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CONTRACTING IN A MARKET WITH DIFFERENTIAL INFORMATION

Marta Rocha and Thomas Greve

September 2016

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Contracting in a market with differential information*

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Abstract

Consider an oligopolistic industry where two firms have access to the same technology and compete in prices, but one firm has access to better information about the customers in the market. We assume that better information allows the better informed firm to attract specific customers. The better informed firm obtains a first customer contact advantage, whereas the uninformed firm can only offer a menu of prices without being able to pre-identify the types of customers. We show that better information does not lead to higher profit.

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1 Introduction

The recent advanced infrastructures in the energy sector based on smart meters are now capable of real lifetime pricing and remote reading. This has generated a debate in relation to the potential sensitivity of data on customers' energy usage that firms will be able to hold once smart meters are fully installed. Indeed, the major players in the

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energy markets, such as network providers, suppliers, regulators and customers, recognise the potential sensitivity of data on customers' energy usage. The Council of European Energy Regulators has already made recommendations over potential discriminatory behaviour and potential measures of data security (CEER 2015).[1] Nevertheless, it is still unclear what impact this new degree of information on competition in the energy markets is.

The key question posed by this paper is whether a firm with better information about the customers consumption profile[2] in the market than their rivals can use that information to earn greater profit. Although it might seem intuitive, one cannot make the general claim that access to better information leads to higher profit.

To study the role of information, we introduce a framework of two firms, which have access to the same technology and where customers have fixed demand, supplying a good composed of many commodities that compete in prices. We are interested in the equilibrium outcomes under no differential information and under differential information. To answer our research question, we compare the equilibrium profits of both firms in two ways. First, we define information advantage as the difference between the equilibrium profits of the better informed firm and the uninformed firm in the differential information case. Second, we define information value as the difference between the equilibrium profits of the better informed firm under differential information and under no differential information.

We show that, under no differential information, both firms equally share the customers and types of customers, charge the same payments and obtain zero profits. Under differential information, we assume that access to better information allows the better informed firm to attract specific customers. Access to better information gives the better informed firm a first customer contact advantage. The uninformed firm can only offer a menu of price vectors without being able to pre-identify the types of customers. Consequently, access to better information leads to a change in the tie-breaking rule.

[1] This potential discriminatory behaviour can come from a vertical connection between the distribution operator (upstream firm) and a retailer firm (downstream firm). This connection can particularly exist if the downstream firm was previously an integrated part of the upstream firm. Then, if the upstream firm has access to all customers' information in the market, there might be incentives for the upstream firm to give access to better data to its affiliated rather than to the remaining downstream firms in the market.

[2] That is, one firm is better informed in the sense that it can see the types of all customers served by any firm in the industry, whereas the uninformed firm does not have access to this information.

The same result would hold if, for another reason other than better information, one firm would have first customer contact advantage. Nonetheless, the uninformed firm can access the market, preventing the better informed firm from making positive profit. We find that better information does not give a firm an advantage or disadvantage, that is, the better informed firm obtains the same equilibrium profit as the uninformed one. We also show that there is no information value because the better informed firm has the same equilibrium profit under both cases.

We also analyse whether our results are robust to changes in the number of customers, number of firms and number of types. We show that as long as it is possible to divide equally the number of customers between firms, the symmetric Nash equilibria in pure strategies exist. Under differential information, the exclusionary Nash equilibria exist despite of the number of customers of each type. However, once we increase the number of better informed firms, the exclusionary equilibria exist as long as it is possible to divide equally the number of customers between the better informed firms.

2 Related Literature

This paper relates to two strands of literature. Firstly, it contributes to the literature on the role of information in oligopolistic markets by analysing the impact of differential information about the types of customers on equilibrium profits in a one-stage Bertrand competition. Though this literature under uncertain demand and incomplete information is quite broad (see, for example Gal-Or 1987, 1988; Raith 1996; and Vives 1984), there is relatively little literature on whether access to better information has a positive impact on the equilibrium profit. Further, there is no general consensus on the result that emerges. This literature is especially small when competition is via prices. Vives (1990), using a two-stage model, shows that better informed firms have an incentive to invest more in the first stage which has the effect of boosting its competitive position and profitability. In Vives's framework, better information always increases expected profit of the better informed firm and it leads to an information advantage. Nevertheless, better information may enhance or diminish the rival's competitive position and profitability depending whether firms compete à la Bertrand or à la Cournot. The consequences of differential information arise because the better informed firm has the option to decide to invest more or less in the first stage.

A more related study to the present paper is Einy et al. (2002). It is shown that a better informed firm is rewarded, under Cournot competition, when firms' technology exhibits constant returns to scale. Chokler et al. (2006) challenge the results of Einy et al. (2002) and prove that in Cournot duopolies with differentiated products and linear demand and cost functions, the better informed firm earns less profit if both firms have symmetric demand functions. Consequently, one cannot claim, under generality, that better information leads to higher equilibrium profit for the better informed firm. Indeed, we show that in a one-stage Bertrand competition, differential information can lead to no information advantage or disadvantage.

