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ABSTRACT

Heterogeneous Price Information and the Effect of Competition

In such a situation, some percentiles fall more than others, which leads to asymmetric consumer welfare gains from increased competition. Third, we provide a sufficient condition under which the higher percentiles of the distribution of prices paid by all types of consumers increase. When this happens, the probability that a consumer already paying a high price will pay even a higher price increases and it may even be the case that some consumers experience a welfare loss on average. Nevertheless, the weighted average price paid by consumers - the consumer surplus - always (weakly) decreases with increased competition. We provide an empirical strategy to identify how the response of prices to increased competition varies along the price distribution and use gasoline price data from the Netherlands to illustrate.

JEL Classification: L1
Keywords: gasoline prices, imperfect information, number of firms and price distribution

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1 Introduction

Standard Cournot and Bertrand oligopoly models predict that an increase in the number of firms will lower the equilibrium price. When an additional firm enters the market the equilibrium price falls because firms cut their output (price) too little (much) since they do not internalize the externalities their output (or pricing) decisions have on one another. These standard models formalize the widely accepted view in economics that more competition, as measured by an increase in the number of firms, (1) lowers prices and (2) benefits all consumers.

An important assumption behind these models is that all prices are known to consumers. This implies that market equilibrium is characterized by a single price, whereas casual observation and empirical studies indicate that identical stores charge different prices for the same product. In a seminal paper, Varian (1980) shows that price dispersion can be generated as an equilibrium phenomenon when consumers differ in the amount of information they have about prices. In Varian's model, the Nash-Bertrand symmetric equilibrium is one of mixed strategies: in equilibrium, firms draw prices from a common non-degenerate price distribution thereby producing price dispersion.[1] His model and, more generally, models based on imperfect and heterogeneous consumer information about prices help rationalize the price dispersion we often observe in real-world markets.[2]

Varian's model, however, predicts that the mean price increases with the number of firms.[3] This is considered an unappealing feature of the model because it is counterintuitive and at odds with what is usually observed in empirical studies (e.g., Barron et al., 2004; Hosken et al, 2008; Haynes and Thompson, 2008). In fact, this distinct prediction has been used to discriminate among possible explanations of observed price dispersion

[1] In the absence of the possibility to price discriminate across different types of consumers, mixing in prices arises as the optimal way to resolve the tension between charging low prices and obtaining profits from the more informed consumers and charging higher prices and profiting from the less informed consumers.

[2] For a recent survey of models that generate price dispersion, see Baye et al. (2006).

[3] Varian himself did not prove this result. For a proof see Janssen and Moraga-González (2004) and Morgan et al. (2006).

and Varian-type models have been dismissed because mean prices are often observed to decline with increased competition.

In this paper we present a more general oligopoly model where we allow for arbitrary heterogeneity in the amount of price information consumers have.[4] In such a model, we study how a change in the number of firms affects different percentiles of the distribution of prices. We do this by assuming only that *after the number of firms increases, all consumers become weakly better informed about prices*; that is, the post-entry distribution of price *information* in the population of consumers dominates the pre-entry distribution of price *information* in a first-order stochastic sense.

The paper makes several contributions. First, we derive a sufficient condition under which all percentiles of the price distribution decrease when competition is intensified. This condition, which is stronger than first-order stochastic dominance but weaker than the monotone likelihood ratio property, requires the ratio of consumers informed about one price to those informed about s prices, $s = 2, \ldots, N$, to decrease when competition is intensified (N is the number of firms). If this condition holds, then we get the result that more competition lowers prices and benefits all consumers, exactly as in standard Cournot and Bertrand models. Put in perspective, whereas the earlier literature on imperfect price information analyzed markets where the distribution of price information had two-point supports (e.g., Varian, 1980; Rosenthal, 1980; Schwartz and Wilde, 1985) our model is, to the best of our knowledge, the first to allow for an arbitrary distribution of information among consumers.[5] It turns out that this generalization, besides being more realistic,

[4] Varian's (1980) model of sales is isomorphic to an all-pay auction where firms bid by cutting prices in order to win a prize consisting in the additional demand stemming from the fully informed customers (Baye et al., 1992; Moldovanu and Sela, 2001). Allowing for an arbitrary distribution of price information in the market, as we do in this paper, sets our model apart from the all-pay auction literature. First, we do have multiple heterogeneous prizes as in Barut and Kovenock (1998) but in our game a single player can win many, even all, prizes at a time. Second, since poorly informed consumers only see a few prices, a firm bidding for these consumers is only in competition with a subset of other rivals; in this sense our game is better seen as one where players participate in multiple simultaneous all-pay auctions with different number of rival players and heterogeneous prizes. To the best of our knowledge, this situation has not been studied so far.

[5] In Burdett and Judd (1983) due to the homogeneity of search costs, consumers search only once or twice in equilibrium. Many consumer search models, specially those involving oligopolistic market structures, use search cost distributions with one- or two-point supports (e.g., Stahl, 1989; Fersthman and Fishman, 1992; Janssen and Moraga-González, 2004). As a result, the distribution of price information

allows for all the percentiles of the price distribution, and by implication the mean price paid by all consumer types, to decrease with the number of firms. It follows, then, that Varian's implication on the relationship between the number of firms and the mean price is a consequence of his assumption on the distribution of information, and not a general characteristic of models with mixed strategy equilibria arising from imperfect and heterogenous consumer information about prices. In fact, as shown by Chen and Riordan (2007) and by Perloff, Suslow and Seguin (2005), prices can also increase with the number of firms in pure strategy equilibria when there is spatial segmentation on the demand side.

Second, we provide a necessary and sufficient condition under which the high percentiles of the price distribution increase with the number of firms, whereas the low percentiles decrease. We show that when the ratio of consumers observing one price only to consumers observing two prices increases with the number of firms, then the upper percentiles of the price distribution increase. This condition is intuitive when we think about the equilibrium price distribution as a set of prices intended to attract different types of consumers. The low prices of the price distribution are meant to attract consumers who are well informed while higher prices are intended for the progressively less informed consumers. If the number of competitors increases, firms have no other alternative than to cut prices if they want to capture the well informed consumers; therefore the low percentiles of the price distribution go down. Note that as we move up in the price distribution, the prices are less and less successful at capturing consumers. At the top of the price distribution, firms, in effect, only care about consumers observing one or two prices because the chance of selling to other consumer types is negligible. Given this, if the number of consumers observing one price relative to those observing two prices increases when we move from an N-firm to an $N+1$-firm market, then firms prefer to raise their higher prices and therefore the upper percentiles of the price distribution increase.

Our third contribution is to study the welfare implications of the price changes generated by an increase in the number of firms. Since an increase in competition may be felt differently at distinct percentiles of the price distribution, consumers exposed to

that arises in market equilibrium has often two- or three-point supports.

more prices may experience a welfare gain that differs in sign and in magnitude from the one derived by consumers exposed to fewer prices. In this regard, and example shows that when all prices fall, intermediate prices fall more than extreme prices and, as a result, poorly informed consumers gain more from increased competition than well-informed consumers. This is an interesting result since it runs counter to the intuition that increased competition is more beneficial to well-informed consumers. Next, we prove that when the frequency of low and high prices increases with competition then, no matter the consumer type, the probability that a consumer already paying a high price will pay even a higher price increases. On average, however, consumers may or may not pay higher prices. This depends on the exact way in which the information structure in the market changes with the number of firms. We provide a sufficient condition under which the least informed consumers experience welfare losses with increased competition, exactly as it occurs in Varian's model. The condition is sufficient and some examples show that it may be the case that various types of consumers, not just the least informed type, derive a welfare loss after the number of firms increases.

Fourth, when we look at aggregate consumer surplus we find that the weighted average price paid by consumers decreases with competition. Because some consumers can experience welfare losses, this implies that the benefits to some consumers more than offset the losses (if any) to some other consumers.

In sum, our results imply that (1) welfare gains from increased competition need not be positive for all consumers; (2) when some consumers gain and others lose, those who gain benefit (weakly) more than those who lose so the weighted average impact of competition is (weakly) favorable; and (3), when all consumers gain from increased competition, the gains can be asymmetrically distributed across consumers.

Our final contribution is to assess the empirical relevance of these observations. For this purpose, we use gasoline prices in the Netherlands to estimate how distinct percentiles of the price distribution respond to changes in the number of gas stations. Given our (essentially) cross-sectional data we show that, under reasonable assumptions, we can identify how the price response to increased competition changes along the price distribution, even though the estimator of the price response itself may be biased due to the potential endogeneity of the number of gas stations. Our data confirm that the response of prices to increased competition varies along the price distribution, as predicted by the theoretical model. In a parametric specification of the model we find that the response of prices to an increase in the number of competitors is more pronounced in the middle of the distribution. This result, which confirms some of the outcomes in the theoretical model, suggests that the less informed consumers benefit twice as much from increased competition than the more informed consumers.

Since imperfect and heterogeneous price information is prevalent in many markets subject to competition-enhancing policies (telecom and financial services, gasoline, gas, electricity, airlines, etc.), the price and welfare effects of such policies might not be as straightforward as those implied by standard models. Typical empirical studies focus on the response of the mean price and variance to increased competition.[6] Since, as shown in this paper, increased competition can potentially have unequal effects among consumers, such focus would be too narrow to be able to capture the complexity of welfare effects generated by increased competition. Our results also emphasize that distributional issues should become a central part of any welfare assessment of competition-enhancing policies (industry deregulation, trade liberalization, transparency laws, etc.). This, again, advocates the importance of taking a broader view where the interaction between competition and consumer policy is taken into consideration (Armstrong, 2008; Armstrong et al., 2009; Waterson, 2003; Wu and Perloff, 2007).

The paper proceeds as follows. In Section 2 we present a model of the distribution of prices in an oligopolistic market where consumers differ in the amount of prices they observe. We analyze the effect of increased competition on prices and on the welfare of different types of consumers. In Section 3 we confront the predictions of the theoretical model with data on gasoline prices in the Netherlands. We close the paper by offering some concluding remarks and potential avenues for further research. Proofs of Propositions are relegated to the Appendix.

[6] See, for example, Borenstein and Rose (1994), Barron, Taylor and Umbeck (2004), Baye et al. (2004), Lewis (2008), and Gerardi and Shapiro (2009).

2 A model of the distribution of prices

In many markets for homogeneous goods the law of one price fails to hold and prices are significantly dispersed.[7] As shown in a large literature on search and advertising costs an important source of price dispersion is the substantial amount of heterogeneity in the information consumers have about prices.[8]

Inspired by the work of Varian (1980) and Burdett and Judd (1983), we propose a model where $N \geq 2$ retailers compete in prices to sell a homogeneous good to a large number L of heterogeneous consumers. At a given moment in time, a consumer wishes to purchase at most a single unit of the good.[9] The maximum willingness to pay for the good of a firm is given by v. Letting c denote the unit cost of a firm, define $k \equiv v - c$. We assume that consumers do not have information about all the prices in the market. To capture consumer heterogeneity in knowledge about prices in a flexible way, we assume that the entire population of consumers L can be divided into various types indexed by $s = 1, 2, ..., N$, each type consisting of all the consumers with similar exposure to price information. In particular, we assume that a fraction $\mu_s(N) \geq 0$ of the consumers is informed about s prices in the market; by construction $\sum_{s=1}^{N} \mu_s(N) = 1$. The vector $\mu(N) = (\mu_1(N), \mu_2(N), \ldots, \mu_N(N))$ is then a probability distribution over the number of prices a consumer can observe and represents the *distribution of price information* in the market. The argument N indicates that $\mu(N)$ has up to N coordinates and that the value taken by each coordinate may change with the number of retailers operating in the market.

There are various reasons for $\mu(N)$ to depend on N. Suppose, for example, that consumers observe prices while they move around the city, as when going to work, to

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[7] Recent empirical studies documenting price dispersion in various markets for homogeneous products include Lach (2002) and Wildenbeest (2011) for grocery products, Hortacsu and Syverson (2004) for mutual funds, Barron, Taylor and Umbeck (2004), Hosken et al. (2008), and Lewis (2008) for gasoline and Baye, Morgan and Scholten (2004) for products sold online.

[8] See the seminal papers by Stigler (1961), Butters (1977), Varian (1980), Rosenthal (1980), Burdett and Judd (1983) and Stahl (1989).

[9] This assumption is inconsequential. All our results extend to the case where consumers have downward sloping demand functions. We assume inelastic demands to ease the exposition only.

school, etc. We could think of this as "passive" search in the sense that consumers do not deliberately take to the streets and search for low prices. A good example of passive search is the way consumers get informed about gasoline prices. In this situation, after entry of a new retailer, some consumers will encounter a new price quotation while some others will not, depending on their movement patterns. This will make $\mu(N)$ different from $\mu(N+1)$. An alternative mechanism through which consumers may gather information is "active" consumer search (e.g., Stahl, 1989; Janssen and Moraga-González, 2004). In this situation, after entry of a new retailer, consumers will adjust their search patterns and, as a result, the outcome $\mu(N+1)$ will differ from $\mu(N)$. Finally, it may be that firms distribute price advertisements to consumers and in this way they get informed about various offers (e.g., Butters, 1977; Stahl, 1994). If, for example, firms use newspapers and magazines to place ads, the structure of information $\mu(N)$ will depend on the reading patterns of the consumers. To the extent that advertising efforts depend on the number of competitors, the outcomes $\mu(N)$ and $\mu(N+1)$ will be different. In our paper we will deliberately remain agnostic about the exact mechanisms through which price information is gathered by and/or distributed to consumers and view $\mu(N)$ as a "reduced form" for such mechanisms. Our focus will then be on the effect of an increase in the number of firms on prices under a reasonable assumption about how the probability distribution $\mu(N)$ changes into $\mu(N+1)$ when the number of competitors increases from N to $N+1$.[10]

Firms play a simultaneous-moves game. Let p_i be the price of a firm i. An individual firm i chooses its price taking the prices of the rival firms as given. We shall assume $1 > \mu_1(N) > 0$ which implies that the game has no pure-strategy equilibria. The intuition is as follows. Consider the position of a firm i and suppose all its rivals were charging a

[10] If we were to fully specify a model of search and/or advertising we would need, instead, to make assumptions on the primitives of the structure of information $\mu(N)$. That is, assumptions on the search cost distribution and/or on the advertising cost function. The difficulty with doing this is that, to the best of our knowledge, there is no theoretical study that pins down how the intensity of consumer search changes with the number of firms for arbitrary search costs distributions. Stahl (1996) and Moraga-González et al. (2010) study sequential and non-sequential search versions but focus on proving existence of equilibrium and on giving conditions for uniqueness. Armstrong et al. (2009) also consider a general model. In their model one would need to make assumptions about how the probability generating functions for the number of prices consumers view change with N, which in spirit is quite similar to what we actually do here. Both Stahl (1989) and Janssen and Moraga-González (2004) focus on the case in which the distribution of search costs has a two-point support.

price $\widetilde{p}$, with $c \leq \widetilde{p} \leq v$. There are two forces that affect the price-setting decision of a firm i. First, there is a desire to *steal business* from competitors, which pushes this firm to offer better deals than the rivals. This desire arises because there exist consumers who happen to see various prices and can therefore choose in which of the firms to buy (i.e., $\mu_s(N) > 0$ for at least one $s \in \{2, 3, ..., N\}$). Second, the possibility of *extracting surplus* from consumers who do not compare prices prompts a firm i to offer higher prices than the rival firms. This desire arises because there exist consumers (in particular, a fraction $\mu_1(N)/N > 0$) who have no other option but to buy at firm i. It is easy to see that either of these deviations destabilizes the proposed equilibrium price $\widetilde{p}$. Therefore a single price level cannot accommodate these two incentives.[11]

Denote the mixed strategy of a firm i by a distribution of prices F_i. We shall only study symmetric equilibria, i.e., equilibria where $F_i = F$ for all $i = 1, 2, \ldots, N$.[12] To calculate the expected profit obtained by a firm i offering the good at a price $p_i \in [c, v]$ when its rivals choose a price randomly chosen from the cumulative distribution function F, we first consider the chance that firm i sells to a consumer of type s, i.e., to a consumer that observes s prices in the market. The chance that such a consumer observes the price of firm i is s/N and, conditional on this, the probability that firm i sells to this consumer at price p_i is $(1 - F(p_i))^{s-1}$. The expected profit to firm i from all types of consumers is therefore

$$\Pi_i(p_i; F) = L(p_i - c) \left[\sum_{s=1}^{N} \frac{s\mu_s(N)}{N} (1 - F(p_i))^{s-1} \right] \tag{1}$$

In a mixed strategy equilibrium, a firm i must be indifferent between offering any price level in the support of F_i and offering the upper bound $\overline{p}_i$. Therefore, any price p_i in the support of F_i must satisfy $\Pi_i(p_i; F) = \Pi_i(\overline{p}_i; F)$. In symmetric equilibrium, $F_i = F$, $\overline{p}_i = \overline{p}$ and $\Pi_i = \Pi$. Therefore, since $\Pi(\overline{p}; F)$ is monotonically increasing in $\overline{p}$, it must be

[11] As in Varian (1980), when $\mu_1(N) = 1$, then all firms offering $p = v$ is a pure-strategy equilibrium. When $\mu_1(N) = 0$ instead, then all firms offering $p = c$ is a pure-strategy equilibrium.

