Missing Price Information and its Impact on Equilibrium Price Dispersion: Evidence from Gasoline Signboards

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Abstract

This article seeks to quantify the importance of price information in reducing consumer search costs and equilibrium price dispersion in a competitive setting. It exploits a natural experiment in the retail gasoline industry in which stations post the prices of only certain grades of gasoline on large street-side signboards, and not others, except where required by law. Differential-by-grade signboard information predicts a specific curvature in price dispersion across grades, and differentiates itself from other non-informational factors such as income and cost. The impact of readily-available price information on search and price dispersion is found to be exceptionally large.

JEL Classification Codes: L11, L15, L81, L91, Q31

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1 Introduction

The "law of one equilibrium price" states that sellers of homogeneous goods will charge the same uniform price in a competitive equilibrium, but this law rarely holds in practice (Sorensen (2000)). Price dispersion is the norm in relatively homogeneous goods industries, and it is well known that both high-price and low-price sellers regularly make positive sales at different prices. Early studies examining this phenomenon (Stigler (1961) and Diamond (1971)) highlight the importance of consumer search in generating price dispersion, and later game-theoretic models (Varian (1980), Stahl (1987), Janssen et al. (2011)) show that search and price-dispersion are interdependent. The

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key insight is that consumers are not homogeneous even if the products are. When consumers differ in their personal costs of searching for the best price, they are not equally informed. Some sellers will offer lower prices to attract more informed consumers, and some will charge higher prices in hopes of snagging less informed ones. Chandra and Tappata (2011) show that the search-price dispersion relationship is non-monotonic in general, but tends to be negative in competitive markets, i.e. lower search costs work to increase consumer search and decrease equilibrium price dispersion.

In this article, we examine the relationship between search costs and price dispersion empirically. We focus on an important source of search costs – the ease of gathering price information. We take the retail gasoline industry as our application and consider one of the most recognizable physical features of gasoline stations in the U.S. – the large often-twenty-foot-tall street-side signboards advertising at least *some* of the prices of gasoline. They make gasoline prices among the most visible of any prices on the street, at least for those grades of gasoline whose prices are not normally excluded from the signboard. We take a closer look at the content of signboard information itself and ask whether displaying gasoline prices on signboards translates into meaningfully lower consumer search costs and price dispersion on those specific gasoline products whose prices are displayed, compared with those gasoline products whose prices are not.

Gasoline signboards are so ubiquitous and visible, it is surprising so little research has been done to examine their content and impact.[1] To our knowledge, only one study has recently attempted to do so (Noel and Qiang (2019)).[2] It is also interesting that researchers often mention gasoline signboards to argue that consumer search is not an issue in their studies, when empirically speaking, complete signboard information is relatively rare.[3] The challenge in evaluating signboard information is identification, namely that signboards in a given area almost always contain the same sets of information, with little variation in what is and is not posted from one station to the

[1] Ironically, they are often used for primary data collection on regular grade gasoline because of the ease in collecting information this way. But this limits researchers using such data to only those prices that are the easiest to see.

[2] Maurizi (1972) considered laws that *prohibited* gasoline price advertising (a sign of the changing times) but with limited data not matched to jurisdictional boundaries, results were inconclusive.

[3] For example, in the important paper by Chandra and Tappata (2011), they state that "the phenomenon of gas stations prominently displaying their prices [...] controls for imperfect information". However, only one of the four states in their dataset requires stations to post complete price information on signboards, and taking all grades of gasoline into account, only about half of the gasoline prices were actually posted on signboards.

next.

In this article, we solve the identification problem by exploiting a unique historical artifact in the retail gasoline industry, and noting that this artifact has been eliminated in some jurisdictions by law. The artifact is that gasoline stations in most areas of the U.S. display only the price of regular grade gasoline on large streetside signboards, but not the price of midgrade or premium grade gasoline. This creates an obvious and discrete divide in consumers' ease of collecting price information, with regular grade gasoline on one side of the divide and both midgrade and premium grade gasoline on the other. If readily-accessible signboard information is empirically important, we should see an equally obvious divide in price dispersion at exactly the same dividing point – lower price dispersion for regular grade gasoline and substantially higher degrees of price dispersion on midgrade and premium grade gasolines. In other words, we would expect a non-linear, concave pattern in price dispersion across the three grades going in order from regular grade to premium grade.

There are other factors affecting price dispersion differentially across grades as well – differences in the incomes of buyers most notably – and we show that these place the divide in a different spot – with regular grade and midgrade on one side of the divide and premium grade in the other. In other words, they work towards a convex pattern instead of a concave one, and are distinguishable from the former in that regard. But since these competing effects all pull on the curvature of the price dispersion-grade relationship simultaneously, it can be difficult to isolate the independent effect of signboard information without the benefit of an explicit control group. In this study, we add such a group. We collect additional data from areas with complete signboard information where the price of all three grades of gasoline must be equally prominently displayed by law. Since differential signboard information cannot explain differential-by-grade price dispersion when the prices of all grades are displayed equally prominently, we should not see a concave divide in price dispersion in these areas. The underlying pattern of price dispersion with complete signboard information is revealed and we can estimate the direct effect of incomplete signboard information free of confounding factors.