Secondly, our paper contributes to the price discrimination literature and in particular, on competitive price discrimination and on personalised pricing, whereby firms charge different prices to different customers based on their willingness to pay. The literature on personalised pricing has been expanded due to the increasing ability of firms to collect customers' data and the ability to offer dynamic pricing. Some papers such as Choudhary et al. (2005) and Ghose and Huang (2009) have studied the competitive implications of personalised pricing in a model with product differentiation. Choudhary et al. (2005) show, in a model with vertical differentiation, that firms can be worse off when they offer personalised pricing. Ghose and Huang (2009) show, in a model of spatial differentiation, that firms are better off when they offer personalised pricing and quality compared to the case when they do not adopt customised pricing. This is because firms can offer higher qualities to each customer at higher rent extraction ability for each firm. Ghose and Huang (2009) assume that when a firm adopts personalised pricing and quality it can perfectly target customers in both price and quality. In our paper, we also assume that a firm that is better informed can perfectly target customers. We contribute to this literature by studying personalised pricing in a model with homogeneous goods and with differential information. In particular, we show that although it is possible for the better informed firm to target customers, it does not allow it to charge higher prices.

The literature on privacy is closely related to the literature on competitive price discrimination and on personalised pricing. The literature on economics of privacy has analysed, for example, how firms use past behaviour of consumers to infer their taste and price (see e.g. Fudenberg and Tirole 2000, and Esteves 2010); and how privacy actions are undertaken by consumers and how consumer information is sold to firms (see e.g. Casadeus-Masanell and Hervas-Drane 2015, Montes et al. 2016, and Taylor and Wagman 2014). This literature has been expanding significantly due to the rise of new technologies and online markets that are able to store consumers' personal information.[3] This also relates to the motivation of our paper in the sense that smart meters will allow for monitoring and recording of electricity consumption on a near real-time basis. Technology will also allow identifying the activities of consumers by matching data on their electricity usage with known appliance load signatures.[4]

3 The Model

Consider an industry where two firms compete in the production of $m > 1$ different commodities. There is a given finite set $A \subset \mathbb{R}^m_+$ of *types* of customers, where a type is a vector $a \in A$ specifying the demand for each of the m commodities. Assume that each commodity is homogeneous.

Suppose that there are only two types of customers, $A = \{a_u, a_p\}$, where a_u is the uniform type and a_p is the peak type. There are four customers with two uniform customers, $n_u = 2$, and two peak customers, $n_p = 2$. Let $U_u = u_u - t_u$ and $U_p = u_p - t_p$ denote the utilities of uniform and peak types, respectively, and where t_u and t_p are the payments to the firm. We identify type a_u customers by the requirement that they consume all commodities of the good by the same amount (i.e. $a_{1u} = a_{2u} = ... = a_{mu}$), whereas the type a_p customers do not consume the same amount of each commodity.[5]

Firms, indexed by $l = 1, 2$, have access to the same technology, given by a cost function $C : \mathbb{R}^m_+ \to \mathbb{R}_+$, where $C(y)$ is the cost of producing the output vector $y = (y_1, \ldots, y_m) \in \mathbb{R}^m_+$. It is assumed throughout that

[3] For an overview of the literature on economics of privacy see Acquisti et al. (2016).

[4] See, for example, Figures 5-1 and 5-2 in NIST (2014) that show how non-intrusive appliance load monitoring techniques can be used to obtain information about individual consumption patterns.

[5] Take the following example. Let $a_1 = (0, 6, 0)$ means that a customer of type a_1 consumes 6 units of commodity 2 and 0 units of commodities 1 and 3. Similar for $a_2 = (2, 2, 2)$. The first type of customer represents the peak type and the second type of customer represents the uniform type. Our framework with a good that consists of different commodities also allows us to have an example where we have 24 commodities. Electricity can be seen as a good that is composed of 24 commodities and so, commodities in this case would represent the hourly electricity demand.

Assumption 1 *C is continuous and strictly quasi-convex, i.e. for each $c \in \mathbb{R}_+$, the lower contour set $L(c) = \{y \in \mathbb{R}^m_+ \mid C(y) \leq c\}$ is strictly convex.*

Assumption 2 *C exhibits constant returns to scale, that is $C(\lambda y) = \lambda C(y)$ for all $y \in \mathbb{R}^m_+$ and $\lambda \geq 0$.*

The assumption of quasi-convexity implies that if y' or y'', with $y' \neq y''$, can be produced at the same cost, then the production of $\frac{1}{2}y' + \frac{1}{2}y''$ will be less costly. For example, assume that $y' = (50, 0, 0)$ and $y'' = (0, 50, 0)$ can be produced at the same cost, then supplying $\frac{1}{2}y' + \frac{1}{2}y'' = (25, 25, 0)$ is less costly than producing y' and y''. In the context of energy supply, where the different commodities may be interpreted as consumption in different time intervals, it means that producing a constant flow over time is cheaper than changing it according to the time of the day.

The assumption of constant returns to scale may seem less convincing, but its role is mainly to avoid overly simplistic arguments for competition in cases where one firm in the market has a larger production than the others; under decreasing returns to scale this would by itself constitute an efficiency loss to society, and we exclude this case by our assumptions. Nevertheless, our motivation derives from the retail energy market where it is not conclusive from the literature that retailers' technology necessarily exhibits decreasing or increasing returns to scale as opposed to constant returns to scale.

The definition below states that an efficient allocation of production across suppliers is one that minimises production costs. That is, (y^1, y^2) being efficient means that a total output of $y = y^1 + y^2$ cannot be produced at a lower cost.