[12] Standard derivations, which can be readily adapted from, e.g., Varian (1980), show that the support of F must be a convex set and that F cannot have atoms.

the case that $\overline{p} = v$ and $\Pi(\overline{p}; F) = \frac{L}{N} k\mu_1(N)$. Hence, F must solve

$$(p-c)\left[\sum_{s=1}^{N} s\mu_s(N)(1-F(p))^{s-1}\right] = k\mu_1(N). \tag{2}$$

for any p in the support of F given by $\left[c + \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N)}, v\right]$.[13]

A close look at equilibrium condition (2) serves to make an important point: what truly matters for determining the equilibrium price distribution of a firm is not N – the number of firms – but the distribution of information among consumers, $\mu(N)$.[14] It is therefore changes in the distribution of information that cause more or less "competitive pressure" in the market; changes in N *per se* have no effect on prices. We summarize this result in:

Proposition 1 *The number of firms N affects the equilibrium price distribution only indirectly through the probability distribution of price information among consumers $\mu(N)$.*

Unfortunately, equation (2) cannot be solved explicitly for F, except in special cases. Existence and uniqueness of an equilibrium price distribution can, however, be easily proven (see Burdett and Judd, 1983). Numerically, the equilibrium price distribution F is obtained by solving equation (2), given values of N, $\mu(N)$, v and c. Let $F(p; \mu(N), c, k)$ be the solution to (2). In Figure 1 we plot two examples of how equilibrium price distributions are affected by the number of firms. In the left panel, the blue line shows the case when $N = 2$, $\mu(N) = (0.5, 0.5)$, $v = 1$ and $c = 0$, while the red curve shows the case of $N = 3$, $\mu(N) = (0.5, 0.25, 0.25)$, $v = 1$ and $c = 0$. The graph advances a point around which the paper revolves, namely, that an increase in the number of firms may result in a upward shift of the price distribution. In such a case, all consumer types would pay lower prices on average, as one would expect from standard oligopoly models. However, this need not

[13] Notice that, since $\mu_1(N) > 0$, the lower bound of the price distribution is always above marginal cost. This reflects the fact that firms have market power and this market power is greater the higher the fraction of consumers who are informed about one price only.

[14] We note that this relies on the assumption of constant returns to scale. With economies or diseconomies of scale, the decrease in quantities caused by an increase in the number of firms would have cost, and by implication, price consequences.

be the case, as shown in the right panel where the blue line is the same as before and the red curve corresponds to the case $N = 3$, $\mu(N) = (0.3, 0.35, 0.35)$, $v = 1$ and $c = 0$

Though it is in general impossible to obtain the equilibrium price distribution analytically, we can easily derive its inverse

$$q(\tau; \mu(N), c, k) = c + \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N) (1-\tau)^{s-1}} \tag{3}$$

If we let τ in equation (3) take on values in the unit simplex we obtain the corresponding percentiles of the equilibrium price distribution of a firm. For example, setting $\tau = 0.8$, equation (3) gives the 80^{th} percentile of the price distribution.

The lower bound of the price distribution follows from setting $F(\underline{p}; \cdot) = 0$, which gives

$$\underline{p} = c + \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N)}.$$

Notice that, since $\mu_1(N) > 0$, the lower bound is always above marginal cost. This reflects the fact that firms have market power and this market power is greater the higher the fraction of consumers who are informed about one price only.

2.1 Equilibrium price distribution and the number of firms

The purpose of this paper is to study the relationship between prices in a market and the number of firms. Typical studies focus on the first and second moments of the price distribution. Here, we take a broader approach and examine the response of all the percentiles of the price distribution, given by (3), to changes in the number of competitors.

From Proposition 1, we know that changes in N per se have no effect on consumer prices. It is therefore the change in the distribution of information from $\mu(N)$ to $\mu(N+1)$ that creates more or less "competitive pressure" in the market. We can then perform comparative statics by examining changes in the inverse of the price distribution (3) caused by a change in the vector $\mu(N)$.

To shorten the expressions, let $q_{\tau N} \equiv q\left(\tau; \mu(N), c, k\right)$. We then have

$$q_{\tau N+1} - q_{\tau N} = \frac{k\mu_1(N+1)}{\sum_{s=1}^{N+1} s\mu_s(N+1)\left(1-\tau\right)^{s-1}} - \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N)\left(1-\tau\right)^{s-1}} \tag{4}$$

$$= \frac{k}{H(\cdot)}\left\{\sum_{s=1}^{N} s\left[\frac{\mu_s(N)}{\mu_1(N)} - \frac{\mu_s(N+1)}{\mu_1(N+1)}\right](1-\tau)^{s-1} - (N+1)\frac{\mu_{N+1}(N+1)}{\mu_1(N+1)}(1-\tau)^N\right\}$$

where

$$H(\cdot) \equiv \left[\sum_{s=1}^{N} s\frac{\mu_s(N)}{\mu_1(N)}(1-\tau)^{s-1}\right]\left[\sum_{s=1}^{N+1} s\frac{\mu_s(N+1)}{\mu_1(N+1)}(1-\tau)^{s-1}\right] > 0.$$

Since k and H are positive, expression (4) clearly makes the point that the way an increase in the number of firms affects the different percentiles of the price distribution is intimately linked to the way $\mu(N)$ changes into $\mu(N+1)$. As mentioned above, the exact way in which the coordinates of $\mu(N)$ and $\mu(N+1)$ may differ depends on the precise mechanism through which price information is gathered by and/or advertised to consumers in the market and little can be said about this without making a number of assumptions regarding movement patterns of buyers, consumer search protocols, distributions of search and advertising costs, etc. Nevertheless, irrespective of the precise mechanism underlying the distribution of price information in the market, what we can reasonably expect is that every consumer has (weakly) more information when the number of firms increases. We therefore make:

Assumption 1. *An increase in the number of firms causes the price information set of every consumer to become weakly larger, and that of some consumers to become strictly larger. As a result, the distribution of price information in a market with $N+1$ firms must dominate the distribution of price information in a market with N firms in a first-order stochastic sense. That is,*

$$\textit{for all } h = 2, 3, ...N, \ \sum_{s=h}^{N+1} \mu_s(N+1) \geq \sum_{s=h}^{N+1} \mu_s(N)$$
$$\textit{and for at least one } h, \ \sum_{s=h}^{N+1} \mu_s(N+1) > \sum_{s=h}^{N+1} \mu_s(N). \tag{5}$$

where $\mu_{N+1}(N) = 0$.

In other words, the fraction of consumers that observe exactly one price when there are $N+1$ firms cannot be larger than the same fraction when there are N firms in the market, i.e., $\mu_1(N+1) \leq \mu_1(N)$. Moreover, the fraction of consumers that observe at least h prices when there are $N+1$ firms cannot be smaller than the same fraction when there are N firms in the market, and for some h it has to be larger.

We believe Assumption 1 is a very sensible assumption. It must certainly be satisfied in settings where consumers gather information through "passive" search, as in the empirical application on gasoline prices studied in Section 3. Admittedly, however, Assumption 1 might be violated in markets where active search and advertising are additional sources of information gathering and transmission.[15] Nevertheless, we choose to focus on situations where Assumption 1 is satisfied because it is in these situations that our result that prices need not decrease after the number of firms increases is surprising.[16] In addition, we also remark that this first-order stochastic dominance assumption is relatively minimal in the sense that it does not impose a lot of structure on the way the probability distribution over the number of prices a consumer is informed about changes when we move from a market with N firms to a market with $N+1$ firms. To illustrate this, Figure 2 shows four possible ways in which the structure of information can change when we move from a market with 3 firms to a market with 4 firms, all of them satisfying Assumption 1.[17]

Despite Assumption 1 being rather weak, it yields interesting, and testable, results:

Proposition 2 *Suppose that the number of firms increases from N to $N+1$ and that Assumption 1 holds. Then:*

[15] For example, in the search model of Janssen and Moraga-González (2004) search intensity may be non-monotonic in the number of firms.

[16] If it were the case that consumers and firms decrease their search and advertising efforts after an increase in the number of firms, it would be reasonable for prices to increase with entry.

[17] In cases 1, 2 and 3, some consumers, the fraction μ_4, start observing 4 prices after entry. In case 1, the fractions of consumers observing either one or two prices stay the same, while in case 2 only the fraction of consumers exposed to two prices remains fixed. In case 3, no fraction of consumers remains constant. In case 4, no consumer starts observing 4 prices after entry; however, more consumers start observing 3 prices.

(I) There exists a percentile $\widehat{\tau} \in (0,1]$ *such that all the percentiles* $\tau < \widehat{\tau}$ *of the price distribution decrease.*

(II) All the percentiles of the price distribution decrease if

$$\frac{\mu_s(N+1)}{\mu_1(N+1)} \geq \frac{\mu_s(N)}{\mu_1(N)}, \text{ for all } s = 1, 2, ...N. \tag{6}$$

(III) There exists a percentile $\widetilde{\tau} \in [0,1)$ *such that all the percentiles* $\tau > \widetilde{\tau}$ *of the price distribution increase if and only if*[18]

$$\frac{\mu_2(N+1)}{\mu_1(N+1)} < \frac{\mu_2(N)}{\mu_1(N)}. \tag{7}$$

Given Assumption 1, more competitors in a market always results in a fall in the lower quantiles of the price distribution. This result is intuitive. When all consumers become (weakly) better informed, firms have no other alternative than to increase the frequency with which they charge lower prices if they want to capture relatively well informed consumers.

Condition (6) is a sufficient condition for the equilibrium price distribution with N firms to dominate in a first-order stochastic sense the distribution with $N+1$ firms. In such a case, all percentiles of the price distribution fall as we move from an N- to an $N+1$-firm market. This situation accords with the usual intuition that markets with more firms have lower prices. We note that (6) is stronger than first-order stochastic dominance (Assumption 1) but weaker than the monotone likelihood ratio property (MLRP).[19] A necessary and sufficient condition for an upward shift of the equilibrium price distribution is, from equation (4),

$$\sum_{s=1}^{N} s \left[\frac{\mu_s(N)}{\mu_1(N)} - \frac{\mu_s(N+1)}{\mu_1(N+1)} \right] (1-\tau)^{s-1} - (N+1)\frac{\mu_{N+1}(N+1)}{\mu_1(N+1)}(1-\tau)^N < 0 \tag{8}$$

[18]If $\mu_2(N)/\mu_1(N)$ and $\mu_2(N+1)/\mu_1(N+1)$ are equal to one another, the condition involves the smaller s for which $\mu_s(N)/\mu_1(N)$ differs from $\mu_s(N+1)/\mu_1(N+1)$ (see Appendix). In Varian's model, $\mu_s(N) = 0$ for all $s = 2, 3, ..., N-1$, and $\mu_s(N+1) = 0$ for all $s = 2, 3, ..., N$. As a result, the condition reads $\mu_N(N+1)/\mu_1(N+1) < \mu_N(N)/\mu_1(N)$, which is always satisfied because $\mu_N(N+1) = 0$. This explains why in Varian's model the price distributions with N and $N+1$ firms always cross one another.

[19]The MLRP requires that the ratio $\mu_s(N)/\mu_s(N+1)$ decreases in s (see Milgrom, 1981). If MLRP is satisfied, then our condition (6) holds. However, when our condition holds, MLRP may be violated, as in case 2 of Figure 2.

for all $\tau \in [0,1]$. We remark that (8) is violated in Varian's (1980) model. In fact, in Varian's model $\mu_1(N) = \mu_1(N+1)$ and $\mu_N(N) = \mu_{N+1}(N+1)$, the rest of the $\mu_s(N)$'s and $\mu_s(N+1)$'s being zero. In this case, condition (8) requires $N\mu_N(N) - (N+1)\mu_{N+1}(N+1)(1-\tau) < 0$, which can never be satisfied for all $\tau \in [0,1]$.

The upper quantiles of the price distribution can increase, and this occurs surely when condition (7) holds (which corresponds to cases 3 and 4 in Figure 2). The result that prices can increase after the number of competitors goes up is counter-intuitive and deserves an explanation. Note that cutting prices to capture well informed consumers results in lower expected profits for the firms. As a result, firms try to compensate by adjusting the frequency with which they charge higher prices, thereby generating profits from the consumers who are less well informed about prices. Note that as we move up in the price distribution, the prices are less and less successful at capturing well informed consumers. In effect, at the top of the price distribution, firms only care about consumers observing one or two prices because the chance of selling to other (better informed) consumers is negligible. Given this, if the number of consumers observing one price relative to those observing two prices increases when we move from an N-firm to an $N+1$-firm market, then firms prefer to raise the frequency of the higher prices and so the upper percentiles of the price distribution increase. The strength of this "compensating" effect can be so strong that the average price paid by some consumer types – the mean of the distribution of transaction prices – may increase after increases in N. We study this issue later in Section 2.2.

Proposition 2 discusses whether the percentiles of the price distribution increase or decrease when we move from a market with N retailers to a market with $N+1$ retailers; however, the proposition is silent with respect to whether some percentiles increase (or decrease) more than others. This is an important issue because an increase in the number of competitors may be felt more in some quantiles than in others and this opens up the possibility that consumers' gains from an increase in competition be asymmetric in sign and magnitude. To investigate this issue further, we analyze in detail some of the cases portrayed in Figure 2.

Example 1 *In case 2 of Figure 2, initially we have* $N = 3$ *and* $\mu(3) = (1/3, 1/3, 1/3)$. *That is, one third of the consumers observe one price, another third two prices and the final third three prices. After entry of a new retailer* $N = 4$ *we have* $\mu(4) = (1/6, 1/3, 1/3, 1/6)$. *That is, the shares of consumers exposed to two or three prices remain constant but the share of consumers observing one price decreases to one sixth in favor of the fraction of consumers observing four prices, which increases to one sixth.*

We start by noting that this example satisfies Assumption 1 and condition (6). As a result, the equilibrium price distribution with N firms dominates in a first-order stochastic sense the equilibrium price distribution with $N+1$ firms. This can be seen in the top-left graph of Figure 3, where we have plotted the resulting equilibrium price distributions of a firm with $v = 1$ and $c = 0$. To see whether all percentiles decrease by the same magnitude, we plot the corresponding equation (4) against τ on the top-right graph of Figure 3. The graph shows that an increase in competition is felt most at intermediate percentiles of the price distribution.