Our study contributes to the literature in several ways. First, very few empirical studies examine price dispersion across all three popular grades of gasoline, and those that do generally assume that any differences are likely to be income-related in some way (Chandra and Tappata (2011)). Here, we explicitly test for the cause of any differential-by-grade price dispersion we find. Second, the only recent study we are aware of that examines the content and role of signboard price information in generating differential-by-grade price dispersion is Noel and Qiang (2019) but that study has an important limitation. It uses data from only a single city, Lubbock, Texas, where virtually all stations display the price of regular grade gasoline on signboards and virtually none display the prices of midgrade and premium grade gasoline. Effects are identified only from curvature patterns and only a net overall effect is estimated. Here, we utilize a larger multi-city dataset that includes multiple large jurisdictions, with and without complete signboard information, which enables us to isolate the effect of signboard price information on price dispersion in a controlled natural experiment setting.

We do three main things using our larger dataset. First, we simply test whether the concavity results of Noel and Qiang (2019) carry over to multiple large metropolitan areas beyond their relative small sample city of Lubbock, Texas. We find that it does. Second, we test the power of their concavity methodology by applying their identification test to a large metropolitan area where signboard information is complete as required by law, and cannot be responsible for differential price dispersion across grades. It is essentially a falsification exercise where their concavity test should fail and we find that it does fail. Third, and most importantly, we use both incomplete signboard information (treatment) and complete signboard information (control) areas to estimate the direct effect of signboard information on price dispersion, holding other factors constant. To preview the final takeaway, we find that signboard price information is far and away the dominant factor behind the different degrees of price dispersion across the three grades of gasoline. Income has surprisingly little independent effect, contrary to the usual presumption in the literature.

The remainder of the study is organized as follows. Section 2 discusses the previous literature, and Section 3 presents the relevant curvature theory. Section 4 describes the data and methodology, and Section 5 presents results. Section 6 concludes.

2 Literature

The theoretical search literature emphasizes the interdependence of consumer search and price dispersion. In an early article, Diamond (1971) shows that if all consumers have positive search costs, no matter how small, prices of homogeneous goods necessarily rise to monopoly levels, price dispersion falls to zero, and consumer search falls to zero – the so-called "Diamond Paradox". At the other extreme, if all consumers have zero search costs, prices fall to competitive levels and consumer search is again zero. Varian (1980), Stahl (1989), Janssen et al. (2011) and others solve the paradox by showing that, as long as some consumers have zero or negative search costs and some consumers have positive search costs, consumer search and price dispersion are both present in equilibrium. Chandra and Tappata (2011) show the relationship between consumer search and price dispersion is non-monotonic – higher search tends to reduce price dispersion in competitive markets but tends to increase price dispersion in largely monopolistic ones.

Empirical studies tend to find a negative relationship, consistent with competitive markets. But since search can be difficult to measure, most studies use a proxy for search costs, or sometimes search benefits, which is expected to impact consumer search in the obvious way. Brynjofsson and Smith (2000) examine on-line stores and brick-and-mortar stores, and argue that price dispersion should be lower in the former, since the costs of searching on a computer are presumably lower than traveling from store to store. Sorensen (2000) examines pharmaceuticals used to treat acute and chronic conditions, and argues that price dispersion should be smaller in the latter case, since the benefits of searching are presumably higher for drugs that are purchased repeatedly. Other studies examining price dispersion with proxies for search costs or benefits include Dahlby and West (1986) on the auto insurance industry, Brown and Goolsbee (2002) on life insurance, Walsh and Whelan (1999), Zhao (2006), Dubois and Perrone (2015) and Sherman and Weiss (2017) on groceries, Baye et al. (2003) and Tang et al. (2010) on shopbots, Hortacsu and Syverson (2004) on stock market investors, Milyo and Waldfogel (1999) on liquor, and Orlov (2011) on airlines.

Specific to the retail gasoline industry, Barron et al. (2004) show that price dispersion falls when competing gasoline stations are more densely situated. Lewis (2008) shows that price dispersion is lower still when nearby gasoline stations are of the same brand type and Chandra and Tappata

(2011) show that price dispersion is lowest between stations at the same intersection. Lewis and Marvel (2011) show that price dispersion is higher when prices are falling, as opposed to rising, since consumers tend to be less concerned and less motivated to search when prices fall.[4] Pennerstorfer et al. (forthcoming) show that gasoline price dispersion depends on the fraction of commuters in the area who are presumably more informed. Byrne et al. (2015), Byrne and de Roos (2015) and Noel (2018) all exploit retail gasoline price cycles (Noel (2007)) to examine how shocks to price dispersion, for reasons other than search, affect consumer search itself.

While there has been much interest in how increased information in the hands of consumers can affect gasoline price dispersion, the primary focus in the literature has been on station and consumer proximity, taking the existence of highly visible prices for granted. But the source of those highly visible prices, the often-twenty-foot-tall streetside signboards with two-foot-tall numbers, has largely been overlooked.

One paper that examines the impact of signboard information on price dispersion is Noel and Qiang (2019), who argue that signboard price information, rather than income, is the stronger of the two effects driving differential price dispersion across the three grades of gasoline. Since virtually all stations in their sample city of Lubbock display the price of regular grade gasoline and virtually none display the price of midgrade or premium grade gasoline, identification is based only on non-linearities in the pattern of price dispersion across grades. Theirs is essentially a horserace between simultaneous competing effects and only a net effect can be estimated. With our natural experiment framework, we can improve upon that here.

