closest plant are not perfectly correlated to their distances to the closest one.

The theoretical model predicts that a profit-maximizing firm should mark down input prices more the longer distance a supplier has to a competitor's plant relative to their own plant. Specifically, the price effect of the distance to the chosen plant should be the negative of the effect of the distance to the alternative plant. Also, for given distances, plants are expected to pay more to suppliers whose alternative plant has a high value of the marginal product of waste (VMP).

To test the predictions of the model, we collected contract-level data from Swedish municipalities that supplied waste during 2010–2019. We assume that the alternative plant is the nearest plant except for the chosen one and proxy the VMP of this plant with fixed effects and the demand for district heating and prices of electricity and biofuels in its area. In specifications 1 and 1b, we do not control for the VMP of the chosen plant, as these, according to the theoretical model, should not affect the prices because plants should set prices as low as they can without losing suppliers, even if this is far below their own VMP. The results of specifications 1 and 1b indicate that the chosen plants mark down their prices by approximately 30% of the increase in transportation costs that suppliers would face if they had instead chosen the alternative plant.

When we relax the assumption (specifications 2–3 and 2b–3b) by also controlling for fixed effects and the VMP of the chosen plants, it gives less negative estimates for the distance variables, indicating that plants price discriminate by absorbing 12–15% of the transport cost to the plant. Our results also show that the price effect of the distance to the chosen plant is close to, or equal to, the negative of the price effect of the distance to the alternative plant. This is in accordance with the theoretical predictions.

A key takeaway from this paper is that it is the relative distances that matter for price discrimination. We have no reason to believe that this result does not also hold for other markets, and we encourage researchers to explore this issue in other oligopsony and oligopoly markets where transport costs are important. To the best of our knowledge, we are the first to study whether firms price discriminate based on information regarding how much closer suppliers or customers are to their plant than to an alternative plant.

The results further indicate that plants not only discriminate based on relative distances to their own and competitors' plants but also differentiate prices based on the identity of their toughest competitor's plant. This is consistent with the theoretical predictions that, for given distances, profit-maximizing plants should pay more to suppliers whose alternative plant has a high value for the marginal product of waste.

Existence of discriminatory pricing reveals that there is not perfect competition in the market, but perfect competition was not expected because the distances between plants and large transportation costs imply that plants should have market power. The more relevant question, then, is how the plants use their market power. Thisse and Vives (1988) showed for a duopoly that price discrimination is a dominant strategy but that the joint profit of the firms would be larger if they could commit to uniform mill pricing. The reason for this is that price discrimination provides firm flexibility to respond to competitors' prices, which intensifies competition. Therefore, one way for firms to increase their profits is to collude by jointly agreeing to use uniform mill pricing. Therefore, observing price discrimination is an indication that some firms compete rather than collude.

Our results indicate that higher transportation costs, e.g., those caused by higher prices of diesel fuel or longer distances to a waste incineration plant because of the exit of a plant, will not only have a direct effect on the prices of waste net of transportation costs, but also strengthen market power and hence increase the markdown. Policymakers should consider this when revising environmental standards that can result in some energy companies deciding to stop burning waste and weigh environmental concerns against concerns for market inefficiencies.

In the market we study, the suppliers who procure their waste can also affect the market power of the plants directly. This is because it is the valuation of distance to plants they write in the procurement document, rather than the real transportation costs, that enable plants to exercise market power against them. The valuations of distance in the procurement documents are legally binding and therefore serve as an effective commitment device for suppliers. Thus, suppliers could reduce the market power of plants by assigning less weight to distances to plants because this would increase the competition pressure from more distant plants. In fact, attributing no value to the distance to the plant in the procurement could eliminate the market power of plants completely. However, a lower evaluation price also increases the probability that a more distant firm wins the procurement, which would increase the real transportation cost of the supplier. Therefore, how low the optimal evaluation price per km is relative to the real transportation cost depends on the local market situation.

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Appendix

Tables A1 and A2 show that the point estimates for $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ are closer to zero when OLS is used, compared to the instrumental variable estimation estimations presented in Tables 3 and 4. This is consistent with the expectations expressed in the econometric section that variation in the VMP of the closest plant that is not fully captured by the explanatory variable can cause a positive bias in the estimator for $t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$ by affecting this variable and the error term in the same direction.