We now proceed to discuss case 3 of Figure 2.

Example 2 *As in Example 1 we start with* $N = 3$ *and* $\mu(3) = (1/3, 1/3, 1/3)$. *After entry of a new retailer we have* $\mu(4) = (7/24, 1/8, 1/3, 1/4)$. *That is, the share of consumers exposed to just one price goes down, but, in contrast to Example 1, the share of consumers observing two prices decreases in favor of the share of consumers observing four prices.*

We first note that this example also satisfies Assumption 1. Moreover, we observe that it satisfies (7) in Proposition 2, which ensures that the upper percentiles of the price distribution increase when we move from an N- to an $N+1$-firm market. In fact, the resulting equilibrium price distributions for a firm with $v = 1$ and $c = 0$ can be seen in the bottom-left graph of Figure 3. What is striking in this graph is that the price distributions cannot be ranked according to the first-order stochastic dominance criterion. This follows from the observations I (low percentiles decrease) and III (high percentiles increase) in Proposition 2. We see, for example, that the 80^{th} percentile of the price distribution increases in N while the 20^{th} percentile decreases.

To see whether all percentiles respond to competitive pressure in the same way, we plot the corresponding equation (4) against τ on the bottom-right graph of Figure 3. The graph shows that an increase in competition is felt most at relatively high percentiles of the price distribution.

2.2 Consumer welfare and the number of firms

We have seen that the response to an increase in competition differs across the percentiles of the price distribution. In particular, when we move from an N-firm to an $N+1$-firm market, we showed that some percentiles may decrease more than others and that some percentiles may increase while others decrease. These two observations along with the fact that consumers differ in their exposure to price information have two important implications. Suppose, first, that all consumers benefit from increased competition. Because some prices may decline more than others it is possible that not all consumers benefit in the same way. That is, some consumers may derive greater benefits from increased competition than others. A second implication is that, because some prices can actually increase rather than decrease, some consumers may not benefit at all; that is, they may end up getting lower utility, even on average. These implications of the model are in stark contrast to standard full-information oligopoly models. In this subsection we proceed to study the welfare gains that different types of consumers derive from an increase in competition.[20]

The utility of a consumer who buys from a firm i at a price p_i is given by $v - p_i$. Denote the utility of a consumer who observes s prices by $u_s = \max\{v - p_1, v - p_2, ..., v - p_s\}$ where $p_1, p_2, ..., p_s$ are i.i.d. random variables drawn from the equilibrium price distribution F. The distribution of u_s is $G(u_s; \mu(N), c, k) = (1 - F(p; \mu(N), c, k))^s$. As in Section 2, we derive the inverse of the distribution of this order statistic,

$$y_s(\tau; \mu(N), k) = k \left[1 - \frac{\mu_1(N)}{\sum_{\ell=1}^{N} \ell \mu_\ell(N) \tau^{\frac{\ell-1}{s}}}\right],$$

where τ takes values on $[0, 1]$.

[20] Note that we ignore non-price effects of competition such as better quality of service, shorter distances to retailers, etc., so that "welfare effects" here refers exclusively to price effects.

Following the same steps as before, we can study how the distribution of utilities received by a consumer of type s (i.e., exposed to s prices) changes when we move from an N-firm to an $N+1$-firm market. Let $y_{s\tau N+1} \equiv y_s(\tau; \mu(N), k)$ to shorten the notation. We then have

$$y_{s\tau N+1} - y_{s\tau N} = k \left[\frac{\mu_1(N)}{\sum_{\ell=1}^{N} \ell \mu_\ell(N) \tau^{\frac{\ell-1}{s}}} - \frac{\mu_1(N+1)}{\sum_{\ell=1}^{N+1} \ell \mu_\ell(N+1) \tau^{\frac{\ell-1}{s}}} \right]$$

$$= \frac{k}{M(\cdot)} \left\{ \sum_{\ell=1}^{N} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)} \right] \tau^{\frac{\ell-1}{s}} + (N+1) \frac{\mu_{N+1}(N+1)}{\mu_1(N+1)} \tau^{\frac{N}{s}} \right\} \tag{9}$$

where

$$M(\cdot) \equiv \left[\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \tau^{\frac{\ell-1}{s}} \right] \left[\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \tau^{\frac{\ell-1}{s}} \right] > 0$$

Given the similarity between the expression in (9) and that in equation (4), we have the following

Corollary 1 (of Proposition 2) *Suppose that the number of firms increases from N to $N+1$ and that Assumption 1 holds. Then, for all $s = 1, 2, ..., N$:*

(I) There exists a percentile $\widehat{\tau} \in [0, 1)$ such that all the percentiles $\tau > \widehat{\tau}$ of the distribution of utilities received by a type-s consumer increase.

(II) All the percentiles of the distribution of utilities received by a type-s consumer increase if condition (6) holds.

(III) There exists a percentile $\widetilde{\tau} \in (0, 1]$ such that all the percentiles $\tau < \widetilde{\tau}$ of the distribution of utilities received by a type-s consumer decrease if and only if condition (7) holds.

In line with Proposition 2, an increase in the number of firms results in an increase in the upper percentiles of the distribution of utilities derived by all consumer types. When condition (6) holds, then all the percentiles of the utility distribution of a given consumer type increase after the number of firms goes up.

The third result is perhaps the most interesting observation. Under condition (7), it can be shown that the distribution of the price paid by any type of consumer when there are $N + 1$ firms in the market "crosses-over" the distribution function when there are N firms (in the same was as in the right panel of Figure 1). In this situation, consider the consumers paying a price above the "cross-over" price when there are N firms in the market. The probability that these consumers pay even a higher price increases with N. It follows that increased competition raises the probability that these consumers are worse off, despite Assumption 1 being satisfied. We find this to be a remarkable result and clearly in contrast with standard Cournot and Bertrand models.[21]

Corollary 1 tells us about how the distribution of prices paid by the different consumer types changes with the number of firms. Although the corollary tells us that under condition (6) all consumers benefit from increased competition, it does not answer the question of whether some consumers benefit more than others. In addition, the result that under condition (7) prices actually paid by some consumers may go up with strictly positive probability after an increase in the number of firms does not necessarily imply that the welfare of these consumer types will be lower on average. To study whether consumer welfare increases or decreases, and whether this depends on the number of prices consumers are exposed to, we first compute the expected utility received by a consumer who observes s prices, namely

$$E[y_{s\tau N}] = \int_{-\infty}^{\infty} (v - p) d(1 - F(p))^s = k \left[1 - \int_0^1 \frac{\mu_1(N)}{\sum_{\ell=1}^{N} \ell \mu_\ell(N) \tau^{\frac{\ell-1}{s}}} d\tau \right], \tag{10}$$

and, following the techniques in Janssen and Moraga-González (2004), we study the sign of

$$E[y_{s\tau N+1}] - E[y_{s\tau N}]. \tag{11}$$

We also study what happens to aggregate consumer welfare defined by the weighted average consumer utility,

$$CS(\mu(N), c, k) = k \sum_{s=1}^{N} \mu_s(N) \left[1 - \int_0^1 \frac{\mu_1(N)}{\sum_{\ell=1}^{N} \ell \mu_\ell(N) \tau^{\frac{\ell-1}{s}}} d\tau \right] \tag{12}$$

[21] Anecdotal evidence tells us that many consumers report not to have felt the "supposed gains" from increased competition in liberalized markets such as airlines, gasoline, telecoms, etc. This might be related to this fact in combination with consumers remembering bad news (about prices) more readily than good news.

Proposition 3 *Suppose that the number of firms increases from* N *to* $N+1$ *and that Assumption 1 holds. Then:*

(I) All consumers derive greater utility on average if (6) holds. However, average utility gains are asymmetrically distributed across consumers.

(II) Consumers of type 1 *derive lower utility if (7) holds and* $\mu_1(N) = \mu_1(N+1)$, *irrespective of how* $\mu_s(N)$ *changes into* $\mu_s(N+1)$, $s = 2, 3, ..., N+1$.

(III) Aggregate consumer welfare increases (remains constant) if and only if $\mu_1(N+1) < (=)\mu_1(N)$.

Under condition (6), it is clear that all consumers will obtain (weakly) greater utilities on average, no matter whether their information set remains constant or increases. Our next example illustrates part (I) of Proposition 3. In addition, the example shows (1) that consumer benefits depend on s and therefore utility gains are asymmetrically distributed across the consumer population, and (2) that these gains need not be increasing in s, that is, poorly informed consumers may benefit more that well informed ones.

Example 3 *(A) Suppose that when* $N = 2$ *we have* $\mu(2) = (0.5, 0.5)$, *when* $N = 3$ *we have* $\mu(3) = (1/3, 1/3, 1/3)$ *and finally, when* $N = 4$ *we have* $\mu(4) = (1/6, 1/3, 1/3, 1/6)$. *If we numerically calculate the average utility received by the different types of consumers* $s = 1, 2, 3, 4$ *and for* $N = 2, 3, 4$, *we obtain,*

	Expected Utility		
	$N=2$	$N=3$	$N=4$
$s=1$	*0.451*	*0.564*	*0.706*
$s=2$	*0.549*	*0.693*	*0.830*
$s=3$		*0.742*	*0.871*
$s=4$			*0.890*

The example illustrates that gains from increased competition when N *increases from 3 to 4 for the type-1 consumers (*$0.706 - 0.564 = 0.142$*) are higher than those for the type-2 consumers (*0.137*), which in turn are higher than those of the type-3 consumers (*0.129*). Therefore, gains from increased competition at* $N = 3$ *decrease in* s.

(B) Suppose that when $N = 2$ *we have* $\mu(2) = (0.5, 0.5)$, *when* $N = 3$ *we have* $\mu(3) = (0.4, 0.45, 0.15)$ *and finally, when* $N = 4$ *we have* $\mu(4) = (0.3, 0.4, 0.2, 0.1)$. *If we*

numerically calculate the average utility received by the different types of consumers we get

	Expected Utility		
	$N=2$	$N=3$	$N=4$
$s=1$	*0.451*	*0.524*	*0.595*
$s=2$	*0.549*	*0.639*	*0.721*
$s=3$		*0.683*	*0.769*
$s=4$			*0.793*

In this case, gains from increased competition at $N=2$ *and* $N=3$ *increase in* s.

Proposition 3 also states the remarkable result that some consumers may experience a welfare loss after the number of competitors increases. In fact, when condition (7) holds, $\mu_1(N) = \mu_1(N+1)$ suffices for the type 1 consumers to experience a welfare loss. This explains why mean prices increase in N in Varian (1980), Rosenthal (1980) and Stahl (1989) (though in the latter the effect is amplified by an increase of the reservation price). We notice that this condition is a sufficient condition and therefore the result is more general. In fact, our next example shows also that when condition (7) is satisfied it may be the case that various consumers types experience a welfare loss from an increase in competition.

Example 4 *Suppose that when* $N=2$ *we have* $\mu(2) = (0.5, 0.5)$*, when* $N=3$ *we have* $\mu(3) = (0.5, 0.2, 0.3)$ *and finally, when* $N=4$ *we have* $\mu(4) = (0.5, 0.1, 0.2, 0.2)$*. If we numerically calculate the average utility received by the different types of consumers* $s = 1, 2, 3, 4$ *and for* $N = 2, 3, 4$*, we obtain,*

	Expected Utility		
	$N=2$	$N=3$	$N=4$
$s=1$	*0.451*	*0.421*	*0.395*
$s=2$	*0.549*	*0.545*	*0.535*
$s=3$		*0.601*	*0.603*
$s=4$			*0.641*

One main point deserves our attention. The average utility received by some consumers may decrease, rather than increase, as we move from an N- to an $N+1$-firm market. This is the case for consumers who remain exposed to one price (as indicated in the Proposition), but also for consumers who remain exposed to two prices. Part III of the Proposition shows that aggregate consumer welfare is constant for this example, which implies that the sum of the gains of the consumers whose utility increases equal the sum of the losses of the consumers whose utility decreases.

3 Empirical application

Our theoretical model makes it clear that the effect of a change in N works through changes in the distribution of price information among consumers. The theoretical model, however, is agnostic about how N affects the distribution of information $\mu(N)$; it can therefore accommodate various types of information gathering and/or transmission activities satisfying Assumption 1. The model offers a framework for thinking about the mechanisms through which N affects prices and offers new predictions regarding the sign and magnitude of the impact of increased competition on the distribution of prices. But are these predictions borne out in the data? To answer this question we use data on gasoline prices in the Netherlands to estimate how the effect of increasing the number of gas stations on prices, $q_{\tau N+1} - q_{\tau N}$, varies along the price distribution (i.e., with τ).

3.1 Adapting the model to the gasoline market

The market for gasoline is a good example of a market where price dispersion is observed.[22] In this market, there are two prominent aspects that contribute to price dispersion. On the one hand, gasoline retailers are typically differentiated in their characteristics. It is reasonable to believe that retailers that offer a broader range of side-benefits such as longer opening hours, credit card acceptance, car-washing facilities, etc. incur higher costs and therefore charge higher prices. As a result, observed price differences may, to a certain extent, be the outcome of such retailer differentiation. On the other hand, consumers in these markets are imperfectly informed about prices and, as shown in Section 2, this constitutes another source of price dispersion.

[22] Price dispersion in gasoline markets has been widely documented. Recent papers on this topic are, for example, Barron, Taylor and Umbeck (2004), Chandra and Tappata (2008), Hosken et al. (2008), and Lewis (2008).

Following Wildenbeest (2011), we extend our theoretical model above to accommodate these two sources of price dispersion in a parsimonious way. Though the basic good sold by firms, gasoline of a given grade, is a perfectly homogeneous product, here we adopt the view that the good is sold bundled with a number of side-services. These services add some value to the basic product and serve to "differentiate" retailers from one another. Let c_i be the unit cost of a firm i inclusive of the unit cost of the side-services available at the gas station.

Consumers wish to fill up their gas tank, say, once a week and the maximum willingness to pay for the good of firm i is given by v_i, which is inclusive of valuation for gasoline as well as for the side-services available at firm i. To keep things simple enough so that we can still compute a symmetric equilibrium, we impose a quasi-symmetry assumption. In particular, we assume that $v_i - c_i$ is constant across firms, and let $k \equiv v_i - c_i$ for all i. This assumption can be rationalized if firms hire factors of production for services in perfectly competitive markets and the production function of services exhibits constant returns to scale (see Wildenbeest, 2011).[23] It is then convenient to view firms as competing in the (net) utilities, $v_i - p_i$, they offer to the buyers (as in Armstrong and Vickers, 2001). Under the constant valuation-to-cost margin assumption, it turns out that firms have symmetric (utility) strategy spaces and a unique symmetric equilibrium exists.

Consumers have full information about the maximum (gross) utility v_i they can get at the different retailers because retailer characteristics can be observed and are fixed during the short run. Consumers, however, do not know all current prices in the market because prices vary across stations and over time. As before, the vector $\mu(N)$ represents the distribution of information in the market.

We now denote the mixed strategy of a firm i by a distribution of utilities U_i. In symmetric equilibrium $U_i = U$ for all $i = 1, 2, \ldots, N$. Following a similar reasoning as in Section 2, the expected profit obtained by a firm i offering a utility level $u_i = v_i - p_i \in [0, k]$

[23] That is, potential gains from offering higher service levels end up being competed away in the market for input factors. The result basically follows from an application of Euler's theorem (see Wildenbeest, 2011). With homogeneous functions of degree 1, and when factors are paid their marginal productivity, the total cost of producing a given level of services equals that level of services.

when its rivals choose a random utility according to the cumulative distribution U is

$$\Pi(u_i; U) = L(k - u_i) \left[\sum_{s=1}^{N} \frac{s\mu_s(N)}{N} U(u_i)^{s-1} \right]. \tag{13}$$

Note that $p_i - c_i = k - u_i$ is the per-consumer margin for firm i from offering utility u_i. In equilibrium, $\Pi(\underline{u}; U) = \frac{L}{N} k\mu_1(N)$ (where $\underline{u} = 0$) has to be equal to $\Pi(u_i; U)$. Therefore U must solve

$$(k - u) \left[\sum_{s=1}^{N} s\mu_s(N) U(u)^{s-1} \right] = k\mu_1. \tag{14}$$

for any u.