3 Theoretical Background

We follow and extend the consumer search model of Janssen et al. (2011). Consider a market with $N \geq 2$ firms providing homogeneous goods at an identical marginal cost c. There are two

[4] This is related to the very large "rockets and feathers" literature, which shows that gasoline prices tend to rise quickly after a cost increase and fall slowly after a cost decrease. These include Bacon (1991), Borenstein et al. (1997), Peltzman (2000), Godby et al. (2000), Bachmeier and Griffin (2003), Galeotti et al. (2003), Radchenko (2005), Deltas (2008), Verlinda (2008), Noel (2009), Kristoufek and Lunachova (2015), Li and Stock (2018), and Eleftheriou et al. (2018). See Eckert (2013) and Noel (2016) for surveys. Yang and Ye (2008), Tappata (2009), Lewis (2011), and Cabral and Fishman (2012) all develop dynamic models of consumer search that produce asymmetric passthrough in equilibrium.

types of consumers – a proportion $\mu \in (0,1)$ who are shoppers and have zero search costs, and the remainder $1-\mu$ who are non-shoppers and have a positive search cost $s > 0$. Consumers search prices sequentially and can always come back to previously searched firms at zero cost. Janssen et al. (2011) show that the cumulative distribution function of Nash equilibrium prices in this situation is given by:

$$F(p) = 1 - \left(\frac{1}{N}\frac{1-\mu}{\mu}\frac{\overline{p}-p}{p-c}\right)^{\frac{1}{N-1}} \tag{1}$$

where $\overline{p}$ is the upper bound of the price distribution equal to:

$$\overline{p}(c,s) = c + s/(1-\alpha) \tag{2}$$

and s is the search cost. The constant α is given by:

$$\alpha = \int_0^1 \frac{dz}{1+\frac{\mu}{1-\mu}Nz^{N-1}} \tag{3}$$

The lower bound of the price distribution is a weighted average of marginal cost and the upper bound price given by:

$$\underline{p}(c,s) = \frac{\mu N}{\mu N + (1-\mu)}c + \frac{(1-\mu)}{\mu N + (1-\mu)}\overline{p}(c,s) \tag{4}$$

One measure of price dispersion is the difference in these two bounds, $r(c,s) = \overline{p}(c,s) - \underline{p}(c,s)$, which we call the max-min range and denote r.

We are interested in two things – how r depends on search cost s, and how search cost s correlates with the three grades of gasoline g. First, it is easy to show that r is linear in the search cost s. We have:

$$\begin{aligned} r(s) &= \overline{p}(c,s) - \underline{p}(c,s) \\ &= c + \frac{s}{(1-\alpha)} - \frac{\mu N}{\mu N + (1-\mu)}c - \frac{(1-\mu)}{\mu N + (1-\mu)}\left(c + \frac{s}{(1-\alpha)}\right) \\ &= \frac{s}{(1-\alpha)} \cdot \frac{\mu N}{\mu N + (1-\mu)} = \lambda s \end{aligned} \tag{5}$$

where

$$\lambda = \frac{1}{(1-\alpha)} \cdot \frac{\mu N}{\mu N + (1-\mu)} \tag{6}$$

so r and s are linear. The same linear relationship holds if we use standard deviations instead of max-min ranges, as shown in the appendix.

Now we turn to how s correlates with g. The key insight is that search cost s is not linear in g but rather takes on either a convex or concave curvature, depending on the net effect of at least three factors.

The first factor is the native visibility of prices. The historical practice in the U.S. is to post the price of regular grade gasoline on large streetside signboards but not the prices of midgrade and premium grade gasolines, unless otherwise required by law. This creates a non-linear divide in search costs across the three grades, with regular grade gasoline on one side of the divide and higher grades of gasoline on the other. Considering this price information effect alone, we expect to see equal degrees of price dispersion on midgrade and premium grade gasoline, which are both substantially higher than that of regular grade gasoline. Denoting regular grade gasoline as R, midgrade as M, and premium grade as P, we have:

$$\begin{aligned} s_R &< s_M = s_P \\ \lambda s_R &< \lambda s_M = \lambda s_P \\ r_R &< r_M = r_P \end{aligned} \tag{7}$$

in the absence of confounding factors. This creates an extreme form of concavity in r across the three ordered grades (regular, midgrade, premium), which we call perfect Γ concavity. (In a plot of price dispersion on the vertical axis and the three ordered grades of gasoline on the horizontal axis, the curve approaches a slanted Γ shape). Of course, we would not necessarily expect to observe such an extreme concavity in practice, even if price information were a dominant effect, since other factors are likely to be pulling on the curvature at the same time.

The second factor, and the one generally discussed in the literature, is income. Buyers of the different grades of gasoline tend to have different incomes and different search costs. Since search cost s itself is linear in income (the primary cost of searching being the opportunity cost of time, i.e. hours searched multiplied by the hourly wage), the question is whether the buyers of the three grades of gasoline are distributed linearly or non-linearly across equal terciles of the income distribution. The relationship turns out not to be linear, and the resulting pattern in r is convex.