Definition 1 *The allocation of production (y^1, y^2) is efficient if and only if it minimises $C(y') + C(y'')$ over all $(y', y'') \in \mathbb{R}^m_+ \times \mathbb{R}^m_+$ with $y' + y'' = y^1 + y^2$.*

Since C is strictly quasi-convex (meaning that the sets $L(c)$ are strictly convex, so that a convex combination of two distinct points of $L(c)$ belongs to its interior), it is simple to see which allocations are cost minimising. That is, $y^1 = \lambda y$ and $y^2 = (1 - \lambda)y$ for $\lambda \in [0, 1]$ and some $y \in \mathbb{R}^m_+$. This means that, for a given y, the cost is minimised when firms produce the same combination of commodities.

Let x, y be two vectors that are not multiples of each other. In particular, this implies $C(x), C(y) > 0$. Let $\delta = C(x)/C(y)$, i.e. $C(x) = C(\delta y)$ by constant returns.

Then,

$$C(x+y) = C\left(x + \frac{1}{\delta}(\delta y)\right),$$

from constant returns to scale:

$$= \left(1+\frac{1}{\delta}\right) C\left(\frac{\delta}{\delta+1}x + \frac{1}{\delta+1}(\delta y)\right),$$

from $C(x) = C(\delta y)$, $x \neq \delta y$, and strict quasi-convexity (note that we must make use of the fact that we have a convex combination between x and δy):

$$< \left(1+\frac{1}{\delta}\right)\left(\frac{\delta}{\delta+1}C(x) + \frac{1}{\delta+1}C(\delta y)\right),$$

multiply through with $\left(1+\frac{1}{\delta}\right)$, using constant returns once again:

$$= C(x) + C(y).$$

Hence,

$$C(x+y) < C(x) + C(y). \tag{1}$$

For example, if $x = a_u$ and $y = a_p$, then $C(a_u + a_p) < C(a_u) + C(a_p)$. That is, the cost of supplying both types of customers is lower than separately supplying both types. Another case used in the paper is $x = 2a_u + a_p$ and $y = a_u + 2a_p$, then $C(3a_u + 3a_p) < C(2a_u + a_p) + C(a_u + 2a_p)$.[6]

Let $\mathbf{p} = (p^1, p^2)$ be two price vectors in $\mathbb{R}^m_+$.[7] Assume that prices are non-negative.[8] Recall that we are working in a context of fixed demand with a finite set of types of customers and firms compete to satisfy this fixed demand. Firms set simultaneously their prices, customers observe and buy from the firm that offers the lowest payment. That is, customers can only buy from one single firm.

[6] A similar result in Cambini and Martein (2009) shows that homogeneity of degree one combined with quasi-convexity produces convexity (Theorem 2.2.2).

[7] Each price is a vector, i.e. we have a price for each commodity, $p^l = (p^l_1, \ldots, p^l_m)$, for $l = 1, 2$. In the context of electricity, this means that we allow for "dynamic pricing" (i.e. time variant electricity prices). The application of more dynamic forms of prices has been limited in the domestic and small business sectors, however advanced metering solutions have made this possible (Haney et al. 2011).

[8] The reasonability on this assumption is based on the lack of evidence of negative electricity retail prices. Nevertheless, if this assumption were to be dropped, it would become easier not to violate the incentive compatibility constraints of the types of customers.

3.1 No Differential Information

So far, we have only delineated the general features of our model, without going into informational problems. Consider first the case where no firm has access to better information. Firm l's problem is, for $l = 1, 2$,

$$\max_{p_u^l, p_p^l} \pi^l = n_u^l p_u^l \cdot a_u + n_p^l p_p^l \cdot a_p - C(n_u^l a_u + n_p^l a_p),$$

where n_u^l and n_p^l are, respectively, the number of uniform and peak types customers that firm l supplies. Customers buy the good if their utility of buying the good is non-negative. That is, for reasonable prices, customers buy the good and choose to buy from the firm that offers the lowest payment. Firms face the incentive compatibility (IC) constraints that require customers not to accept a different price vector other than the one that corresponds to their type.

$$u_u - p_u \cdot a_u \geq u_u - p_p \cdot a_u, \tag{2}$$

$$u_p - p_p \cdot a_p \geq u_p - p_u \cdot a_p. \tag{3}$$

These constraints can be re-written as

$$(p_p - p_u) \cdot a_p \leq 0 \leq (p_p - p_u) \cdot a_u. \tag{4}$$

Equation 4 has a geometrical interpretation in the sense that it indicates the space for non-binding IC constraints.

The IC constraints play an important role in finding potential equilibrium outcomes. Firms need to construct a menu of price vectors that ensures that the IC constraints are satisfied for the same total payment. Since demand vectors of both types are different and fixed, IC constraints can be satisfied by changing p_u in the following way: increasing the price of the commodities that the peak type customer consumes more and decreasing the price of the commodities that the peak type customer consumes less. This is illustrated in the example below.