Every firm offers a utility randomly drawn from the same utility distribution U. However, the equilibrium distribution of firms' prices differs from firm to firm because each firm offers a different amount of side-benefits to consumers. In fact, the distribution of prices of firm i is

$$F_i(p; \mu(N), v_i, k) = 1 - U(v_i - p; \mu(N), k) \tag{15}$$

for $p \in \left[c_i + \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N)}, v_i \right]$.

The inverse of the equilibrium price distribution F_i of a firm i is then

$$q_{i\tau N} = c_i + \frac{k\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N) \left(1 - \tau\right)^{s-1}} \tag{16}$$

where τ takes values on $[0, 1]$. Because $c_i = v_i - k$, this equation clearly shows that the prices of different firms reflect their differences in side-benefits. To illustrate this, Figure 4 plots the price distributions corresponding to three different firms with $v_1 = 1, v_2 = 1.1$, $v_3 = 1.2$, $\mu(N) = (0.3, 0.35, 0.35)$ and $k = 1$.

A desirable feature of this model is that it has the ability to explain two features typically observed in price data from retail markets: the existence of serial correlation in firm-level prices, and the observation that firms undercut one another (see e.g., Lach, 2002; Lewis, 2008; Wildenbeest, 2011).[24] Serial correlation is the result of the "fixed firm-effect" v_i (or c_i): firms offering higher side-benefits draw their prices from supports containing

[24]Seee also our working paper, Lach and Moraga-González (2009), for empirical evidence consistent with the use of mixed strategies by gas stations in the Netherlands.

higher prices and, as a result, they typically charge higher prices than firms offering lower side-benefits. This, however, need not occur always because, when side-benefits are somewhat similar across firms, the price supports of different firms will overlap. This implies that, from time to time, firms offering higher side-benefits may be seen charging lower prices than firms offering lower side-benefits.

In the next subsection we present the data that will allow us to estimate equation (16) and test some of the theoretical findings in Section 2.

3.2 The price data

We use daily prices for Euro 95 gasoline from a large sample of gas stations in the Netherlands. The price data were obtained from Athlon Car Lease Nederland B.V., the largest private car leasing company in the Netherlands with over 129,000 cars as of the end of 2008 (www.athloncarlease.com).[25] The typical contract between Athlon and its lessees stipulates that Athlon pays for the gasoline consumed (up to a limit) as well as for car maintenance, insurance, etc. In order to do this, Athlon gets the lessees' gas receipts and it is from these receipts that the fuel prices are retrieved. Athlon's lessees do not get special discounts so the prices reported by Athlon are actual prices paid by drivers at the pump.

Prices were obtained from 3,143 gas stations for the 6-month period March 1, 2006–September 1, 2006. Because the price information arrives directly from the lessees, not all stations are sampled every day, which results in an unbalanced panel data of gas stations.[26] There are 247,962 station-day observations on Euro 95 prices. For illustration, Figure 5 displays the density function of prices in all gas stations in the sample.

The mean and median price of Euro 95 gas in our sample is 142.2 and 142 cents,

[25] The data used in this paper are part of the data collected and analyzed by Soetevent, Heijnen and Haan (2008). We are indebted to them for providing us with the gasoline price data and the list of gas stations operating in the Netherlands. They study whether ownership changes in highway gas stations originating from a government program of auctions and divestitures enhances competition. For details on the data collection, see their Appendix B.

[26] The number of days or, equivalently, the number of price quotations per gas station in the sample ranges from 1 to 115 days with an average of 92 days and a median of 101 days. We have one price of Euro 95 per station per day. Prices do not change during the day.

respectively, and the standard deviation is 5.4 cents. Most of this variation is within markets (municipalities): the average of the within-market standard deviations is 4.8 while the average of the within-market mean prices is 142.3. The lowest price is 102 cents while the highest price in the sample is 167. Not surprisingly, there is dispersion in gasoline prices and, although, not very large it has some economic significance. As an illustration, we computed the difference between the highest and lowest prices offered by gas stations within the same market and during the same day. The largest difference was 38 cents (in Langedijk on May 2 and in Boxtel on June 4). This implies that a consumer filling a 50-liter tank at the lowest-priced station instead of at the highest-priced station would have saved 19 euros.

We view our sample of prices from a gas station i as random draws from the distribution F_i. We are able to assume this because of several reasons. First, Athlon's lessees do not pay themselves for the gas (it is part of the contract) and therefore it is reasonable to assume that they have no incentives to search for gas stations offering the lowest prices. This is important because, otherwise, our sample would have been a sample of the stations with lowest-priced gasoline.[27] Second, all gas stations in the Netherlands are self-service and therefore there is a single price for gas in each station. Finally, we believe that the extent to which various prices in a given market are set by a single firm (because of joint-ownership) and/or reflect collusive agreements is minor, implying that prices can be viewed as independent draws.[28]

[27] On the other hand, these consumers may be choosing to buy from gas stations offering higher service values and therefore higher prices. We do not control for this type of selection but we do not think it is much of a problem since, as mentioned below, our sample covers 88 percent of all gas stations in The Netherlands

[28] Although we do not have information on the gas stations' owners, according to the Dutch Competition Authority, about 62 percent of the gas stations are owned and operated by independent dealers (NMa, 2006). The remaining stations belong to the main oil producers: BP, Esso, Shell, Texaco and Total. But even among these branded stations, most are dealer-operated. For example, Shell serves fewer than 15 percent of the gas stations and about 2/3 of the Shell-branded gas stations are operated by dealers who are free to set their own prices. This suggests that joint ownership of gas stations is not such a prevalent phenomenon as one may be led to believe from casual observation (although we have no data on joint ownership of gas stations by independent owners). An exception to this characterization was the highway market, where most gas stations, 63 percent, were owned and operated by the large oil producers (NMa, 2006). However, starting in 2002, the Dutch government has forced divestitures of highway stations in order to increase competition.

Equilibrium utility (price) distributions are defined for a given market. We define markets as the geographical area comprised by a municipality. There are 439 municipalities in the Netherlands for which we have gasoline price data. The majority of the municipalities are quite small in terms of population: two thirds of the municipalities have less than 30,000 inhabitants.[29] We have a list of all the gas stations in each market (in August 2007) and we can therefore compute N, but we do not have prices for all the N stations since we only observe prices from Athlon's lessees. On average across markets, however, the number of stations in the sample represents 88 percent of all the gas stations.

The mean number of stations by market is 8.2, respectively, and there is a lot of variation across markets – the standard deviation is almost as large as the mean, 7.6 stations. This variation is better seen in Table 1 where the distribution of N per market (municipality) is tabulated. N ranges between 1 and 80 (Amsterdam has 59 stations and Rotterdam has 80). Note that two thirds of the markets have 8 or less gas stations.

An important limitation of our data (common to most datasets) is the lack of information on production costs. As will be seen next, lack of data on c_i is likely to make the number of stations endogenous.

3.3 Econometric methodology and results

We define the responsiveness of prices to a change in N at quantile τ – the "*competitive response*" at quantile τ– as

$$\theta_{N\tau} \equiv q_{i\tau N+1} - q_{i\tau N} = g(N+1,\tau) - g(N,\tau)$$

where $g(N,\tau) = k\frac{\mu_1(N)}{\sum_{s=1}^{N} s\mu_s(N)(1-\tau)^{s-1}}$.

Because c_i is differenced out and the function $g(N,\tau)$ is the same to all firms in the market, $\theta_{N\tau}$ is also common to all firms in the market. We are interested in assessing whether different quantiles respond differently to changes in competition. We will therefore

[29] This definition of the market ignores stations that may be geographically close (or in the way to work) but located in different municipalities. However, it is not necessary for the gas stations to be located in a given municipality, provided every gas station in a given municipality factors into its pricing strategy the same distribution of information $\mu(N)$. This would approximately be true as long as neighboring municipalities do not differ much.

study how $\theta_{N\tau}$ varies over quantiles τ (for each value of N) as this will indicate whether prices respond to changes in N equally along the price distribution. In order to do this, we use the data on prices and on N to estimate the function $g(N, \tau)$ in equation (16) treating the unobserved unit cost c_i as a disturbance.

In the data, we observe prices of gas stations located in the 439 municipalities in the Netherlands. Let $m = 1, \ldots, 439$ index markets. Assume, for the moment, that the function $g(N, \tau)$ is the same across all markets. Then, the τ^{th} percentile or quantile of the distribution of prices for firm i in market m is

$$q_{im\tau} = c_{im} + g(N_m, \tau) \qquad \tau \in [0, 1] \tag{17}$$

Because N_m varies only at the municipality level, identification of its effect on prices is based on the cross-sectional variation in the number of stations.[30] This variation should be exogenous, i.e., not correlated with unobserved factors that affect prices in the market. The unobserved unit cost c_{im}, however, may be correlated with factors affecting N for a variety of reasons, making N_m endogenous in (17). In order to generate exogenous variation in N across markets one would need to examine the determinants of N and use those variables that do not affect prices to create such variation (e.g., entry costs). We will argue, however, that although $g(N_m, \tau)$ cannot in general be identified (without appropriate instrumental variables), changes in the competitive response, $\theta_{N\tau}$, are.

To see this, we write the unobservable c_{im} as the conditional expectation $E(c_{im}|N_m)$ plus a mean-independent disturbance e_i, yielding

$$q_{im\tau} = E(c_{im}|N_m) + g(N_m, \tau) + e_{im} \qquad \tau \in [0, 1] \tag{18}$$

Thus, without imposing functional form restrictions, we can consistently estimate $E(c_{im}|N_m) + g(N_m, \tau)$ but cannot separately identify $E(c_{im}|N_m)$ and $g(N_m, \tau)$. The estimated competitive response would then identify $E(c_{im}|N_m{+}1){+}g(N_m{+}1, \tau){-}E(c_{im}|N_m){-}g(N_m, \tau)$ which is biased for $\theta_{N\tau}$ unless c is mean-independent of N_m. Note, however, that

[30]The length of the sample period, 6 months, is too short to observe much entry and in fact we do not have records of entry episodes in our data.

when $E(c_{im}|N_m)$ does not depend on a particular quantile, changes in the estimated competitive response across quantiles τ do identify *changes* in the competitive effect. That is, for any two quantiles τ and τ' we have

$$
\begin{aligned}
&\{E(c_{im}|N_m+1)+g(N_m+1,\tau)-E(c_{im}|N_m)-g(N_m,\tau)\}\\
&-\{E(c_{im}|N_m+1)+g(N_m+1,\tau')-E(c_{im}|N_m)-g(N_m,\tau')\}\\
&=[g(N_m+1,\tau)-g(N_m,\tau)]-[g(N_m+1,\tau')-g(N_m,\tau')]\\
&=\theta_{N\tau}-\theta_{N\tau'}
\end{aligned}
$$

The intuition for this result rests on the observation that c_{im} enters additively in (17) and does not depend on the quantile. Loosely speaking, although it might be the case that $\frac{\partial c}{\partial N}\neq 0$, we have $\frac{\partial^2 c}{\partial N \partial \tau}=0$, which allows us to identify the cross-partial effect $\frac{\partial^2 q}{\partial N \partial \tau}$. That marginal cost c does not depend on the quantile implies that the mean cost at stations pricing at, say, the high end of the distribution does not differ from the mean cost at stations pricing at the low end. This is reasonable in our context since gas prices are not driven by idiosyncratic station-level cost but rather by the wholesale price which is common to all gas stations. Moreover, gas stations sometimes post high prices and other times post low prices as implied by the use of mixed strategies so that it is the same set of stations observed with high and low prices. In sum, if we can estimate $E(c_{im}|N_m)+g(N_m,\tau)$ for each (N_m,τ) we can then consistently estimate how the response of prices to changes in competition varies along the distribution of prices.

We have assumed that the function $g(N,\tau)$ is the same across markets. That is, $g(N,\tau)$ varies across markets only through variation in N. This means that the distribution of information depends on N only which may be an overly strong assumption since there may be additional market-specific factors, besides N, that affect the mechanism through which price information is gathered and/or advertised in the market. The point is that some of these factors may also be correlated with N_m, as they may affect the level of profits in the market, thereby precluding consistent estimation of (the mean value of) $g(N_m,\tau)$. Similarly, one could also argue that the function $E(c_{im}|N_m)$ varies across markets.

We deal with this heterogeneity issue by adding market-level covariates to (18). In essence, we assume that differences across markets enter additively and can be proxied by a linear combination of covariates. Let $E(c_{im}|N_m) \equiv h_m(N_m)$ and $g_m(N_m, \tau)$ be the market-specific functions. We then assume that there is a vector of covariates X_m such that $h_m(N_m)+g_m(N_m, \tau) = E(c_{im}|N_m)+g(N_m, \tau)+X_m\gamma_\tau+\xi_m$, where ξ_m is a proxy error uncorrelated with N_m and X_m, and the functions $E(c_{im}|N_m)$ and $g(N_m, \tau)$ are common to all markets. Note that we allow the covariates to have a differential impact across quantiles.[31] X_m includes the average household income in the municipality and the share of cars registered to businesses (out of total cars in the municipality) which we expect both to be positively correlated with the willingness to pay and with the share of non-price sensitive consumers. Thus, income and business cars should positively affect prices. In addition, since consumers' shopping behavior may be different in a geographically small, interconnected municipality than in a large, spatially-spread municipality, the distribution of price information may vary with the geography of the market. We therefore include control variables related to the geographic or spatial characteristics of markets, in particular, the total area of the municipality (in km^2), the area that is land (also in km^2), the share of land that is built (urbanized), the share that is agrarian (the remainder is land for recreation and forests), and the kilometers of roads within the municipality borders.

We have, so far, ignored the time dimension of the price data and implicitly assumed that the prices for each gas station are sampled from the same time-invariant distribution. This is an unrealistic assumption because changes in retail costs are mainly driven by changes in the wholesale price of gasoline and this price changed frequently over the six months sample period, thereby changing the distribution from which prices are drawn. We will therefore include the daily spot price of gasoline from the Amsterdam-Rotterdam-Antwerp (ARA) spot market in the estimation of each quantile to account for fluctuations in retail costs over time.[32]

[31] But we assume no interaction between N and X so that, for given τ, the plots of q against N across markets are parallel to each other.

[32] The estimates are not affected if we use a distributed lag of the spot price instead of the contemporaneous price. To minimize the computation burden we use only the latter.

Adding controls to (18) does not, of course, completely solve the endogeneity problem that arises from unobserved heterogeneity. Recall, however, that we do not wish to estimate $E(c_{im}|N_m) + g(N_m, \tau)$ but rather its change over τ. Thus, using the same argument as before, we can argue that *any* unobserved (additive) factor affecting price quantiles that is correlated with N_m but does not vary across quantiles does not affect the consistent estimation of $\theta_{N\tau} - \theta_{N\tau'}$. In other words, we can estimate $\theta_{N\tau} - \theta_{N\tau'}$ consistently even if there is unobserved variation in $E(c_{im}|N_m) + g(N_m, \tau)$ correlated with N as long as it is not quantile-specific.