To understand why, note that there is a fundamental physical identity across the three grades of gasoline. Midgrade gasoline (with an octane of 89) is nothing more than a 50-50 mix of regular grade gasoline (octane 87) and premium grade gasoline (octane 91), generally mixed on the fly, in the hose, by drawing equally from regular and premium grade underground gasoline tanks. A gallon of midgrade gasoline is a perfect physical substitute to half a gallon of regular grade and half a gallon of premium grade combined. This means a consumer's type can be represented as a single probability number p, where $p = 1$ corresponds to a consumer who always purchases premium grade, $p = 0$ corresponds to a consumer who always purchases regular grade, and $p = 0.5$ corresponds to a consumer who always purchases midgrade, or alternatively who buys the other two grades in equal proportions over time. Now imagine an Engel curve with income Y on the vertical axis and probability p on the horizontal. Coats et al. (2005) estimates income elasticities across the three grades and their results imply a convex Engel curve when drawn in this way. A convex Engel curve is also shown empirically by Noel and Qiang (2019). The convexity in the Engel curve in turn means that r takes on a convex pattern across the three ordered grades of gasoline, since Y, s, and r are all interchangeable up to scaling factor:

$$\frac{\partial^2 r}{\partial p^2} = \frac{\partial^2 \lambda s}{\partial p^2} = \frac{\lambda \partial^2 \tau \omega}{\partial p^2} = \lambda \tau \varphi \frac{\partial^2 Y}{\partial p^2} > 0 \tag{8}$$

where τ is the time required to conduct a search, ω is the hourly wage, φ is a scaling factor, and λ is as above. Considering the income effect alone, we should see relatively similar degrees of price dispersion on regular grade and midgrade, which are both substantially lower than that of premium grade gasoline:

$$
\begin{aligned}
s_R &\approx s_M < s_P \\
\lambda s_R &\approx \lambda s_M < \lambda s_P \\
r_R &\approx r_M < r_P
\end{aligned} \tag{9}
$$

in the absence of confounding effects. Intuitively, the incomes of midgrade buyers are empirically "closer" to those of regular grade buyers than to those of premium grade buyers, so the largest divide in search costs now falls between midgrade and premium grade gasoline, with regular grade and midgrade gasoline on one side of the divide and premium grade gasoline on the other.

There is a practical reality underlying the convexity. The vast majority of vehicles are designed to run only on regular grade gasoline, and higher grades of gasoline are neither necessary nor helpful for these vehicles. These vehicles are owned by low and moderate income consumers. Only certain luxury vehicles and high performance vehicles require premium grade gasoline to prevent engine knock in their high performance engines, and these are generally owned by the wealthiest individuals. There are virtually no vehicles that require a minimum of midgrade gasoline, so midgrade is neither appropriate for high performance vehicles nor necessary for the rest. Those who buy midgrade gasoline anyway tend to own the same types of vehicles as those who exclusively buy regular grade gasoline, and come from a more similar range in the income distribution.[5] This leads to a convex curve in the absence of other factors.

A third factor that has received little attention but in principle can generate price dispersion is cost dispersion. Stations have different suppliers with different contract terms, and their product acquisition costs can potentially vary. While we see no reason for cost dispersion to vary differentially by grade of gasoline (and there is evidence that it does not),[6] a cost dispersion effect would work towards a convex price dispersion pattern across the three grades. The reason is that

[5] One might expect that midgrade is chosen over regular grade by slightly wealther consumers, but anecdotal evidence also suggests that midgrade (or equivaently the occasional premium) is sometimes purchased by owners of older cars hoping to improve declining engine performance.

[6] Noel and Qiang (2021) show that wholesale price differentials between regular grade and midgrade and between regular grade and premium grade are virtually constant over time. Any cost-based price dispersion in regular grade gasoline should then carry over equally strongly into higher grades.

the aforementioned physical identity necessarily means that a station's selling cost of midgrade gasoline is the simple average of the selling cost of the other two grades:

$$c_M = (c_R + c_P)/2 \tag{10}$$

Simple calculations show:

$$\begin{gathered}\max(c_M) \leq (\max(c_R) + \max(c_P))/2 \text{ and } \min(c_M) \geq (\min(c_R) + \min(c_P))/2 \\ (\max(c_M) - \min(c_M))/2 \leq (\max(c_R) - \min(c_R))/2 + (\max(c_P) - \min(c_P))/2\end{gathered} \tag{11}$$

which in a competitive market with proportional margins implies that:

$$r_M \leq (r_R + r_P))/2 \tag{12}$$

in the absence of other factors. In words, it generates a convex pattern in r. The left hand side is equal to the right hand side (and the pattern of price dispersion is linear) if the maximum prices of all three grades always occur at the same station and the minimum prices of all three grades also occur at the same station (the max-min equivalent of perfect correlation). The inequality is strict and the pattern is strictly convex otherwise.

In summary, there are competing effects pulling on the curvature of the (s, g) relationship. Differential-by-grade signboard information works towards a perfectly concave pattern in price dispersion across the three grades, whereas income and cost dispersion effects both work towards a convex one. With all three effects simultaneously present, we would see the combined impact of all these effects. If signboard information is dominant we would expect to see concavity on net, and if income and/or cost-dispersion were dominant we should see convexity on net. We would not expect to observe perfect Γ concavity unless signboard information were the only meaningful effect. However, with a suitable control region to control for the effects of income and cost variation, we may be able to detect a more extreme form of concavity if signboard information is important.