Example 1 *Let* $a_u = (3, 3, 3)$ *be the demand of the uniform customer and* $a_p = (7, 1, 1)$

be the demand of the peak customer with the following price vectors for each type, $p_u = (1, 1, 1)$ *and* $p_p = (2, 1, 1)$. *The uniform customer pays a total payment equal to* 9, *whereas the peak customer pays a total payment equal to* 16 *if it accepts the peak payment and it pays a total payment equal to* 9 *if it accepts the uniform type payment. Thus, the IC constraint for the peak type is no longer satisfied. However, we can find a price that satisfies this condition. Take the price vector* $\hat{p}_u = (2.2, 0.4, 0.4)$. *This generates the same total payment for the uniform type. The peak type would need to pay a total payment equal to* 16.2 *when accepting the uniform type payment. Thus, it prefers to accept the peak type payment.*[9]

Both firms simultaneously set their prices, customers observe all posted prices and buy from the firm with the lowest payment. The lowest payments are

$$p_u \cdot a_u = \min\{p_u^1 \cdot a_u, p_u^2 \cdot a_u\},$$

$$p_p \cdot a_p = \min\{p_p^1 \cdot a_p, p_p^2 \cdot a_p\}.$$

If both firms post $p_u \cdot a_u$ and $p_p \cdot a_p$, then they equally split the customers (i.e. $n_u^l = 1$ and $n_p^l = 1$, for $l = 1, 2$) such that the IC constraints hold. We want to investigate Nash equilibria in which both firms are active in the market, set the same payments and supply the same composition of types. The set of such symmetric equilibria is characterised by two conditions. First, both firms have in equilibrium $\pi^l \geq 0$. Second, unilateral price under-cutting should not be profitable. The next proposition shows existence of Nash equilibria with symmetric payments. All proofs are in the Appendix.

Proposition 1 *There are two classes of Nash equilibria with symmetric payments in pure strategies with* $\pi^l = 0$, $l = 1, 2$, *and with the following payments:*

(i) $p_u \cdot a_u = C(2a_u + a_p) - C(a_u + a_p)$ *and* $p_p \cdot a_p = 2C(a_u + a_p) - C(2a_u + a_p)$,

(ii) $p_u \cdot a_u = 2C(a_u + a_p) - C(a_u + 2a_p)$ *and* $p_p \cdot a_p = C(a_u + 2a_p) - C(a_u + a_p)$.

Proposition 1 shows that both firms can equally share the customers in terms of types while offering the same payment to each type. There is a continuum of Nash equilibria

[9] This can also be achieved by allowing for negative prices in some commodities or by changing both price vectors. Further, the general case with m commodities makes the problem less restricted. That is, if the IC constraints are satisfied with three commodities, these will also be satisfied with m commodities because there are more degrees of freedom for the firm to find different combinations of prices.

because for the same total payment there can be different prices for each commodity. Thus, there is symmetry in terms of payments, but there can be asymmetry in terms of prices. Proposition 2 considers the existence of equilibria with symmetric payments when firms make zero profits. It is important to consider a) the existence of an equilibrium with symmetric payments where at least one firm makes positive profit; and b) the existence of an equilibrium with asymmetric payments.

Proposition 2 *There is no Nash equilibrium with asymmetric payments or where at least one firm makes positive profit.*

Proposition 2 shows that there is no Nash equilibrium with asymmetric payments. Further, it will not be an equilibrium if one firm gains positive profit and the other makes zero profit. This is because if firms obtain different profits, then the firm with lower profit has an incentive to mimic the other firm's payments.

3.2 Differential Information

Assume that firms have different access to information about customers. Let firm 1 be better *informed* in the sense that it can see the types of all customers served by any firm in the industry, whereas firm 2 does not have access to this information. In connection with this difference in information, we assume that firm 1 can use the information on types to offer personalised payments, $w_a \in \mathbb{R}$, to customers of type $a \in A$, whereas firm 2 can only offer a menu of price vectors, $(p_u, p_p) \subset \mathbb{R}^m \times \mathbb{R}^m$. We assume the tie-breaking rule that customers buy from firm 1 in case of indifference.[10]

Given firm 2's payments, firm 1 can attract customers of type a, subject to a payment w_a, such that

$$w_a \leq p_a^2 \cdot a_a, \text{with } a = u, p. \tag{5}$$

If the payment offered by firm 1 is higher, then customers will not accept it. Firm 2 takes w_a as given and supplies the remaining customers as long as its profit is non-negative.

[10] This tie-breaking rule makes sense in our framework because firm 1, the better informed firm, can approach each customer knowing beforehand its type, whereas firm 2 needs to wait for each customer to approach the firm.

Firm 2's problem is

$$\max_{p_u, p_p} \pi^2 = n_u^2 p_u^2 \cdot a_u + n_p^2 p_p^2 \cdot a_p - C(n_u^2 a_u + n_p^2 a_p). \tag{6}$$

Since firm 2 does not have access to the same information about customers as firm 1, firm 2's problem is subject to the IC constraints as in the no differential information case.

We can observe three potential equilibrium outcomes: (1) firm 1 sells only to uniform customers and firm 2 sells to peak customers, (2) firm 1 sells only to peak customers and firm 2 sells to uniform customers, and (3) firm 1 sells to both types of customers. We show that there is no equilibrium where the allocation of customers is as in (1) or (2), but there is an exclusionary equilibrium where the better informed firm sells to both types of customers. Further, the case where both firms equally split the customers cannot be an equilibrium due to the tie-breaking rule. The proposition below states this result.

Proposition 3 *(Exclusionary equilibria) First, there is no equilibrium where firms supply equally the customers or where each firm supplies a type of customer. Second, there is a continuum of equilibria, where the better informed firm sells to both types such that:*
(i) $w_u + w_p = C(a_u + a_p)$,
(ii) $w_u \leq C(2a_u + a_p) - C(a_u + a_p)$ *and* $w_p \leq C(a_u + 2a_p) - C(a_u + a_p)$,
(iii) $w_u = p_u^2 \cdot a_u$ *and* $w_p = p_p^2 \cdot a_p$,
with allocation $n_u^1 = 2$ *and* $n_p^1 = 2$, *thereby achieving profit* $\pi^1 = 0$.