Table A1: Effects on mill prices (P_{iy}^{C}) from OLS estimation of specifications 1–3.

	OLS 1	OLS 2	OLS 3
$t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$	-0.158^{++}	-0.0859	-0.110^{++}
	(0.0838)	(0.0823)	(0.0530)
$Elec\_P_{iy}^{S}$	0.537		
	(0.893)		
$DH\_D_{iy}^{S}$	0.00896		
	(0.0504)		
$Bio\_P_{iy}^{S}$	-3.565^{+}		
	(2.431)		
$Elec\_P_{iy}^{S-C}$		-1.660	
		(3.071)	
$DH\_P_{iy}^{S-C}$		0.221^{+}	
		(0.156)	
$Bio\_P_{iy}^{S-C}$		8.946	
		(10.45)	
$Elec\_P_{iy}^{C}$		-0.0254	0.182
		(0.779)	(0.735)
$DH\_D_{iy}^{C}$		0.00651	-0.0211
		(0.0607)	(0.0508)
$Bio\_P_{iy}^{C}$		-2.013	-1.875
		(1.994)	(1.962)
N	219	219	219
Year F.E. (η_y)	yes	yes	yes
Plant *C* F.E. (θ_{iy}^{C})	no	yes	yes
Plant *S* F.E. (θ_{iy}^{S})	yes	yes	no
R^2	0.984	0.989	0.987
Adj. R^2	0.980	0.984	0.984

Notes: *(i)* The dependent variable is P_{iy}^{C}; see Table 1 for variable definitions. *(ii)* Standard errors are reported within parentheses. *(iii)* *, **, and *** indicate statistical significance at the 10%, 5%, and 1% significance level for two-sided tests, while $^{+}$, $^{++}$, and $^{+++}$ indicate statistical significance at the 10%, 5%, and 1% significance level for one-sided tests. *(iv)* The R^2-values include the variation explained by the fixed effects.

Table A2: Effects on mill prices (P_{iy}^{C}) from OLS estimation of specifications 1b, 2b, and 3b.

	OLS 1b	OLS 2b	OLS 3b
$t_{iy}\left(D_{iy}^{S} - D_{iy}^{C}\right)$	-0.212^{+++}	-0.0647	-0.129^{+}
	(0.0801)	(0.102)	(0.0943)
$t_{iy}D_{iy}^{C}$	-0.0790	0.0322	-0.0255
	(0.0963)	(0.0971)	(0.0943)
$Elec\_P_{iy}^{S}$	0.575		
	(0.794)		
$DH\_D_{iy}^{S}$	0.00470		
	(0.0448)		
$Bio\_P_{iy}^{S}$	-3.527^{+}		
	(2.183)		
$Elec\_P_{iy}^{S-C}$		-1.757	
		(3.056)	
$DH\_P_{iy}^{S-C}$		0.231^{+}	
		(0.165)	
$Bio\_P_{iy}^{S-C}$		9.194	
		(10.47)	
$Elec\_P_{iy}^{C}$		-0.0490	0.187
		(0.783)	(0.734)
$DH\_D_{iy}^{C}$		0.00783	-0.0213
		(0.0611)	(0.0510)
$Bio\_P_{iy}^{C}$		-1.991	-1.875
		(1.993)	(1.959)
$\partial P_{iy} / \partial D_{iy}^{C}$	0.133^{+}	0.0969	0.103^{++}
	(0.0891)	(0.0912)	(0.0540)
N	219	219	219
Year F.E. (η_y)	yes	yes	yes
Plant *C* F.E. (θ_{iy}^{C})	no	yes	yes
Plant *S* F.E. (θ_{iy}^{S})	yes	yes	no
R^2	0.984	0.989	0.987
Adj. R^2	0.980	0.984	0.984

Notes: *(i)* The dependent variable is P_{iy}^{C}; see Table 1 for variable definitions. (*ii)* Standard errors are reported within parentheses. (*iii)* *, **, and *** indicate statistical significance at the 10%, 5%, and 1% significance level for two-sided tests, while $^{+}$, $^{++}$, and $^{+++}$ indicate statistical significance at the 10%, 5%, and 1% significance level for one-sided tests. *(iv)* The R^2-values include the variation explained by the fixed effects.