4 Data and Methodology

We test for the effect of differential-by-grade signboard information on differential-by-grade price dispersion in several ways. First, we perform the concavity test on the large metropolitan areas in our dataset that have incomplete signboard information. Second, we perform a falsification exercise in which we perform the concavity test on a large metropolitan area where signboard information is complete. Third, we incorporate both our incomplete (treatment) and complete (control) signboard information metropolitan areas into a single model to isolate the direct effect of signboard price information on price dispersion and estimate it directly.

< insert Table 1 about here >

We collect station-level daily retail gasoline prices for each of the three common grades of gasoline – regular, midgrade, and premium – in three U.S. metropolitan areas, Houston, Los Angeles, and Phoenix. The data consists of 27,089 individual prices across 1,721 stations which were reported to the GasBuddy.com website each Thursday between September 17, 2020 to November 5, 2020, a total of eight weeks. Summary statistics are in Table 1. GasBuddy.com is a crowdsharing website where interested drivers can report recently observed gasoline prices for use by other drivers that also use the site. GasBuddy price data has been widely used in academic research (e.g. Lewis and Marvel (2011), Atkinson et al. (2014), Noel (2018)) and is shown to give a good representation of the distribution of gasoline prices at a point in time (Atkinson (2009)).[7]

We test for concavity in a single metropolitan area using:

$$\begin{aligned} PDISP_{gmrct} &= \alpha_{0c} + \alpha_{1c}MIDGRADE_g + \alpha_{2c}PREMIUM_g \\ &\quad + \sum_{t=2}^{\overline{T}} \phi_{tc}^{T} T_t + + \sum_{m=2}^{\overline{M}} \phi_{tc}^{M} M_m + \alpha_{3c}SCOUNT_{mrct} + \eta_{gmrct} \end{aligned} \tag{13}$$

where $PDISP_{gmrct}$ is price dispersion measured either as the standard deviation of prices or the difference between maximum and minimum prices (the "max-min range"), for gasoline grade g across all stations s within a market area m of a larger region r of a Metropolitan Statistical Area

[7] The site is popular enough with reporters to ensure near complete coverage of gasoline (noting that price reporters collect and report prices for large numbers of stations), but not so popular as to replace signboard information.

(MSA) c at time t. The unit of observation is a grade-market-time triplet. Each market is defined as having one of the sample stations at its center and includes all competing stations within a two mile radius of that central station.[8] Since markets centered on nearby stations can overlap, price dispersion measures across neighboring markets are not independent. We adjust standard errors to account for the non-independence by dividing each MSA into equally sized large regions and cluster standard errors at this larger regional level.[9]

The two variables of interest are dichotomous variables $MIDGRADE_g$, equal to one if the price is for midgrade gasoline and zero otherwise, and $PREMIUM_g$, equal to one if the price is for premium grade gasoline and zero otherwise. The omitted grade is regular grade gasoline. We include daily fixed effects T_t and market fixed effects M_m. We define $SCOUNT$ to be the number of stations within a market, to control for possible competitive effects.[10] The η_{gst} are normally distributed error terms, potentially correlated within regions.

We discard all prices for a given station on a given day unless we have all three prices for that station that day. This prevents our grade-specific measures of price dispersion from being based on different subsets of stations, which would create an obvious composition bias.

One possible concern with the above analysis is that we assume that a price that is not posted is also not widely known (or easily predictable) without additional search. While reasonable, a consumer could potentially infer the non-posted price of higher grades of gasoline from regular grade alone if stations are known to apply constant price differentials across grades. To account for this, we estimate a price *residuals* version of Equation 13, using station-specific and grade-specific price residuals on the left hand side instead of prices, that removes this potential predictability. We acquire the residuals by regressing prices on a set of station-specific indicator variables, grade-

[8] We use the term "market" here for convenience, and in no way means that these areas constitute markets in an antitrust sense. Using other reasonable radii has no meaningful effect on our results or conclusions.

[9] There are between 35 and 47 regions in each MSA. We experimented with other regional breakdowns and our results do not meaningfully change.

[10] $SCOUNT$ is included for completeness only. The effects of competitive density have been well studied elsewhere (e.g. Lewis (2008), Deltas (2008)) and we do not wish to rehash that literature here. We refrain from a causal interpretation on $SCOUNT$ as well, given endogenous entry and essentially no market structure variation over our short eight-week, largely cross-sectional sample. The theoretical effect of competitive density on price dispersion is ambiguous in general (Borenstein and Rose (1994), Barron et al. (2004), Dai et al. (2004). Variants of the competition control variable or no competition control variable at all does not affect our results of interest.

specific indicator variables, and all interactions of the two:

$$\begin{aligned} PRICE_{gsmrct} &= \gamma_0 + \gamma_1 MIDGRADE_g + \gamma_2 PREMIUM_g + \sum_{s=2}^{\overline{S}} \zeta_s I_s \\ &\quad + \sum_{s=2}^{\overline{S}} \zeta_s^{MID} I_s MIDGRADE_g + \sum_{s=2}^{\overline{S}} \zeta_s^{PRE} I_s PREMIUM_g + \nu_{gsmrct} \end{aligned} \quad (14)$$

where $PRICE_{grsct}$ is the price of gasoline grade g at station s in market m of region r of metropolitan area c at time t. We then use the price residuals instead of prices to calculate price dispersion on the left hand side of Equation 13. The residuals-based analysis keeps only unpredictable surprise deviations from a station's average price differentials across grades.