We approximate $E(c_{im}|N_m) + g(N_m, \tau)$ by the natural logarithm of N ($\ln N$) and estimate

$$q_{im\tau} = \delta_0 + \delta_\tau \ln N_m + X_m \gamma_\tau + \varepsilon_{im\tau} \qquad \text{for } \tau \in \Upsilon \tag{19}$$

where $\varepsilon_{im\tau}$ embeds the various unobserved components and is assumed to be independent of the covariates.[33]

We estimate (19) for the 11 percentiles in $\Upsilon = \{0.05, .1, .2, .3, .4, .5, .6, .7, .8, .9, .95\}$ jointly using standard quantile regression methods.[34] We do not use the 15 markets with $N = 1$ in the estimation since the model in Section 2 does not apply to monopolies.

Under (19), the estimated competitive response is $\widehat{\theta}_{N\tau} = \ln[N + 1/N]\,\widehat{\delta}_\tau$. Figure 6 plots $\widehat{\delta}_\tau$ against τ (the factor $\ln[N + 1/N]$ starts at 0.41 when $N = 2$ and declines very rapidly). Recall, however, that $\ln[N + 1/N]\,\widehat{\delta}_\tau$ is not a consistent estimate of $\theta_{N\tau}$ since $\widehat{\delta}_\tau$ is biased for $g(N, \tau)$. This bias, however, does not vary across quantiles and therefore the "true" (unbiased) plot in Figure 6 is a parallel shift of the observed plot.[35] We should therefore focus on how the estimated price response changes with τ rather than on the precise level of this response.

A flat line in Figure 6 would indicate that the price response does not vary along the distribution of prices. This is not what we observe. In fact, the competitive response

[33] $\varepsilon_{im\tau}$ includes the retail cost shock e_{im}, the proxy error ξ_m as well as functional form approximation errors.

[34] We use the command *sqreg* in Stata 11. We do not estimate more extreme quantiles since the asymptotic distribution of estimators of extreme quantiles is non-standard (see Chernozhukov, 2005).

[35] The sign of the bias $E(c|N + 1) - E(c|N)$ is not clear a-priori.

varies, sometimes dramatically, across quantiles. $\theta_{N\tau}$ declines until the middle part of the price distribution and thereafter increases. Overall, the empirical evidence supports a prediction of the model in Section 2, namely that, when the equilibrium is characterized by price dispersion, an increase in competition can have asymmetric effects on prices.

The equilibrium price distribution, however, is not the same as the distribution of prices actually paid by consumers.[36] In general, consumers observing only a few prices end up paying prices close to the mean of the distribution, while consumers observing many prices buy at the lowest prices. Figure 6 suggests that consumers observing only a few prices benefit twice as much than consumers observing many prices. This means that it is the less informed consumers that seem to benefit more from increased competition. This empirical result is novel and surprising and can be rationalized by changes in the distribution of price information in the market (see top panel of Figure 3).

The statistical significance of our estimates of $\theta_{N\tau} - \theta_{N\tau'}$, the slope of the plot in Figure 6, depends on the stochastic properties of the error term $\varepsilon_{im\tau}$ in (19) because these matter for the way in which we compute standard errors. Recall that we control for aggregate price fluctuations and market-level factors and that the theoretical model implies that price observations are random draws from a given equilibrium distribution for each value of N. This suggests that the $\varepsilon_{im\tau}$'s could be treated as serially uncorrelated and independent across stations. However, because we allow for unobserved market-level heterogeneity in $h_m(N_m) + g_m(N_m, \tau)$ it is also likely that the $\varepsilon_{im\tau}$'s are correlated within markets. We estimate standard errors by bootstrapping the sample 200 times clustering at the municipality level. This allows for arbitrary correlation over time (days) and across stations within the same market. We compute the 55 $\left(\frac{11\times10}{2}\right)$ pairwise comparisons $\theta_{N\tau} - \theta_{N\tau'}$ and test for $H_0 : \theta_{N\tau} - \theta_{N\tau'} = 0$. Table 2 presents the p-values of these 55 simple tests. We reject the null hypothesis that $\theta_{N\tau}$ does not vary across quantiles in 20 percent of the cases, at a 5 percent significance level, and in 31 percent of the cases, at a 10 percent significance level.[37] Note that these tests include comparisons across adjacent

[36] This distribution depends on the type of consumer and, for consumers of type s, it is given by the distribution of the minimum among the s prices they observe.

[37] If we do not cluster by market the rejection rate climbs to 91 percent. We test the 55 pairwise

quantiles which are probably not expected to differ too much from one another. In fact, significant differences are found between the top quantiles ($\tau = 0.8, 0.9, 0.95$) and the middle quantiles ($\tau = 0.3, \ldots, 0.7$).

We can also take advantage of the fact that N is discrete to estimate (18) semi-parametrically using dummy variables for each of the 35 distinct values taken by $N \geq 2$ (see Table 1). We obviously allow the coefficient of each dummy variable to vary across quantiles since we are interested in examining how $\theta_{N\tau}$ varies across quantiles. As in linear regression, the estimated coefficients obtained from the quantile regressions with dummy variables capture the effect of N relative to a reference group which we choose to be markets with $N = 2$. We therefore estimate

$$q_{im\tau} = \beta_{0\tau} + \sum_{n \in \Omega} \beta_{n\tau} D_{nm} + X_m \gamma_\tau + \widetilde{\varepsilon}_{im\tau} \qquad \text{for } \tau \in \Upsilon \tag{20}$$

where $D_{nm} = 1$ if $N_m = n$ and 0 otherwise, and Ω is the set of values taken by $N \geq 3$ in Table 1. Under the chosen normalization, the theoretical model implies

$$\beta_{0\tau} = g(2, \tau) + E(c_{im}|N = 2)$$
$$\beta_{n\tau} = g(n, \tau) - g(2, \tau) + E(c_{im}|N = n) - E(c_{im}|N = 2) \qquad n \in \Omega, \tau \in \Upsilon$$

Note that

$$(\beta_{n+1\tau} - \beta_{n\tau}) - (\beta_{n+1\tau'} - \beta_{n\tau'}) = \theta_{n\tau} - \theta_{n\tau'} \tag{21}$$

so that, as previously observed, although we cannot consistently estimate the competitive effect of increased competition (unless we assume c to be mean-independent of N), we can identify how it changes across quantiles τ.

We estimate the $385 = 35 \times 11$ coefficients $(\beta_{0\tau}, \beta_{n\tau})$, $n \in \Omega$, $\tau \in \Upsilon$, from (20).[38]

combinations $\widehat{\delta}_\tau - \widehat{\delta}_{\tau'} = 0$ since the multiplicative factor $\ln[N + 1/N]$ does not change the significance of the test.

[38] The estimator of $\beta_{n\tau}$ is essentially the τ^{th} estimated quantile using all price observations with $N = n$ adjusting for the covariates. In fact, we obtain almost identical plots to those in Figure 7 if we proceed as follows. We first regress station-level prices on X_m allowing for a market-specific constant effect (a municipality dummy) and compute the residual prices from this regression. We then add the market-specific constant to this residual so that it will not be uncorrelated with N_m by construction. We use these residuals to compute the quantiles $q_{m\tau}$ for each market and estimate (20) as a system of seemingly unrelated equations without the controls X_m.

Figure 7 plots $\widehat{\theta}_{n\tau} = \widehat{\beta}_{n+1\tau} - \widehat{\beta}_{n\tau}$ against τ for each of the 26 values of N for which we have consecutive values, i.e., n and $n+1$ (see Table 1). Again, we focus on the slope of the plots and not on their levels. The pattern of the competitive response to changes in N is difficult to characterize as it varies with the initial number of gas stations in the market.[39] Nevertheless, it is clear that $\widehat{\theta}_{n\tau}$ varies along the price distribution supporting, at least qualitatively, the conclusions from the parametric model.

4 Conclusions

Consumers differ in the amount of price information they have, depending on their movement patterns, reading attitudes, search costs, etc. In homogeneous product markets, a large literature has shown that this implies that prices are typically dispersed in equilibrium. In this paper we have extended Varian's (1980) model of sales by allowing the information on prices to be arbitrarily distributed across consumers, and studied the price implications of an increase in the number of firms in such a situation. We have shown that allowing for an arbitrary distribution of information generates new results that have important implications for the way we take these models to the data.

We have observed that an increase in the number of competitors affects prices only indirectly through changes in the amount of price information consumers have. That is, increasing competition affects prices via an informational channel because the number (and location) of firms in a market is intimately related to the amount and distribution of price information among consumers.

We have provided three important results on how the price distribution changes when the number of competitors increases. First, if after an increase in the number of competitors every consumer observes (weakly) more prices, then the prices at the bottom of the price distribution decrease (more precisely, the frequency of the low prices in the support of the price distribution increases). However, the middle and high prices need not

[39]This is due to the nonparametric approach which allows for the effect of competition to differ in an unrestricted way across different values of N. This "local" approach also reduces the number of observations used to estimate the $\beta_{n\tau}^{'}s$ rendering most of the estimates not significantly different from zero.

decrease. Second, we have put forward a sufficient condition under which the distribution of prices with N competitors dominates the distribution of prices with $N+1$ competitors in a first-order stochastic sense. This implies that the mean price can decrease with N, which is in contrast to Varian's (1980) model and other models on imperfect price information and competition. In such a situation, however, the responsiveness of prices varies along the percentiles of the price distribution. Finally, we have also shown that when the number of consumers observing one price relative to those observing two prices increases when we move from an N- to an $N+1$-firm market, then firms prefer to raise the upper percentiles of the price distribution. The intuition is that, at the top of the price distribution, firms, in effect, only care about consumers observing one or two prices because the chance of selling to others is negligible. Given this, the trade-off goes against the uninformed consumers and the top prices of the price distribution go up.

Because the utility received by consumers will depend on the price actually paid, these three results have important welfare implications. In particular, we have noted three. First, we have observed that even if all prices decrease some percentiles decrease more than others and this actually leads to asymmetric consumer gains from increased competition. That is, some consumers gain more than others when the number of firms increases and it may be the case that poorly informed consumers benefit more from competition than well informed ones. Second, we have shown that, because (the frequency of) high prices can increase as a result of an increase in the number of firms, the probability that some consumers experience welfare losses increases when the number of competitors goes up. Finally, we have provided a sufficient condition under which the least informed consumers lose out on average after the number of firms increases. Nevertheless, the weighted average price paid by consumers – the consumer surplus – always (weakly) decreases with increased competition.

We have illustrated the theoretical results using disaggregated gasoline price data for the Netherlands. Due to data constraints, we are limited in what we can consistently estimate; nevertheless, we have shown that the magnitude and sign of the change in gasoline prices due to an increase in the number of firms is not uniform across the price distribution. In a parametric specification of the model we find that the response of prices to an increase in the number of competitors is more pronounced in the middle of the distribution. This result, which confirms some of the outcomes in the theoretical model, suggests that the less informed consumers benefit twice as much from increased competition than the more informed consumers.

We believe the results of this paper are important since in markets where the structure of information changes with the number of competitors, the price effects of competition-enhancing policies are not as straightforward as one may have initially expected. The novelty of our approach has been to model general structures of information. In this respect, understanding how these general structures of information arise endogenously and change with policy measures is an important and promising area for further research.

References

[1] Armstrong, Mark (2008), “Interactions between Competition and Consumer Policy,” *Competition Policy International* 4(1), 97-147.

[2] Armstrong, Mark and John Vickers (2001), “Competitive Price Discrimination,” *Rand Journal of Economics* 32, 579-605.

[3] Armstrong, Mark, John Vickers and Jidong Zhou (2009), “Consumer Protection and the Incentive to Become Informed”, *Journal of the European Economic Association* (Papers and Proceedings) 7(2-3), 399-410.

[4] Barut, Yasar and Dan Kovenock (1998), “The Symmetric Multiple Prize All-Pay Auction with Complete Information,” *European Journal of Political Economy* 14, 627-644.

[5] Baye, Michael. R., John Morgan and Patrick Scholten (2004), “Price Dispersion in the Small and in the Large: Evidence from an Internet Price Comparison Site”, *The Journal of Industrial Economics* 52(4), 463-496.

[6] Baye, Michael. R., John Morgan and Patrick Scholten (2006), “Information, Search, and Price Dispersion, chapter 6 in *Handbook on Economics and Information Systems Volume 1,* (T. Hendershott, Ed.), Amsterdam: Elsevier.

[7] Baye, Michael R., Dan Kovenock and Casper de Vries (1992), “It Takes Two to Tango: Equilibria in a Model of Sales,” *Games and Economic Behavior*, 4(4), 493-510.

[8] Barron, John M., Beck A. Taylor and John R. Umbeck (2004), “Number of sellers, average prices, and price dispersion”, *International Journal of Industrial Organization* 22(8-9), 1041-1066.

[9] Borenstein, Severin and Nancy Rose (1994), “Competition and Price Dispersion in the U.S. Airline Industry,” *Journal of Political Economy* 102, 653-683.

[10] Burdett, Kenneth and Kenneth L. Judd (1983), "Equilibrium Price Dispersion," *Econometrica* 51, 955-70.

[11] Butters, Gerard (1977), "Equilibrium Distributions of Sales and Advertising Prices", *Review of Economic Studies* 44, 465-491.

[12] Canay, Ivan A. (2011), "A Simple Approach to Quantile Regression for Panel Data," *The Econometrics Journal*, forthcoming.

[13] Chandra, Ambarish and Mariano Tapatta (2011), "Consumer Search and Dynamic Price Dispersion: An Application to Gasoline Markets," *Rand Journal of Economics* Vol.42, No.4, Winter 2011.

[14] Chen, Yongmin and Michael H. Riordan (2007), "Price and Variety in the Spokes Model," *Economic Journal* 117, 897-921.

[15] Chernozhukov, Victor (2005), "Extremal quantile regression," *Annals of Statistics* 33(2), 806-839.

[16] Janssen, Maarten and José L. Moraga-González (2004), "Strategic Pricing, Consumer Search and the Number of Firms", *Review of Economic Studies* 71(4), 1089-1118.

[17] Fershtman, Chaim and Arthur Fishman (1992), "Price Cycles and Booms: Dynamic Search Equilibrium," *American Economic Review*, 82, 1221–1233.

[18] Gerardi, Kristopher S. and Adam Hale Shapiro (2009), "Does Competition Reduce Price Dispersion: New Evidence from the Airline Industry", *Journal of Political Economy* 117(1), 1-37.

[19] Hortaçsu, Ali and Chad Syverson (2004), "Product Differentiation, Search Costs and Competition in the Mutual Fund Industry: A Case Study of S&P 500 Index Funds", *Quarterly Journal of Economics* 119, 403-456.

[20] Haynes, Michelle and S. Thompson (2008), "Price, Price Dispersion and Number of Sellers at a Low Entry Cost Shopbo", *International Journal of Industrial Organisation*, 26, 459-72.

[21] Hosken, Daniel S., Robert S. McMillan and Christopher T. Taylor (2008), "Retail Gasoline Pricing: What Do We Know?", *International Journal of Industrial Organization* 26(6), 1425-1436.

[22] Koenker, Roger (2005), "Quantile regression", Econometric Society Monograph, Cambridge.

[23] Lach, Saul (2002), "Existence and Persistence of Price Dispersion: an Empirical Analysis", *Review of Economics and Statistics*, August, 433-444.

[24] Lach Saul and José L. Moraga-González (2009), "Asymmetric Price Effects of Competition", CEPR Discussion Paper 7319.

[25] Lewis, Matthew (2008), "Price Dispersion and Competition with Differentiated Sellers", *Journal of Industrial Economics* 56 (3), 654-678.

[26] Milgrom, Paul R. (1981), "Good News and Bad News: Representation Theorems and Applications," *The Bell Journal of Economics* 12(2), 380-391.

[27] Moldovanu, Benny and Aner Sela (2001), "The Optimal Allocation of Prizes in Contests," *American Economic Review*, 91(3), 542-558.