Proposition 3 implies that holding better information about the customers in the market and the ability to contact customers before firm 2, does not translate into higher profit for firm 1. This is because positive profit would give firm 2 an incentive to undercut firm 1's payments.

3.3 Market Structure and Social Surplus

There is one possible market structure with differential information and one possible case without differential information. In each case, firms earn zero profits, with the difference that firm 2 is excluded from the market in the differential information case. This arises from our assumption of homogeneous commodities.

Proposition 2 shows that, under no differential information, there is no Nash equilibrium with asymmetric payments. This holds even when one firm in the market supplies both types of customers. This result is reversed once we introduce differential information. In fact, Proposition 3 shows that there is a continuum of Nash equilibria when the better informed firm supplies both types of customers. The tie-breaking rule plays a key role in this difference. Access to information about the types of customers in the market provides firm 1 a first customer contact advantage. Firm 2 can only offer a menu of price vectors without being able to pre-identify the types of customers.

We have defined information advantage as the difference between the equilibrium profits of the better informed firm and the uninformed firm in the differential information case. In this case, firm 2 is excluded while firm 1 supplies all customers. There is no information advantage because firm 2 is excluded from the market.

We have defined information value as the difference between the equilibrium profits of the better informed firm in the differential information case and in the no differential information. There is no information value because the better informed firm has the same equilibrium profit in both cases.

These results contrast with the literature that from our knowledge says that there is an information advantage or disadvantage depending on the firms' information setup (Chokler et al. 2006). This result is explained by two main reasons. First, the presence of competition because the residual customer can switch to the other firm, it is not possible for the better informed firm to extract surplus from the customers through its access to information about the customers. Second, firm 2 is allowed to offer a menu of two price vectors (i.e. one for each type). The price vectors allow firm 2 to avoid giving an information rent that induces the customers to reveal their private information regarding their types. If, instead of offering a menu of price vectors, firm 2 could only offer one price vector to all customers, then firm 1 would be able to charge higher prices and enjoy an information advantage.

This conclusion holds in the short-run where the uninformed firm imposes a competitive constraint to the better informed firm and therefore, the better informed firm gains zero profit despite holding better information about all customers in the market. In the medium-run, the uninformed firm will not enter the market, or leave quickly, which creates the possibility of the informed firm being able to charge higher prices and enjoy an information advantage.

In each of the market structures mentioned above, social surplus equals the utility of customers less the operating cost. The social surplus is the same in all cases because there is no difference in terms of costs and the fixed demand is fully covered. The customer surplus will also be the same in both market structures. However, the surplus of each type may differ; in fact, each type may be better, worse or remain the same when we compare both market structures. The reason being is that there are two classes of Nash equilibria for each market structure. For example, if under no differential information the set of equilibrium payments is $p_u \cdot a_u = C(2a_u + a_p) - C(a_u + a_p)$ and $p_p \cdot a_p = 2C(a_u + a_p) - C(2a_u + a_p)$, whereas in the differential information case the set of equilibrium payments is $p_u \cdot a_u = 2C(a_u + a_p) - C(a_u + 2a_p)$ and $p_p \cdot a_p = C(a_u + 2a_p) - C(a_u + a_p)$. Then, the uniform type will be better off and the peak type will be worse off when firm 1 is better informed. Nevertheless, the customer surplus remains the same.

Based on definition 1, the allocation of production is efficient in both market structures. This is because a combination of different types is supplied by a given firm.

4 Robustness Analysis

To this point, we have assumed that there are two firms and two types of customers. We are now interested in examining the robustness of the results to small changes in the number of customers, firms and types.

4.1 Number of customers

So far, we have assumed that there are a total of four customers, two of each type. Suppose now that there are n_u uniform customers and n_p peak customers, with $n_u, n_p \in \mathbb{Z}^+$ and finite numbers. Suppose that no firm has access to better information.

If for at least one type $\frac{n_a}{2} \notin \mathbb{Z}^+$, $a \in A$, then it is no longer possible to split each type of customers equally between firms. Consequently, production is not efficient. By (1), combining all customers in one single firm leads to cost savings and so, higher profit. The same applies for a situation with asymmetric payments. Hence, the result of Proposition 1 will not hold if it is not possible to share equally each type of customers between both firms.

Furthermore, under differential information the same result holds. That is, the better informed firm has incentives to supply both types of customers, independently of the number of customers of each type. Thus, the result of no information advantage and no information disadvantage holds if it is possible to split equally the customers between firms.

4.2 Number of firms

We are now interested in analysing the impact on the market outcomes once we add one more firm. Assume that there are three firms and consider three customers of each type instead of two in order to avoid the unequal split. As shown above, if it is not possible to split equally the customers between firms, then Nash equilibria with symmetric payments in pure strategies under no differential information no longer exist.

If we add one more uninformed firm, then this firm will behave as firm 2 above because it is not a profitable deviation to decrease (or increase) the payment for the peak type or uniform type. The payments will remain the same and the same Nash equilibria with symmetric payments exist.

Assume now that firm 1 and firm 3 are equally informed, whereas firm 2 remains uninformed. Since firms 1 and 3 cannot equally split the customers of each type, then the exclusionary outcome under differential information will no longer hold. As before, the result of no information advantage and no information disadvantage holds if it is possible to split equally the customers between firms.