We quickly establish that there are significant differences in price dispersion across grades, and the next step is to understand why. The price information hypothesis works toward a concave shape in the grade-specific price dispersion coefficients, i.e. in the ordered triplet $\{0, \alpha_1, \alpha_2\}$, taking the omitted regular grade price dispersion coefficient to be zero, and where α_1 and α_2 are the coefficients of $MIDGRADE$ and $PREMIUM$ respectively. The income-based and cost-based hypotheses work towards a convex pattern instead. Concavity requires $0 - 2\alpha_1 + \alpha_2 < 0$, or $2\alpha_1 > \alpha_2$, yielding our Concavity Test:

$$\begin{aligned} H_0 &: \quad 2\alpha_1 = \alpha_2 \\ H_A &: \quad 2\alpha_1 \neq \alpha_2 \end{aligned}$$

The null hypothesis is that there is no concavity on net, i.e. linearity. A statistically significant negative test statistic rejects linearity in favor of concavity, and a statistically significant positive test statistic rejects linearity in favor of convexity.

If the price information hypothesis dominates to the near exclusion of other effects, we would not only expect a concave pattern, but something approaching perfect Γ concavity, $\alpha_1 = \alpha_2 \gg 0$, which we test with our Perfect Concavity Test:

$$H_0 \quad : \quad \alpha_1 = \alpha_2$$
$$H_A \quad : \quad \alpha_1 < \alpha_2$$

The Perfect Concavity Test statistic is only meaningful when the Concavity Test statistic is significant and negative.[11] The interpretation of it is also different. In the Concavity Test, a rejection of linearity in favor of concavity provides support for a concave relationship among the coefficients, i.e. the price information hypothesis. In the Perfect Concavity Test, a rejection of equality in the coefficients rejects that there is a perfectly concave relationship among the coefficients and provides support for a less perfect concave relationship. If we have both concavity and perfect Γ concavity, we should reject the first and not reject the second.

The above analysis follows Noel and Qiang (2019) and is useful because it requires only variation in the content of signboard information across *grades* and not variation in the content of signboard information across *stations*. In this study, we do have exogenous variation in the content of signboards across stations, and use it here. We use data from the Los Angeles metropolitan area, an MSA that is subject to a complete signboard information law. Los Angeles serves as a control for the pattern of price dispersion across grades that is likely to occur in the absence of incomplete signboard information.

After performing a single-MSA falsification exercise using Los Angeles, we pool the Houston and Los Angeles data together and estimate a difference-in-differences model – comparing differences in price dispersion across the three grades of gasoline in Houston where signboard information is incomplete, to differences in price dispersion across the three grades of gasoline in Los Angeles

[11] Perfect concavity is obviously rejected if the coefficients are convex, so the case $\alpha_1 > \alpha_2$ is irrelevant.

where signboard information is complete. The estimating equation is given by:

$$\begin{aligned} PDISP_{gmrct} &= \beta_0 + \beta_1 MIDGRADE_g + \beta_2 PREMIUM_g \\ &\quad + \beta_3 MIDGRADE \cdot INCOMPLETE_c + \beta_4 PREMIUM_g \cdot INCOMPLETE_c \\ &\quad + \sum_{t=2}^{\overline{T}} \theta_t^T T_t + \sum_{m=2}^{\overline{M}} \theta_m^M M_m + \beta_5 SCOUNT_{gmrct} + \eta_{gmrst} \end{aligned} \tag{15}$$

where $INCOMPLETE_c$ is an indicator variable equal to one if MSA c does not have a law requiring complete posting of gasoline prices for all three grades, and zero otherwise. The coefficients of interest are on the interaction terms. They measure the excess price dispersion on midgrade and premium grade gasoline up and above that of regular, in the treatment MSA up and above that of the control MSA. We conduct concavity tests on the interactions.

Houston and Los Angeles are different gasoline markets, but this is not an issue in and of itself. We never compare Houston prices to Los Angeles prices directly or Houston price dispersion to Los Angeles price dispersion directly. We only compare the difference in price dispersion across the three different grades of gasoline in Houston on one hand, to the difference in price dispersion across the three different grades of gasoline in Los Angeles. The identifying assumption is that the pattern of price dispersion across grades of gasoline in Los Angeles reflects what the pattern of price dispersion would be in Houston if not for incomplete signboard information. There is no reason to suspect that the patterns would meaningfully differ.[12]

5 Results

We begin with the Houston metropolitan area. Virtually all gasoline stations in Houston post the price of regular grade gasoline on streetside signboards but only a very small percentage post the price of both midgrade and premium grade.[13] Prices of higher grades are visible at a station only by driving up the gas pump and viewing a roughly one-inch tall display.