[28] Moraga-González, José L., Zsolt Sándor and Matthijs Wildenbeest (2010), "Nonsequential Search Equilibrium with Search Cost Heterogeneity," IESE Business School Working Paper WP-869, July 2010.

[29] Morgan, John, Henrik Orzen and Martin Sefton (2006), "An experimental study of price dispersion," *Games and Economic Behavior*, 54, 134–158.

[30] NMa (2006): Benzinescan 2005/2006, De Nederlandse Mededingingsautoriteit.

[31] Perloff, Jeffrey M., Valerie Y. Suslow and Paul J. Seguin (2006), "Higher Prices from Entry: Pricing of Brand-Name Drugs," unpublished manuscript.

[32] Rosenthal, Robert W. (1980), "A Model in Which an Increase in the Number of Sellers Leads to a Higher Price", *Econometrica* 48, 1575–1579.

[33] Stahl, Dale O. (1989), "Oligopolistic Pricing with Sequential Consumer Search", *American-Economic-Review* 79(4), 700-712.

[34] Stahl, Dale O. (1996), "Oligopolistic Pricing with Heterogeneous Consumer Search," *International Journal of Industrial Organization* 14, 243-268.

[35] Stigler, George (1961), "The Economics of Information," *Journal of Political Economy* 69, 213-225.

[36] Soetevent, Adriaan R., Marco A. Haan, and Pim Heijnen (2008), "Do Auctions and Forced Divestitures Increase Competition?", Tinbergen Institute Discussion Paper TI 2008-117/1, The Netherlands.

[37] Schwartz, Alan and Louis L. Wilde (1985), "Product Quality and Imperfect Information," *The Review of Economic Studies*, 52-2, 251-262.

[38] Varian, Hal (1980), "A Model of Sales," *American Economic Review*, 70, 651-659.

[39] Waterson, Michael (2003), "The Role of Consumers in Competition and Competition Policy," *International Journal of Industrial Organization* 21, 129-50, 2003.

[40] Wildenbeest, Matthijs R. (2011), An empirical model of search with vertically differentiated products, *Rand Journal of Economics*, forthcoming.

[41] Wu, Ximing and Jeffrey M. Perloff (2007), "Tax Incidence Varies Across the Price Distribution," *Economics Letters* 96, 93-99.

Appendix for Online Publication

Proof of Proposition 2. From the expression in (4), we know that the sign of $q_{i\tau N+1} - q_{i\tau N}$ is given by the sign of

$$G(\cdot) \equiv \sum_{s=1}^{N} s\left[\frac{\mu_s(N)}{\mu_1(N)} - \frac{\mu_s(N+1)}{\mu_1(N+1)}\right](1-\tau)^{s-1} - (N+1)\frac{\mu_{N+1}(N+1)}{\mu_1(N+1)}(1-\tau)^N \qquad (22)$$

To prove (I), let us set $\tau = 0$ in this expression. It follows that the sign of $q_{i\tau N+1} - q_{i\tau N}$ equals the sign of

$$-\frac{1}{\mu_1(N+1)\mu_1(N)}\left\{\sum_{s=1}^{N} s\left[\mu_1(N)\mu_s(N+1) - \mu_1(N+1)\mu_s(N)\right] + (N+1)\mu_1(N)\mu_{N+1}(N+1)\right\}.$$

Since $\mu_1(N) \geq \mu_1(N+1)$, for the term in curly brackets we have

$$\begin{aligned}
&\sum_{s=1}^{N} s\left[\mu_1(N)\mu_s(N+1) - \mu_1(N+1)\mu_s(N)\right] + (N+1)\mu_1(N)\mu_{N+1}(N+1) \\
&> \mu_1(N)\left\{\sum_{s=1}^{N} s\left[\mu_s(N+1) - \mu_s(N)\right] + (N+1)\mu_{N+1}(N+1)\right\} \\
&> \mu_1(N)\left\{\sum_{s=1}^{N} s\left[\mu_s(N+1) - \mu_s(N)\right] + N\mu_{N+1}(N+1)\right\} > 0.
\end{aligned}$$

The last inequality follows from using Assumption 1, that is, using (5) we have:

$$\begin{aligned}
&\sum_{s=1}^{N} s\left[\mu_s(N+1) - \mu_s(N)\right] + N\mu_{N+1}(N+1) \\
&= \sum_{s=1}^{N-1} s\left[\mu_s(N+1) - \mu_s(N)\right] + N\left[\mu_N(N+1) + \mu_{N+1}(N+1) - \mu_N(N)\right] \\
&> \sum_{s=1}^{N-2} s\left(\mu_s(N+1) - \mu_s(N)\right) + (N-1)\left[\sum_{k=N-1}^{N+1} \mu_k(N+1) - \sum_{k=N-1}^{N} \mu_k(N)\right] \\
&> \sum_{s=1}^{N-3} s\left(\mu_s(N+1) - \mu_s(N)\right) + (N-2)\left[\sum_{k=N-2}^{N+1} \mu_k(N+1) - \sum_{k=N-2}^{N} \mu_k(N)\right] \\
&> \ldots > \sum_{k=1}^{N+1} \mu_k(N+1) - \sum_{k=1}^{N} \mu_k(N) = 0.
\end{aligned}$$

Since $q_{i\tau N+1} - q_{i\tau N}$ is strictly negative at $\tau = 0$, by continuity of the function $q_{i\tau N+1} - q_{i\tau N}$ in τ, we conclude that there exists a $\widehat{\tau} \in (0, 1]$ such that all the percentiles $\tau < \widehat{\tau}$ of the price distribution of a firm i decrease.

Part (II) of the Proposition follows straightforwardly from using condition (6) in the expression above for $q_{i\tau N+1} - q_{i\tau N}$.

To prove the final statement (III), we first note that setting $\tau = 1$ in (22) yields $q_{i\tau N+1} - q_{i\tau N} = 0$. Now, let us take the derivative of $q_{i\tau N+1} - q_{i\tau N}$ with respect to τ. Using (4) we get:

$$\frac{\partial}{\partial \tau}\left(q_{i\tau N+1} - q_{i\tau N}\right) = k\frac{G'(\cdot)H(\cdot) - G(\cdot)H'(\cdot)}{H(\cdot)^2}$$

where

$$G'(\cdot) = -\sum_{s=2}^{N} s(s-1)\left[\frac{\mu_s(N)}{\mu_1(N)} - \frac{\mu_s(N+1)}{\mu_1(N+1)}\right](1-\tau)^{s-2} + N(N+1)\frac{\mu_{N+1}(N+1)}{\mu_1(N+1)}(1-\tau)^{N-1} > 0$$

and

$$H'(\cdot) \equiv -\left[\sum_{s=2}^{N} s(s-1)\frac{\mu_s(N)}{\mu_1(N)}(1-\tau)^{s-2}\right]\left[\sum_{s=1}^{N+1} s\frac{\mu_s(N+1)}{\mu_1(N+1)}(1-\tau)^{s-1}\right] - \left[\sum_{s=1}^{N} s\frac{\mu_s(N)}{\mu_1(N)}(1-\tau)^{s-1}\right]\left[\sum_{s=2}^{N+1} s(s-1)\frac{\mu_s(N+1)}{\mu_1(N+1)}(1-\tau)^{s-2}\right] < 0$$

Taking the limit when $\tau \to 1$, we note that $G(\cdot) \to 0$, $H(\cdot) \to 1$,

$$G'(\cdot) \to -2\left[\frac{\mu_2(N)}{\mu_1(N)} - \frac{\mu_2(N+1)}{\mu_1(N+1)}\right]$$

and $H'(\cdot) \to -2\left[\mu_2(N)/\mu_1(N) + \mu_2(N+1)/\mu_1(N+1)\right] < 0$. As a result, the limit when $\tau \to 1$ of the derivative of the function $q_{i\tau N+1} - q_{i\tau N}$ with respect to τ is equal to

$$-2\left[\frac{\mu_2(N)}{\mu_1(N)} - \frac{\mu_2(N+1)}{\mu_1(N+1)}\right].$$

When condition (7) holds, this expression is negative. This implies that the difference $q_{i\tau N+1} - q_{i\tau N}$ is decreasing in a neighborhood of $\tau \to 1$. Since it is zero when $\tau = 1$, by continuity of the function $q_{i\tau N+1} - q_{i\tau N}$ in τ we conclude that there exists a $\widetilde{\tau} \in [0, 1]$ such that all the percentiles $\tau > \widetilde{\tau}$ of the price distribution of a firm i increase.

It could be the case that $\mu_2(N)/\mu_1(N) - \mu_2(N+1)/\mu_1(N+1) = 0$. In that case $\lim_{\tau\to 1} G'(\cdot) = 0$. If this is so, we can take the derivative

$$\frac{\partial^2}{\partial \tau^2}\left(q_{i\tau N+1} - q_{i\tau N}\right) = k\frac{G''H^2 - GHH'' - 2G'HH' + 2G(H')^2}{H(\cdot)^3}.$$

Since $G \to 0, G' \to 0$, and $H(\cdot) \to 1$ when $\tau \to 1$, we note that the sign of $\lim_{\tau\to1} \frac{\partial^2}{\partial\tau^2}(q_{i\tau N+1} - q_{i\tau N})$ is equal to the sign of

$$\lim_{\tau\to1} G'' = 6\left[\frac{\mu_3(N)}{\mu_1(N)} - \frac{\mu_3(N+1)}{\mu_1(N+1)}\right].$$

Therefore, if $\mu_2(N)/\mu_1(N) - \mu_2(N+1)/\mu_1(N+1) = 0$ but $\mu_3(N)/\mu_1(N) - \mu_3(N+1)/\mu_1(N+1) > 0$, then the derivative of the function $q_{i\tau N+1} - q_{i\tau N}$ increases in a neighborhood of $\tau = 1$. Therefore, the function $q_{i\tau N+1} - q_{i\tau N}$ must be convex and since it itself and its derivative are equal to zero at $\tau = 1$, we conclude $q_{i\tau N+1} - q_{i\tau N} > 0$ in a neighborhood of $\tau = 1$.

And so on and so forth. When $\mu_2(N)/\mu_1(N) - \mu_2(N+1)/\mu_1(N+1) = 0$ and $\mu_3(N)/\mu_1(N) - \mu_3(N+1)/\mu_1(N+1) = 0$, higher order derivatives can be invoked. ■

Proof of Proposition 3. We compare the expected utility a consumer in group μ_s derives in a market with N firms with that in a market with $N+1$ firms. We have:

$$\begin{aligned}
&E[y_{s\tau N+1}] - E[y_{s\tau N}] \\
&= \int_0^1 \frac{\mu_1(N)}{\sum_{\ell=1}^{N} \ell\mu_\ell(N)\tau^{\frac{\ell-1}{s}}} d\tau - \int_0^1 \frac{\mu_1(N+1)}{\sum_{\ell=1}^{N+1} \ell\mu_\ell(N+1)\tau^{\frac{\ell-1}{s}}} d\tau \\
&= \int_0^1 \frac{1}{\sum_{\ell=1}^{N} \ell\frac{\mu_\ell(N)}{\mu_1(N)}\tau^{\frac{\ell-1}{s}}} d\tau - \int_0^1 \frac{1}{\sum_{\ell=1}^{N+1} \ell\frac{\mu_\ell(N+1)}{\mu_1(N+1)}\tau^{\frac{\ell-1}{s}}} d\tau \\
&= \int_0^1 \frac{\sum_{\ell=1}^{N+1} \ell\left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right]\tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell\frac{\mu_\ell(N)}{\mu_1(N)}\tau^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell\frac{\mu_\ell(N+1)}{\mu_1(N+1)}\tau^{\frac{\ell-1}{s}}\right)} d\tau
\end{aligned} \tag{23}$$

When condition (6) holds, then the integrand of this equation is positive. As a result, all consumer types derive greater utility after an increase in competition. Moreover, since the expression (23) depends on s, we conclude gains from increased competition are asymmetrically distributed across the consumer population. In the main text, we provide a (counter-) example that shows two points: One, consumers exposed to greater information sets derive gains from increased competition different from those derived by consumers exposed to smaller information sets. Two, the gains of the former need not be larger than the gains from the latter. This proves (I).

To prove (II), we start by noting that when condition (7) holds, there exist a unique $\overline{\tau} \in [0,1)$ for which $y_{s\tau N+1} = y_{s\tau N}$. In fact, using the expression (9) above, we have that

$y_{s\tau N+1} = y_{s\tau N}$ if and only if

$$\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)} \right] \tau^{\frac{\ell-1}{s}} = 0$$

Since, by condition (7), $\mu_2(N)/\mu_1(N) > \mu_2(N+1)/\mu_1(N+1)$ we can write this expression as

$$\sum_{\ell=3}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)} \right] \tau^{\frac{\ell-1}{s}} = 2 \left[\frac{\mu_2(N)}{\mu_1(N)} - \frac{\mu_2(N+1)}{\mu_1(N+1)} \right] \tau^{\frac{1}{s}}$$

Dividing by $\tau^{\frac{1}{s}}$, we obtain

$$\sum_{\ell=3}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)} \right] \tau^{\frac{\ell-2}{s}} = 2 \left[\frac{\mu_2(N)}{\mu_1(N)} - \frac{\mu_2(N+1)}{\mu_1(N+1)} \right]$$

We now note that the RHS of this expression is constant in τ. By contrast, the LHS is increasing in τ. As a result, there is a unique point $\overline{\tau}$ at which the LHS and the RHS cross. By condition (7), $\overline{\tau} \in [0, 1)$.

Since the (inverse of the) utility distributions $y_{s\tau N+1}$ and $y_{s\tau N}$ cross one another only at $\overline{\tau}$, we can split the integral in (23) as follows:

$$\begin{aligned}
&\int_0^1 \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)} \right] \tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \tau^{\frac{\ell-1}{s}} \right) \left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \tau^{\frac{\ell-1}{s}} \right)} d\tau \\
&= -\int_0^{\overline{\tau}} \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N)}{\mu_1(N)} - \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \right] \tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \tau^{\frac{\ell-1}{s}} \right) \left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \tau^{\frac{\ell-1}{s}} \right)} d\tau \\
&+ \int_{\overline{\tau}}^1 \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N)}{\mu_1(N)} - \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \right] \tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \tau^{\frac{\ell-1}{s}} \right) \left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \tau^{\frac{\ell-1}{s}} \right)} d\tau \qquad (24)
\end{aligned}$$

Notice that the denominator of these integrals increases in τ. Therefore, (24) is lower than

$$-\int_0^{\overline{\tau}} \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right] \tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \overline{\tau}^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \overline{\tau}^{\frac{\ell-1}{s}}\right)}$$

$$+\int_{\overline{\tau}}^{1} \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N)}{\mu_1(N)} - \frac{\mu_\ell(N+1)}{\mu_1(N+1)}\right] \tau^{\frac{\ell-1}{s}}}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \overline{\tau}^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \overline{\tau}^{\frac{\ell-1}{s}}\right)} d\tau$$

$$= \frac{\int_0^1 \sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right] \tau^{\frac{\ell-1}{s}} d\tau}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \overline{\tau}^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \overline{\tau}^{\frac{\ell-1}{s}}\right)}$$

$$= \frac{\sum_{\ell=1}^{N+1} \ell \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right] \int_0^1 \tau^{\frac{\ell-1}{s}} d\tau}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \overline{\tau}^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \overline{\tau}^{\frac{\ell-1}{s}}\right)}$$

$$= \frac{\sum_{\ell=1}^{N+1} \frac{\ell s}{s+\ell-1} \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right]}{\left(\sum_{\ell=1}^{N} \ell \frac{\mu_\ell(N)}{\mu_1(N)} \overline{\tau}^{\frac{\ell-1}{s}}\right)\left(\sum_{\ell=1}^{N+1} \ell \frac{\mu_\ell(N+1)}{\mu_1(N+1)} \overline{\tau}^{\frac{\ell-1}{s}}\right)} \tag{25}$$

The sign of (25) is equal to the sign of the numerator. Setting $s = 1$ in the numerator of (25) gives

$$\sum_{\ell=1}^{N+1} \left[\frac{\mu_\ell(N+1)}{\mu_1(N+1)} - \frac{\mu_\ell(N)}{\mu_1(N)}\right] = \frac{1}{\mu_1(N+1)} - \frac{1}{\mu_1(N)}$$

which is equal to zero if the condition $\mu_1(N) = \mu_1(N+1)$ is satisfied. As a result, we conclude that $E[y_{s\tau N+1}] - E[y_{s\tau N}] < 0$ for $s = 1$.