4.3 Number of types

The number of types increases the complexity in setting a menu of price vectors. Consider three types, a_u, a_r, and a_p. In order to avoid the unequal split, assume that there are two customers of each type. Now, we have the following additional IC constraints to those already mentioned before: $p_u \cdot a_u \leq p_r \cdot a_u$, $p_p \cdot a_p \leq p_r \cdot a_p$, $p_r \cdot a_r \leq p_u \cdot a_r$ and $p_r \cdot a_r \leq p_p \cdot a_r$. Example 2 shows that if there are not enough degrees of freedom to find different combinations of prices (i.e. three types and three commodities), then it is not possible to adjust the payments such that the IC constraints are satisfied.

Example 2 *Consider the following consumption profiles of three different types of customers:* $a_u = (3, 3, 3)$*,* $a_r = (3, 3.5, 2.5)$ *and* $a_p = (7, 1, 1)$*. Consider the following price vectors for each type,* $p_u = (1, 1, 1)$*,* $p_r = (1, 1.5, 1)$ *and* $p_p = (2, 1, 1)$*. In this case, both types* a_r *and* a_p *would prefer to accept the payment offered to the uniform type because they would pay less. Even by considering changes in all price vectors, in order to maintain the same total payment, no solution exists with non-negative prices. Thus, the IC constraints would not be satisfied.*

If the IC constraints are not satisfied, the result stated in Proposition 1 would no longer hold as one firm can offer a higher price and enjoy profits. However, this problem can be solved by adding enough commodities. The example below shows that the IC constraints are satisfied once we add two more commodities. Note that, as before, we imposed a non-negativity constraint in the price vectors. Without such constraint it would be possible to solve the problem in Example 2 without the violation of the IC constraints.

Example 3 *Consider the following consumption profiles of three different types of customers:* $a_u = (2.5, 2.5, 2.5, 2.5, 2.5)$*,* $a_r = (3, 2.5, 2.5, 2.5, 2)$ *and* $a_p = (7, 1, 1.5, 1.5, 1.5)$*. Consider the following price vectors for each type:* $p_u = (1, 1, 1, 1, 1)$*,* $p_r = (1.5, 1, 1, 1, 1)$ *and* $p_p = (1.5, 1, 1, 1, 1)$*. As before, types* a_r *and* a_p *would prefer to accept the payment offered to the uniform type because they would pay less. If we change the price vectors as follows:* $p_u = (3, 2, 0, 0, 0)$*,* $p_r = (1.8, 3.4, 0, 0, 0)$ *and* $p_p = (1.8, 3.4, 0, 0, 0)$*, then the same total payments remain the same and the IC constraints are satisfied.*

In order to find different combinations of prices that ensure the IC constraints to hold, we need to have a large number of commodities that is greater than the number of types. Under that case, the result of no information advantage or disadvantage is robust to changes in the number of types.

5 Conclusion

We have analysed whether there is an information advantage or disadvantage in a market where firms compete in prices with a good composed by homogeneous commodities. We have assumed that if one of the firms knows the corresponding type of all customers in the market, then this firm can offer personalised payments. Even though it is possible for the better informed firm to select its own customers as opposed to the uninformed firm, it obtains the same equilibrium profit as the uninformed firm and as in the case with no differential information.

While the literature does not generally conclude that better information entails higher profit, to the best of our knowledge it exclusively shows cases where there is information advantage or disadvantage. Indeed, this paper presents a game where the equilibrium profits for both firms (better informed and uninformed) remain the same.

Furthermore, we show that it is not the additional ability to price discriminate that allows the better informed firm to be able to exclude the uninformed firm from the market; but rather the first customer contact advantage. The uninformed firm can only offer a menu of price vectors without being able to pre-identify the type of customers.

Future research could be to consider the impact on the results of some type of demand-side management where customers could shift their own demand for electricity during peak periods in order to reduce their energy consumption overall. Another potential extension would be to consider differentiated goods. Electricity can be sold as a differentiated good if, for example, we consider reliability, which may be crucial in case there is a positive probability of power blackouts. In this case, each contract offered to a given customer would specify the price and the customer's service order or priority.

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7 Appendix

Proof of Proposition 1:

Let prices be as in (i) stated in Proposition 1, then $\pi^l = 0$, $l = 1, 2$, with corresponding allocation of customers $n_u^l = 1$ and $n_p^l = 1$. Further, we can assume that prices are in the interior of the feasible set given by the IC constraints and that small unilateral changes on prices do not violate these constraints. This means that the following conditions need to hold:

$$p_u \cdot a_u \leq p_p \cdot a_u,$$

$$p_p \cdot a_p \leq p_u \cdot a_p,$$

$$\text{and } p_u \cdot a_u + p_p \cdot a_p = C(a_u + a_p).$$

Given that a_u and a_p are not multiples of each other, firms can adjust the payments such that the IC constraints are satisfied. That is, p_u can be adjusted such that $p_u \cdot a_u$ changes, but $p_u \cdot a_p$ remains constant. Thus, we can move any price vector from the boundary into the interior of the feasible set. Hence, payments set in (i) can be implemented while IC constraints are satisfied. The same applies for the payments set in (ii) stated in Proposition 1.

Even with IC constraints being satisfied, there are several ways in which a firm could deviate.