[12] For example, there is no reason to suspect that the difference in search between a more wealthy person and a less wealthy person in one city would be different than the difference in search between an equally wealthy person and an equally less wealthy person in another.

[13] In our review of Google Earth images, less than one in ten stations in Houston displayed all three prices.

< *insert Table 2 about here* >

Price dispersion results for Houston are shown in Table 2. Specifications (1) and (2) use standard deviations as the measure of price dispersion and Specifications (3) and (4) use max-min ranges. Odd numbered specifications use price levels on the left hand side and even numbered ones use price residuals. We are interested in the coefficients on the grade indicator variables (including the omitted regular grade gasoline "coefficient" of zero), and any non-linearity across them. Test statistics for the Concavity Test and the Perfect Concavity Test are presented near the bottom of each column. A significant negative Concavity Test statistic implies the price information hypothesis is dominant (concavity) and a significant positive test statistic implies income- and/or cost-based hypotheses are dominant (convexity). Conditional on concavity, an insignificant Perfect Concavity Test means that we cannot reject complete dominance of the price information hypothesis to the near exclusion of other effects.

Specification (1) uses the standard deviation of price levels on the left hand side. The $MIDGRADE$ coefficient is estimated at 9.900 and the $PREMIUM$ coefficient is estimated at 10.790, both large and statistically significantly different from zero. The Concavity Test easily rejects linearity in favor of concavity, $(0.00, 9.90, 10.79)$ (recalling that the first zero represents the omitted regular grade coefficient), and the Perfect Concavity Test cannot reject that the pattern is also perfectly concave. The two coefficients are extremely close economically, and statistically indistinguishable from one another even with tight standard errors. The results support the hypothesis that signboard price information is the dominant cause of differential-by-grade price dispersion. In fact, the extreme nature of the concavity suggests that signboard price information is dominant to the near exclusion of other effects.

Other specifications in Table 2 confirm this. Specification (2) uses the standard deviation of price residuals instead of the standard deviation of prices, and yields a $MIDGRADE$ coefficient of 0.702 and a $PREMIUM$ coefficient of 0.694, both large and statistically significantly different from zero.[14] The Concavity Test rejects linearity in favor of concavity and the Perfect Concavity Test cannot reject that the pattern is perfectly concave. The coefficients are statistically indistin-

[14] Since these are based on price residuals rather than price levels, the point estimates are not directly comparable across specifications.

guishable from one another, with a difference of just 0.009.

Specification (3) uses the max-min range of prices on the left hand side. It yields a $MIDGRADE$ coefficient of 28.59 and a $PREMIUM$ coefficient of 30.22, easily rejecting linearity in favor of concavity $(0.00, 28.59, 30.22)$ and consistent with perfect concavity as well. Specification (4) uses max-min ranges of price residuals, and shows a $MIDGRADE$ coefficient of 2.132 and a $PREMIUM$ coefficient of 2.115, significantly concave and again consistent with perfect Γ concavity.

The above results point to the importance – and dominance – of the price information hypothesis. But it also assumes that the price information hypothesis is the only hypothesis that predicts a concave relationship. We are not aware of other reasonable concave-inducing hypotheses, but we can test our methodological assumption nonetheless by performing a falsification exercise using the Los Angeles metropolitan area, which has complete signboard information and where differential-by-grade price dispersion cannot be caused by differential-by-grade signboard information. The concavity test should fail.

< insert Table 3 about here >

We report results in Table 3. Specification (5) uses the standard deviation of prices as the measure of price dispersion on the left hand side. We find a $MIDGRADE$ coefficient of -0.128 and a $PREMIUM$ coefficient of 0.311, both vastly smaller than the corresponding coefficients for Houston from Specification (1) of Table 2. The $MIDGRADE$ coefficient is just $1/77^{th}$ as much (in absolute value) and the $PREMIUM$ coefficient is just $1/35^{th}$ as much. Only the $PREMIUM$ coefficient is statistically significant and then only at the 10% level. Economically speaking, the estimates are very small, just fractions of a penny, and price dispersion across all three grades are effectively the same. The Concavity Test rejects linearity this time in favor of convexity, noting that the convexity is very weak.

Specification (6) uses the standard deviation of price residuals on the left hand side, and yields a similar result. The $MIDGRADE$ coefficient is estimated at -0.028 and the $PREMIUM$ coefficient is estimated at 0.008, economically very small, and neither one statistically significant from zero, nor from each other. The Concavity Test can no longer reject linearity and we cannot reject that price dispersion is exactly the same across every grade. Specifications (7) and (8) use max-min ranges of prices and price residuals instead, and produce coefficients that are again economically very small. We find a statistically significant but weak convex relationship in the coefficients in Specification (7), which then disappears when price residuals are used in Specification (8).

In summary, there is no evidence of any concavity in any specification in the complete information setting, and in fact, no evidence of economically meaningful differences in price dispersion across the three grades at all. The falsification exercise performs exceptionally well – when signboard information is complete and cannot be the cause of differential-by-grade price dispersion in a concave pattern, we find no hint of a concave pattern, and little hint of anything else.