(III) From (12) it readily follows that we need to show that

$$\sum_{j=1}^{N} \mu_j \left[\int_0^1 \frac{1}{\sum_{\ell=1}^{N} \ell \mu_\ell x^{\frac{\ell-1}{j}}} dx\right] = 1,$$

By changing $x^{\frac{1}{j}}$ by t in the integral we get

$$\int_0^1 \frac{1}{\sum_{\ell=1}^{N} \ell \mu_\ell x^{\frac{\ell-1}{j}}} dx = \int_0^1 \frac{j t^{j-1}}{\sum_{\ell=1}^{N} \ell \mu_\ell t^{\ell-1}} dt$$

because $dx = j t^{j-1} dt$. Then

$$\sum_{j=1}^{N} \mu_j \left[\int_0^1 \frac{1}{\sum_{\ell=1}^{N} \ell \mu_\ell x^{\frac{\ell-1}{j}}} dx\right] = \int_0^1 \frac{\sum_{j=1}^{N} j \mu_j t^{j-1}}{\sum_{\ell=1}^{N} \ell \mu_\ell t^{\ell-1}} dt = \int_0^1 1 dt = 1.$$

■

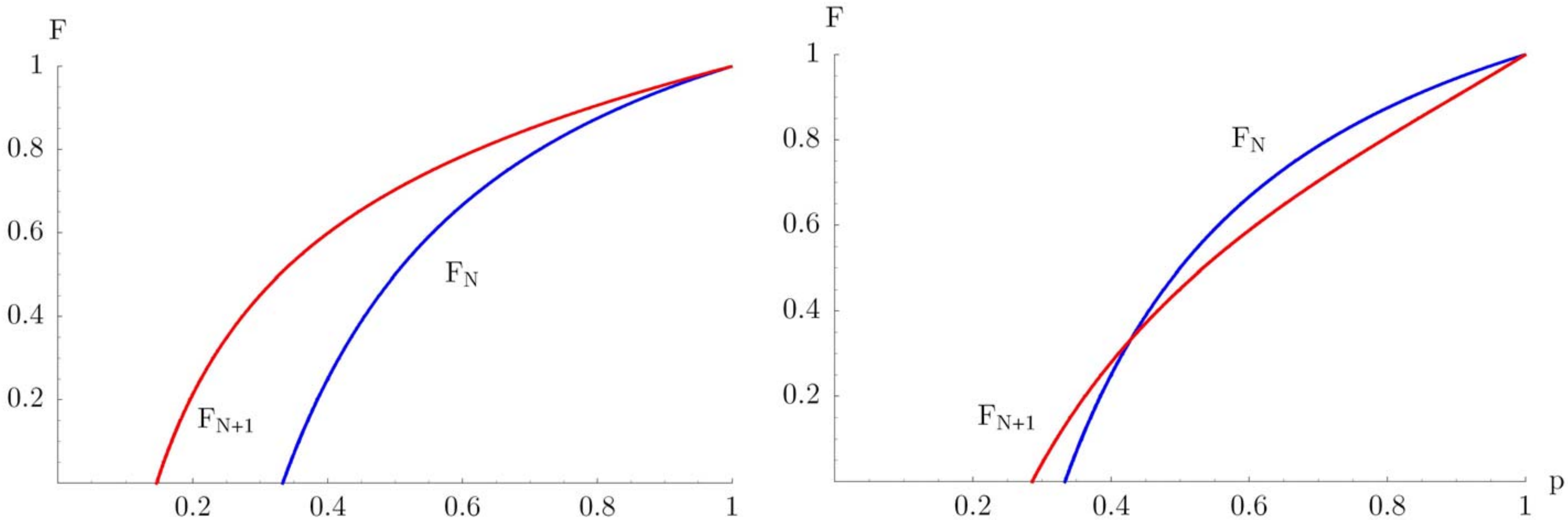
Table 1. Distribution of the number of gas stations (N) by market and by price observations

N	Number of markets	Percent	Cumulative	Number of observations	Percent	Cumulative
1	15	3.4	3.4	1447.0	0.6	0.6
2	35	8.0	11.4	4856.0	2.0	2.5
3	45	10.3	21.6	9086.0	3.7	6.2
4	48	10.9	32.6	13773.0	5.6	11.8
5	56	12.8	45.3	19854.0	8.0	19.8
6	36	8.2	53.5	15608.0	6.3	26.1
7	26	5.9	59.5	12222.0	4.9	31.0
8	30	6.8	66.3	15796.0	6.4	37.4
9	24	5.5	71.8	14813.0	6.0	43.3
10	21	4.8	76.5	11954.0	4.8	48.2
11	19	4.3	80.9	13081.0	5.3	53.4
12	17	3.9	84.7	14605.0	5.9	59.3
13	8	1.8	86.6	6254.0	2.5	61.8
14	10	2.3	88.8	9351.0	3.8	65.6
15	8	1.8	90.7	7195.0	2.9	68.5
16	6	1.4	92.0	6515.0	2.6	71.1
17	2	0.5	92.5	2121.0	0.9	72.0
18	7	1.6	94.1	9204.0	3.7	75.7
19	3	0.7	94.8	3901.0	1.6	77.3
21	1	0.2	95.0	1633.0	0.7	77.9
22	2	0.5	95.4	3127.0	1.3	79.2
23	2	0.5	95.9	2734.0	1.1	80.3
24	1	0.2	96.1	1531.0	0.6	80.9
25	2	0.5	96.6	3657.0	1.5	82.4
26	1	0.2	96.8	1615.0	0.7	83.1
27	3	0.7	97.5	6257.0	2.5	85.6
29	1	0.2	97.7	2068.0	0.8	86.4
30	1	0.2	98.0	2532.0	1.0	87.4
31	1	0.2	98.2	2544.0	1.0	88.5
32	1	0.2	98.4	2491.0	1.0	89.5
33	1	0.2	98.6	1288.0	0.5	90.0
37	2	0.5	99.1	5895.0	2.4	92.4
39	1	0.2	99.3	2837.0	1.1	93.5
47	1	0.2	99.5	4209.0	1.7	95.2
59	1	0.2	99.8	5021.0	2.0	97.2
80	1	0.2	100.0	6887.0	2.8	100.0
Total	439	100		247,962	100	

Table 2: p-value of tests for equal competitive response across quantiles

percentile	5	10	20	30	40	50	60	70	80	90
10	0.52									
20	0.32	0.25								
30	0.22	0.17	0.15							
40	0.21	0.19	0.20	0.35						
50	0.32	0.32	0.43	0.71	0.88					
60	0.45	0.49	0.66	0.95	0.75	0.68				
70	0.87	0.97	0.79	0.50	0.29	0.20	**0.07**			
80	0.53	0.43	0.26	0.13	**0.06**	**0.05**	**0.03**	**0.07**		
90	0.22	0.16	**0.08**	**0.03**	**0.02**	**0.02**	**0.02**	**0.07**	0.24	
95	0.14	**0.09**	**0.04**	**0.01**	**0.01**	**0.01**	**0.03**	**0.10**	0.44	1.00

tests based on standard errors clustered at municipality level



(a) N=2, μ(2)=(0.5,0.5), μ(3)=(0.3,0.35,0.35)

(b) N=2, μ(2)=(0.5,0.5), μ(3)=(0.5,0.25,0.25)

Figure 1: The impact of N on the equilibrium price CDF

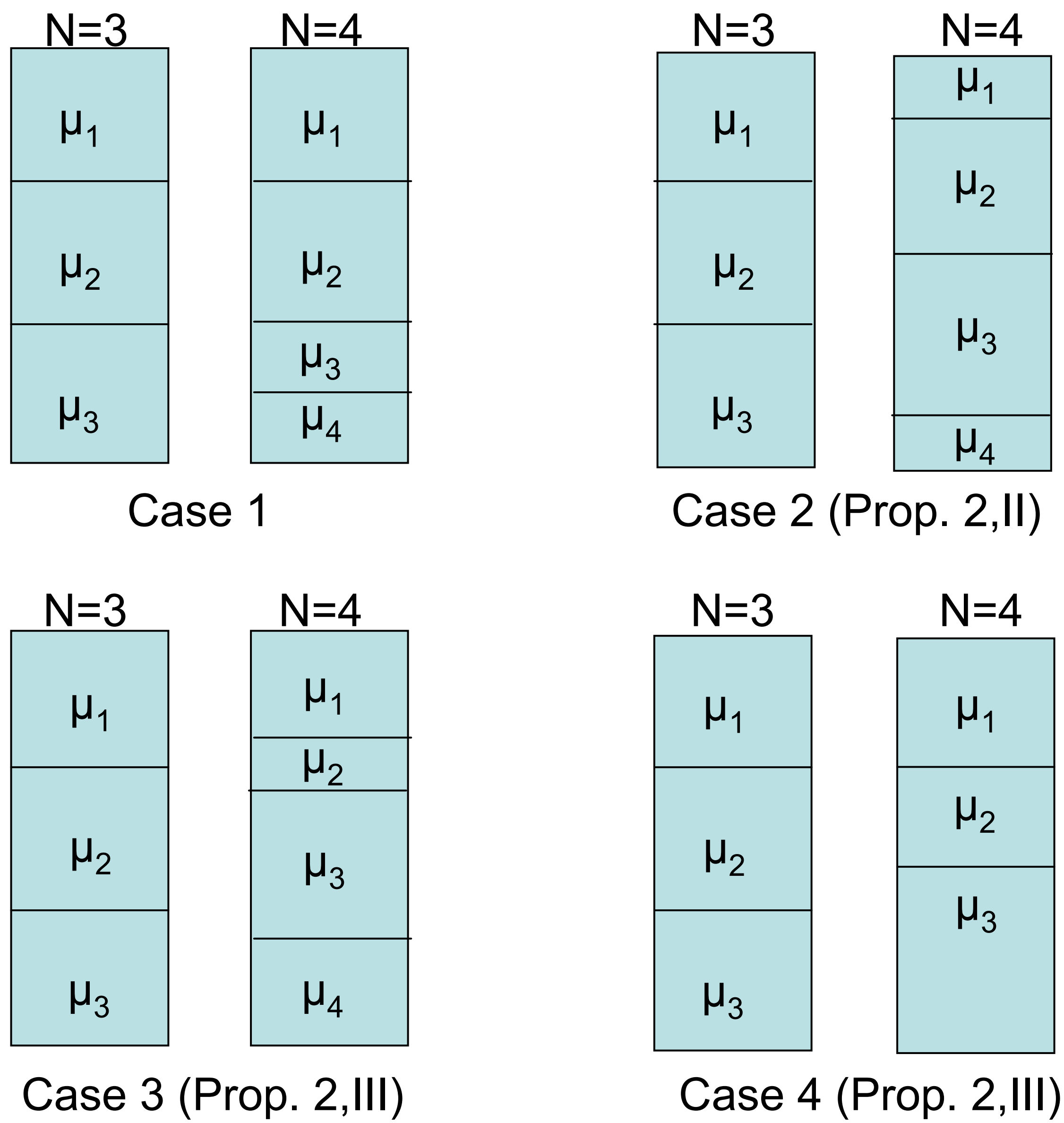


Figure 2: Distribution of price information at N=3 and N=4

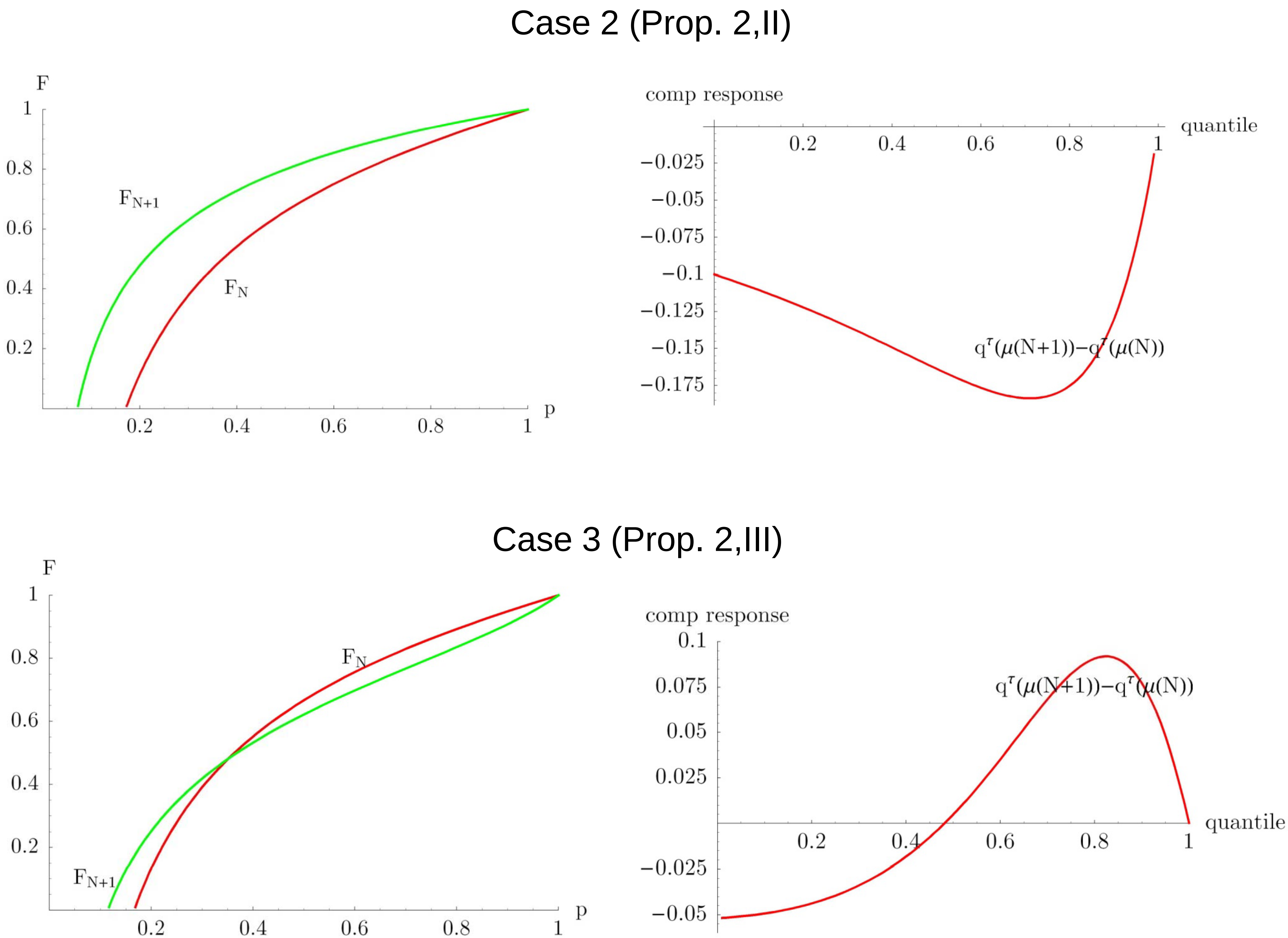


Figure 3: Equilibrium price CDFs and competitive response when N increases from 3 to 4