(a) If one firm increases the price of the uniform type, then it loses the uniform customer and obtains

$$\begin{aligned}\hat{\pi} &= p_p \cdot a_p - C(a_p) \\ &= 2C(a_u + a_p) - C(2a_u + a_p) - C(a_p) < 0,\end{aligned}$$

where the inequality in the second line comes from (1). Thus, increasing the price of the uniform type is not a profitable deviation. Similarly, if one firm increases the price of the uniform customer and decreases the price of the peak type customer, then it loses the uniform type and attracts one more peak type at $\hat{p}_p \cdot a_p < p_p \cdot a_p$. Then, $\hat{\pi} = 2(\hat{p}_p \cdot a_p) - C(2a_p) = 2(\hat{p}_p \cdot a_p - C(a_p))$, where the second equality comes from constant returns to scale. However, $\hat{\pi} = 2(\hat{p}_p \cdot a_p - C(a_p)) < 0$ because $\hat{p}_p \cdot a_p < p_p \cdot a_p =$

$2C(a_u + a_p) - C(2a_u + a_p) < C(a_p)$.

(b) By the same reasoning, if firm one decreases the price of the uniform customer and increases the payment of the peak type customer, then it loses the peak type customer and attracts one more uniform type customer at $\hat{p}_u \cdot a_u < p_u \cdot a_u$. By (1), $p_u \cdot a_u = C(2a_u + a_p) - C(a_u + a_p) < C(a_u)$, then $\hat{\pi} < \pi = 0$. By the same reasoning, increasing the price of the peak type is not a unilateral profitable deviation.

(c) If one firm slightly decreases the price of the uniform type (i.e. $\hat{p}_u \cdot a_u < p_u \cdot a_u$), then it supplies both uniform customers and one peak customer and it obtains $\hat{\pi} = 2(\hat{p}_u \cdot a_u) + p_p \cdot a_p - C(2a_u + a_p) < 2p_u \cdot a_u + p_p \cdot a_p - C(2a_u + a_p) = 0$. Therefore, decreasing the price of one of the commodities of the uniform type is not a profitable deviation.

(d) If one firm slightly decreases the price of the peak type (i.e. $\hat{p}_p \cdot a_p < p_p \cdot a_p$), it supplies one uniform type and two peak type, obtaining $\hat{\pi} = p_u \cdot a_u + 2(\hat{p}_p \cdot a_p) - C(a_u + 2a_p) < p_u \cdot a_u + 2p_p \cdot a_p - C(a_u + 2a_p) = 3C(a_u + a_p) - C(2a_u + a_p) - C(a_u + 2a_p) < 0$, by (1). Hence, decreasing the price of the peak type is not a profitable deviation.

(e) If one firm increases the price of both peak and uniform types, then loses all customers and therefore, it is not a profitable deviation.

(f) If one firm decreases the price of both peak and uniform types, such that $\hat{p}_p \cdot a_p < p_p \cdot a_p$ and $\hat{p}_u \cdot a_u < p_u \cdot a_u$, then revenue falls below total cost of supplying peak and uniform type customers, i.e. $\hat{\pi} < \pi = 0$.

We conclude that it is not profitable for a firm to unilaterally deviate. Similarly, it is not profitable for a firm to unilaterally deviate if $p_u \cdot a_u = 2C(a_u + a_p) - C(a_u + 2a_p)$ and $p_p \cdot a_p = C(a_u + 2a_p) - C(a_u + a_p)$. □

Proof of Proposition 2:

As shown in the proof of proposition 1, we can assume that unilateral small changes in prices do not violate IC constraints. There are different cases that need to be analysed.

Case 1. Assume that $\pi^1 = 0$ and $\pi^2 > 0$. Then, firm 1 has an incentive to mimic firm 2's payments and increase profit. The same reasoning applies to the reverse case.

Case 2. Let payments be symmetric such that $\pi^l > 0$, $l = 1, 2$. As shown in case 1, profits of both firms need to be equal. It is a profitable deviation to slightly decrease both payments, $\hat{p}_u \cdot a_u < p_u \cdot a_u$ and $\hat{p}_p \cdot a_p < p_p \cdot a_p$, such that IC constraints still hold. Then, the deviating firm gains $\hat{\pi} = 2\hat{p}_u \cdot a_u + 2\hat{p}_p \cdot a_p - C(2a_u + 2a_p) = 2(\hat{p}_u \cdot a_u + \hat{p}_p \cdot a_p - C(a_u + a_p))$ (by constant returns to scale). Given that demand is fixed and unilateral changes are very small, we can say w.l.o.g. that $p_u \cdot a_u \approx \hat{p}_u \cdot a_u$ and $p_p \cdot a_p \approx \hat{p}_p \cdot a_p$. Then, $\hat{\pi} \approx 2(p_u \cdot a_u + p_p \cdot a_p - C(a_u + a_p)) = 2\pi > \pi > 0$.

Case 3. Let payments be asymmetric such that $\pi^l = 0$, $l = 1, 2$. Again, we can assume that unilateral small changes in prices do not violate IC constraints. There are several cases that need to be analysed. In all these cases, one firm will offer a lower payment than the other firm for at least one type. Then, that firm has an incentive to slightly increase the payment without matching the other firm's offer and hence, without losing customers.

Case 4. Let payments be asymmetric such that $\pi^l > 0$, $l = 1, 2$.

(i) Suppose that $p_u^1 \cdot a_u = p_u^2 \cdot a_u$ and $p_p^1 \cdot a_p < p_p^2 \cdot a_p$ (the same applies if $p_u^1 \cdot a_u = p_u^2 \cdot a_u$ and $p_p^2 \cdot a_p < p_p^1 \cdot a_p$). Then, $\pi^1 = \pi^2$ because otherwise any firm could deviate to the same allocation of types and charge the same payment as the other firm and increase profit. We can then use $\pi^1 = \pi^2$ to obtain $p_p^1 \cdot a_p = \frac{1}{2}C(a_u + 2a_p) - \frac{1}{2}C(a_u)$. If firm 2 decreases the price of the peak type such that it attracts one peak type customer, it obtains $\hat{\pi}^2 = p_u \cdot a_u + p_p \cdot a_p - C(a_u + a_p)$. By $\frac{1}{2}C(a_u) > C(a_u + a_p) - C(\frac{1}{2}a_u + a_p)$ (that follows from (1)), we know that $\hat{\pi}^2 > \pi^2$. Thus, decreasing the price of the peak type is a unilateral profitable deviation.

(ii) By the same reasoning, there is a profitable deviation if $p_u^1 \cdot a_u < p_u^2 \cdot a_u$ and $p_p^1 \cdot a_p = p_p^2 \cdot a_p$ with $\pi^l > 0$ (the same applies if $p_u^2 \cdot a_u < p_u^1 \cdot a_u$ and $p_p^1 \cdot a_p = p_p^2 \cdot a_p$).

(iii) Suppose that $p_u^1 \cdot a_u < p_u^2 \cdot a_u$ and $p_p^1 \cdot a_p > p_p^2 \cdot a_p$. If firm 1 matches the same peak payment as firm 1, it obtains $\hat{\pi}^1 = 2p_u \cdot a_u + p_p \cdot a_p - C(2a_u + a_p) > \pi^1 + \frac{1}{2}\pi^2 = 0$.

(iv) Suppose that $p_u^1 \cdot a_u < p_u^2 \cdot a_u$ and $p_p^1 \cdot a_p < p_p^2 \cdot a_p$. Then, firm 2 is not supplying any customers and therefore, firm 2 can match exactly the same as firm 1 and supply equally uniform and peak type customers as firm 1.

We conclude that there is no equilibrium with asymmetric payments and $\pi^l > 0$. □

Proof of Proposition 3:

In order to analyse the potential outcomes of introducing differential information, we need to consider an equilibrium where firm 1 sells to both uniform customers and firm 2 sells to peak customers (case 1), or firm 1 sells to peak customers and firm 2 sells to uniform customers (case 2), and an exclusionary equilibrium where firm 1 sells to all customers (case 3). The case where both firms supply equally the customers is ruled out because of the tie-breaking rule.

Case 1. Consider the requirements for a situation in which firm 1 sells to type a_u customers and firm 2 sells to type a_p customers. Both customers and firms must be satisfied with this split. For customers, this requires that type a_u prefers to buy from firm 1,

$$w_u \leq p_u^2 \cdot a_u, \tag{7}$$

and that type a_p prefers firm 2,

$$w_p > p_p^2 \cdot a_p. \tag{8}$$

Then, firm 2 has an incentive to slightly increase $p_p^2 \cdot a_p$ and increase profit. Therefore, this cannot be an equilibrium.

Case 2. By the same token, there is no equilibrium if firm 1 sells only to a_p customers and firm 2 sells only to a_u customers.

Case 3. Now, we consider the requirements for a situation in which firm 1 sells to both types a_u and a_p customers. That is, firm 1 excludes firm 2 serving both customer types at payments that do not allow firm 2 to cover the cost of attracting any type of customers. For this to be an equilibrium, it is necessary that firm 1's profit is non-negative and the payments of both firms are identical. The latter condition is needed because otherwise firm 1 could increase the payments up to firm 2's offers without losing the customers and gain profit under the assumption that IC constraints hold. Furthermore, firm 1's profit must be zero, otherwise firm 2 could undercut and increase profit, i.e. $w_u + w_p = C(a_u + a_p)$.

For firm 1, this requires that supplying both types of customers at w_u and w_p is more profitable than selling only to type a_u. Further, firm 1 must prefer supplying all customers rather than competing only for the peak type customers or leaving one peak customer to firm 2 or to compete for both peak type customers and leaving one uniform type for firm 2.

$$2w_u + 2w_p - C(2a_u + 2a_p) \geq 2w_u - C(2a_u), \tag{9}$$

$$2w_u + 2w_p - C(2a_u + 2a_p) \geq 2w_p - C(2a_p), \tag{10}$$

$$2w_u + 2w_p - C(2a_u + 2a_p) \geq 2w_u + w_p - C(2a_u + a_p), \tag{11}$$

$$2w_u + 2w_p - C(2a_u + 2a_p) \geq w_u + 2w_p - C(a_u + 2a_p). \tag{12}$$

Simplifying equations (9) -(10) and using $w_u + w_p = C(a_u + a_p)$, we obtain the following conditions:

$$w_a \leq C(a_a), \text{for } a = u, p, \tag{13}$$

$$w_u \leq C(2a_u + a_p) - C(a_u + a_p), \tag{14}$$

$$w_p \leq C(a_u + 2a_p) - C(a_u + a_p). \tag{15}$$

Further, (14) and (15) are stricter than (13) by strict quasi-convexity.

We suffice to show that $w_u + w_p = C(a_u + a_p)$, (14) and (15) is non-empty. By summing equations (14) and (15), we obtain $C(3a_u + 3a_p) \leq C(2a_u + a_p) + C(a_u + 2a_p)$. By (1) we know that the resulting condition is strictly satisfied.

There will be different combinations of (w_u, w_p) that satisfy these conditions and therefore, we can have a continuum of equilibria. □