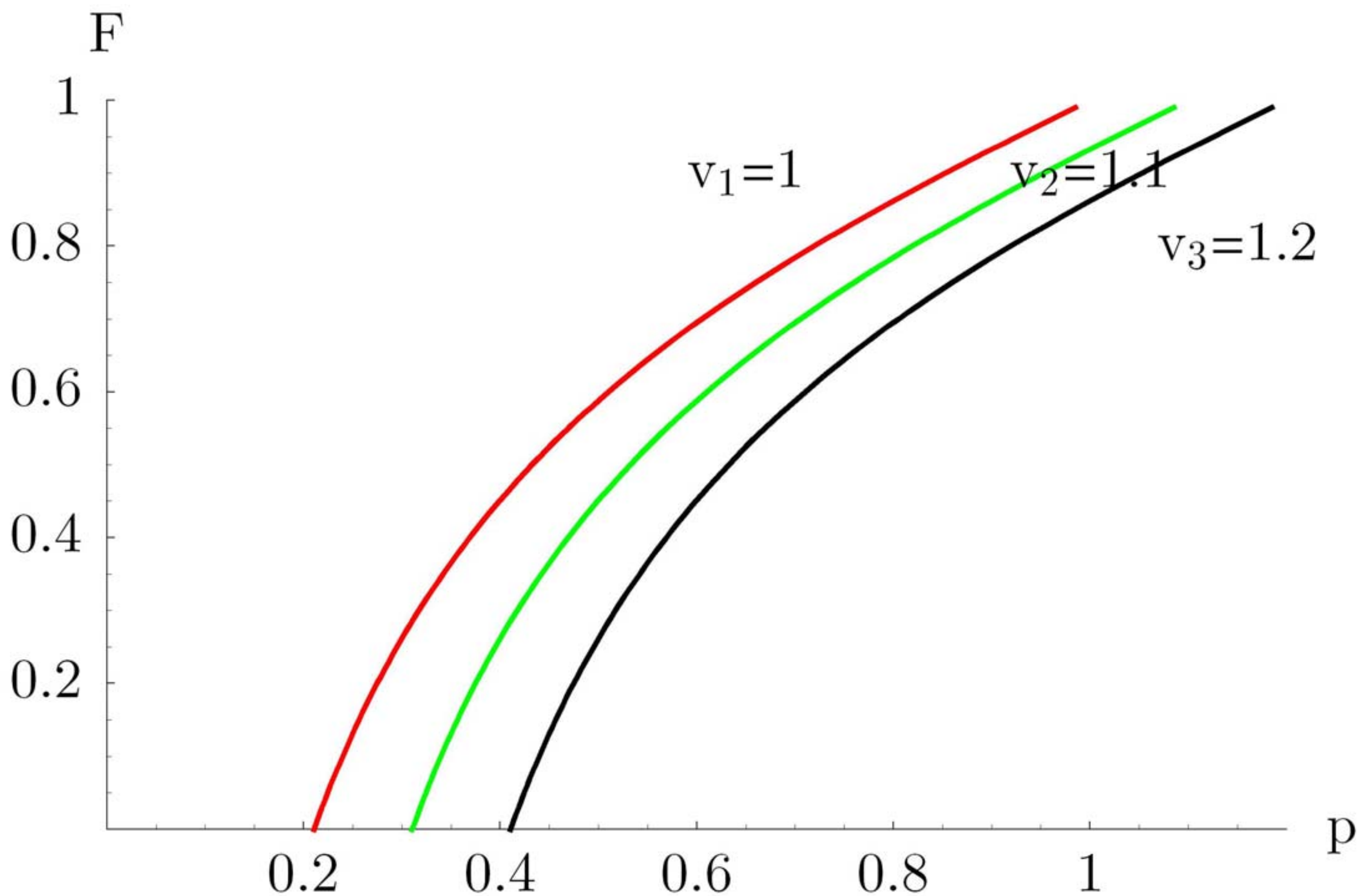


Figure 4: Equilibrium price CDFs of different firms

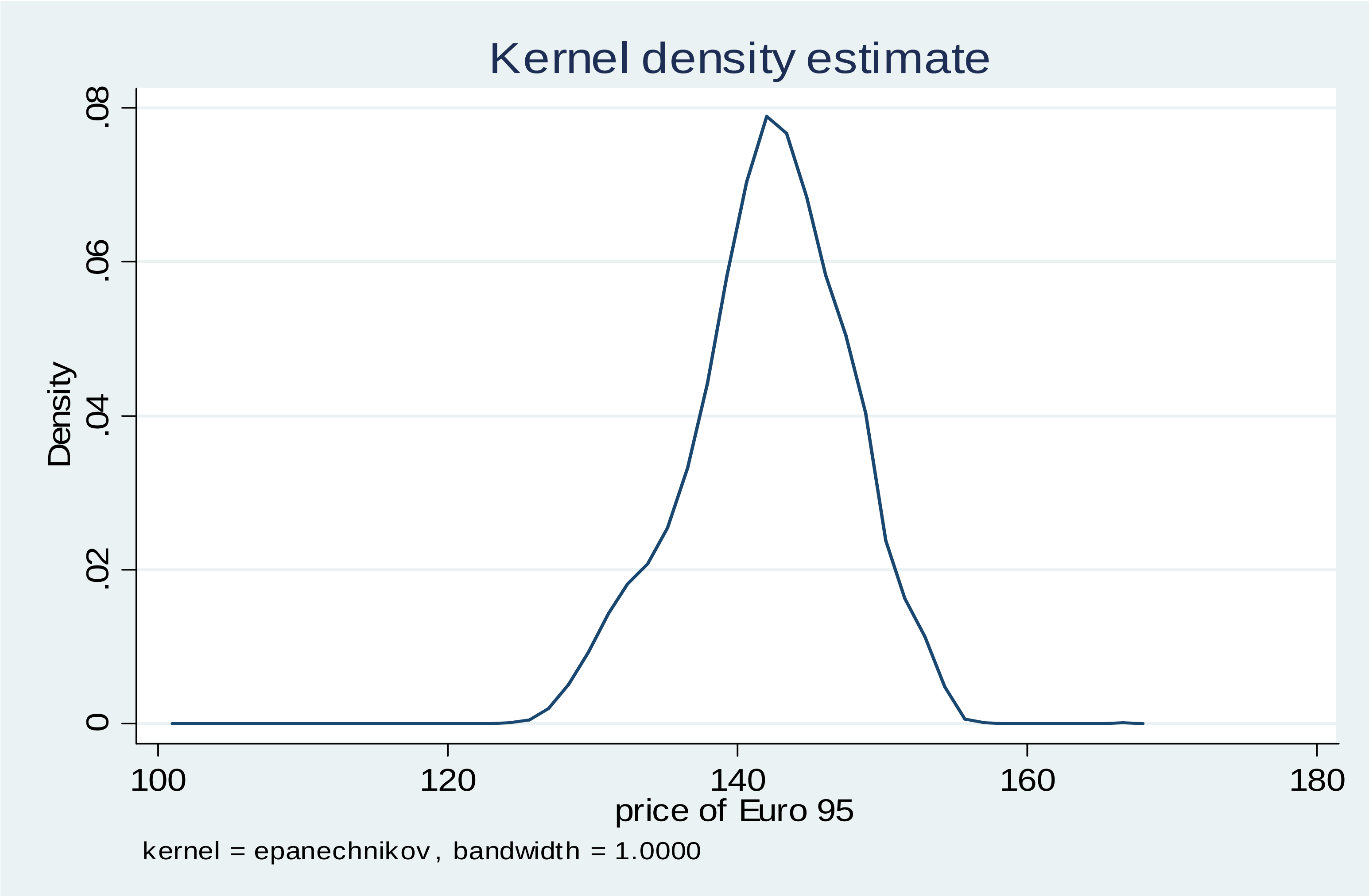


Figure 5: Density of Euro 95 prices (cents)

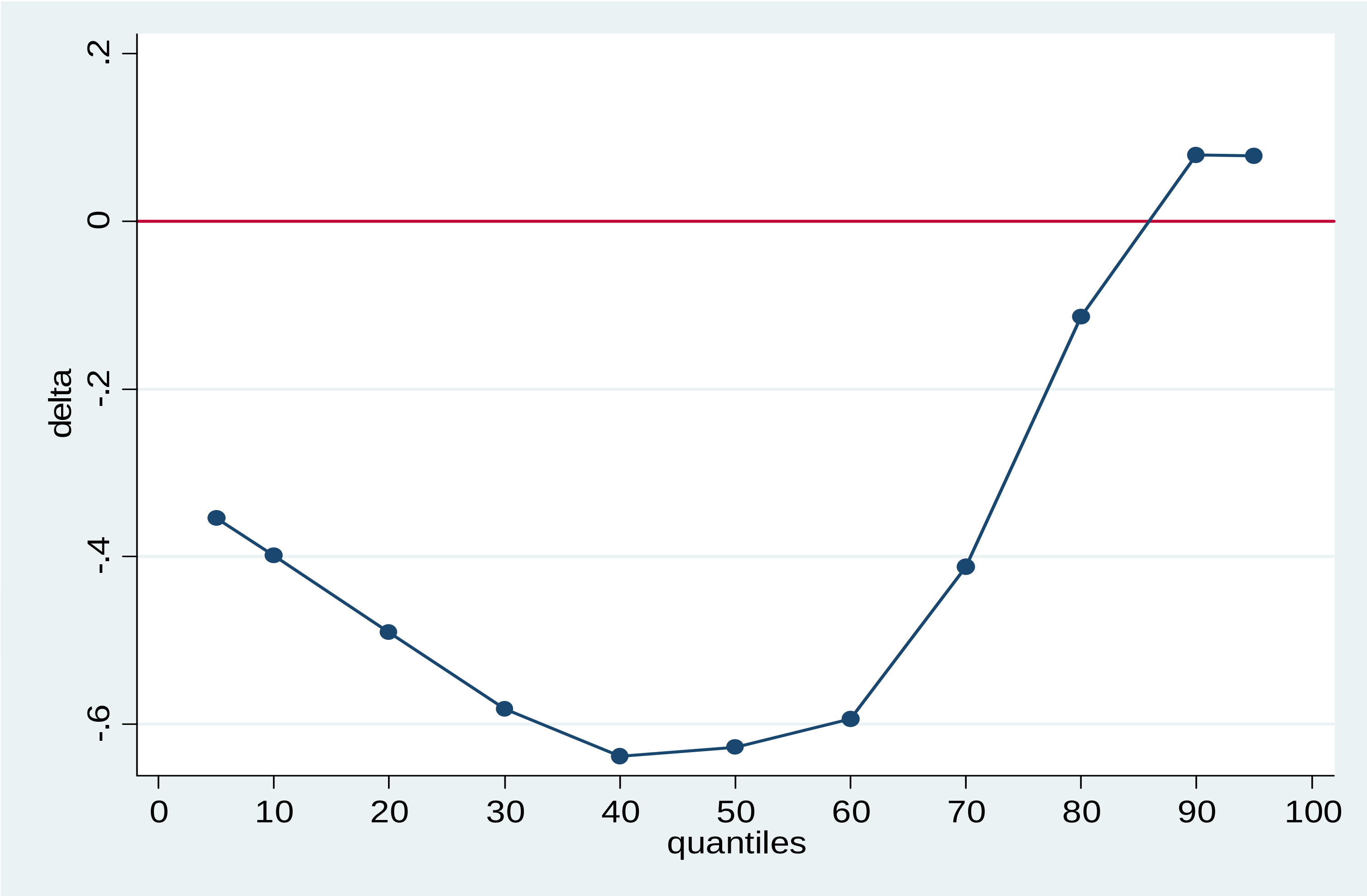


Figure 6: Estimates of δ_τ across quantiles

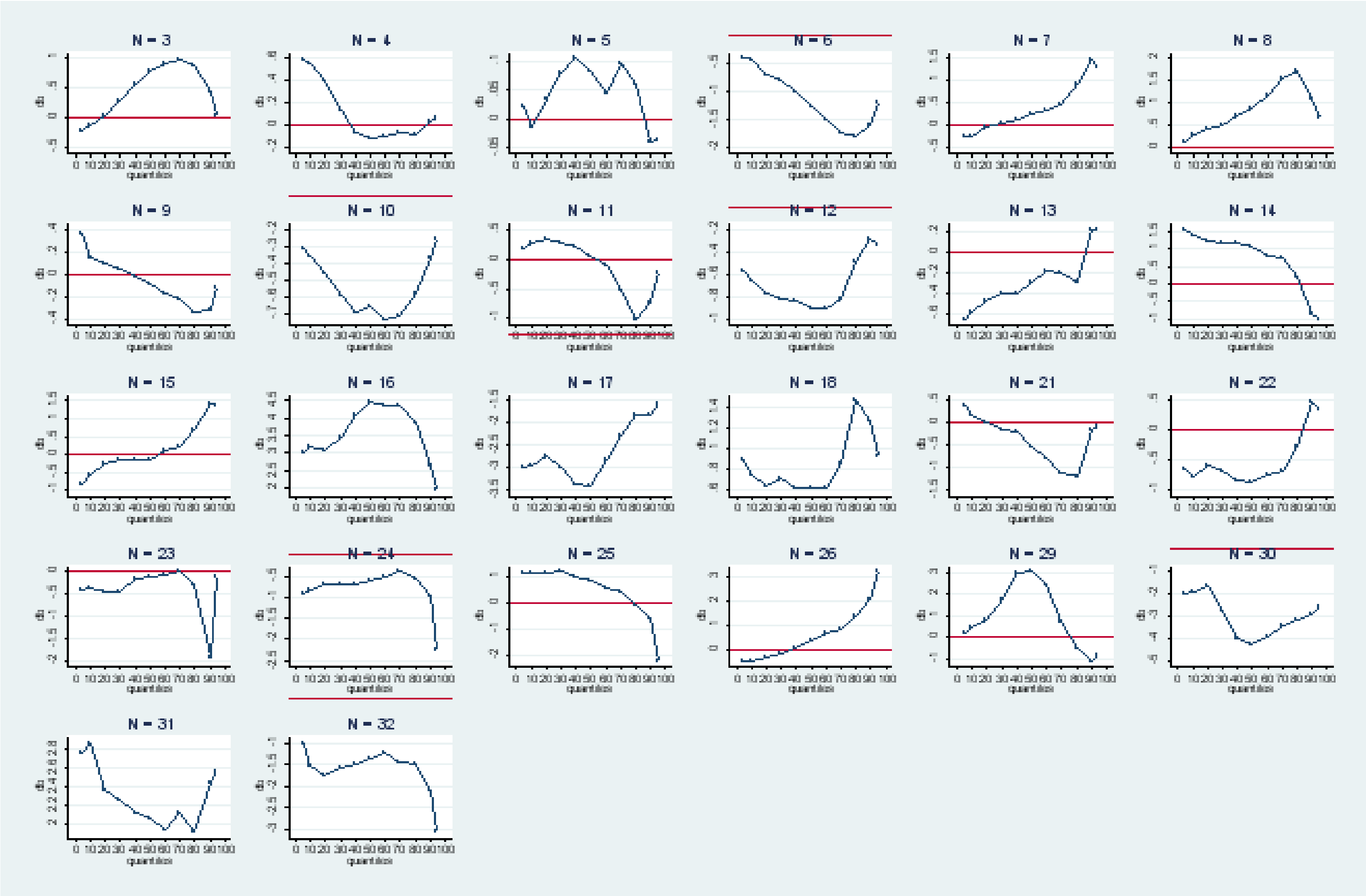


Figure 7: Competitive response across quantiles