The above single-MSA analyses all rely on testing for net non-linearities in the coefficients. One can estimate an overall net effect in this way, but to isolate the direct effect of signboard price information distinct from confounding factors, we need to incorporate both incomplete and complete signboard information areas into the analysis. We thus pool data together from both Houston and Los Angeles and use them to estimate the direct effect of signboard price information in a difference-in-differences model. Houston is our treatment city (with the incomplete information treatment) and Los Angeles is our control city (with the complete information control). Essentially, we are using the complete-signboard-information environment of Los Angeles as a benchmark for what the pattern of price dispersion would otherwise look like in Houston if signboard information were not a factor.[15]

< insert Table 4 about here >

We report results in Specifications (9) through (12) of Table 4. The variables of interest are the interaction terms $MIDGRADE \cdot INCOMPLETE$ and $PREMIUM \cdot INCOMPLETE$, which reflect the excess price dispersion on higher grades of gasoline vis-a-vis regular grade gasoline in Houston, all relative to any excess price dispersion in the higher grades of gasoline vis-a-vis regular grade gasoline in Los Angeles.

[15] The previous results for Houston and the falsification exercise for Los Angeles further supports our the identifying assumption. We found little to no income-generated convexity in the Los Angeles MSA, and there is no reason to suspect that income would not matter in a place such as Los Angeles but then suddenly matter a great deal in a place such as Houston. Moreover, we found minimal room for income-generated convexity in Houston, because of the almost perfect concavity in the coefficients, showing that income is likely to have similar (and minimal) impact on price dispserion in Houston as well.

Specification (9) uses the standard deviation of prices as the measure of price dispersion on the left hand side. The midgrade interaction coefficient is 10.028 and the premium interaction coefficient is 10.479, both economically large, statistically significantly different from zero, and statistically indistinguishable from each other. They are more than ten cents per gallon higher than the regular grade "coefficient" of zero, yet the difference between them is less than one half of one cent per gallon. We strongly reject linearity in favor of concavity, and cannot reject perfect Γ concavity as well $(0.00, 10.03, 10.48)$, even with tight standard errors. The results are stronger than the single MSA results and support the hypothesis that price information is singularly the dominant cause of the differences in price dispersion across the three grades of gasoline. Specification (10) uses the standard deviation of price residuals on the left hand side, and we again easily reject linearity in favor of concavity and cannot reject perfect Γ concavity in the coefficients.

Specification (11) uses the max-min range of prices and shows that the max-min ranges of both midgrade and premium grade are approximately 28 cents per gallon higher than that of regular grade, yet the difference between them is just $1/6^{th}$ of one cent per gallon. We find essentially perfect concavity again in this case. Specification (12) uses the max-min range of price residuals and shows a similarly strong concavity in the coefficients.

Since it is well known that Los Angeles prices tend to be higher than Houston prices, one possible concern with the above analysis is that higher prices in Los Angeles may leak into our price dispersion estimates and, conceivably, into our price dispersion difference estimates. We address this concern by normalizing the price of gasoline in each metropolitan area to be equal to one ($\widehat{p}_{gsmrct} = p_{gsmrct}/p_c$), and using these standardized prices, instead of actual prices, on the left hand side of Equation 15. We present results in Table A1, in the tables appendix. In short, none of our results meaningfully change and all our results carry through as strongly. The Concavity Test rejects linearity in favor of concavity in all four specifications and the Perfect Concavity Test does not reject perfect Γ concavity in any.

As an additional robustness check, we use price data from a third metropolitan area, that of Phoenix. On one hand, Phoenix is more similar to Los Angeles geographically and culturally and its prices are closer to Los Angeles prices than Houston prices are. On the other hand, Phoenix is more similar to Houston informationally, since stations are not required to provide complete signboard information and very rarely do. Under the price information hypothesis, we should see a concave shape on the grade specific coefficients in Phoenix, as we did for Houston.

We report our single-MSA results for Phoenix in Table A2. In short, we find similar results to that of Houston. The Concavity Test rejects linearity in favor of concavity at better than the 1% level of significance in every specification. We can rule out a perfectly concave pattern in the coefficients only when price levels are used on the left hand side, and cannot rule it out when price residuals are used to remove average price differentials.

Next, we pool Phoenix and Los Angeles prices together and perform a difference-in-differences estimation, as presented in Table A3. The coefficient patterns continue to be exceptionally concave. We reject linearity in favor of concavity in all specifications and do not reject the most extreme form of concavity in three out of four specifications, including both specifications that use price residuals.

Finally, we pool the data from all three metropolitan areas together and perform a difference-in-differences specification using all three. We report results in Table A4. The coefficient patterns are exceptionally concave and all conclusions carry through. We reject linearity in all specifications and cannot reject that the coefficients are perfectly concave at the 5% level in any. The degree of concavity is very strong, statistically and economically speaking.

Taking all the results together, we conclude that differential-by-grade signboard information is singularly the most dominant factor in explaining differential-by-grade price dispersion on gasoline. When signboard information is incomplete, we observe a precise divide in price dispersion across the three grades of gasoline exactly where the divide in signboard information occurs – with regular grade gasoline on one side of the divide and higher grades of gasoline on the other. Where signboard information is complete, there is no such divide there or meaningfully anywhere. Our results provide evidence that more easily-accessible information in the hands of consumers has important effects on consumer search and price dispersion. Greater information in the hands of consumers enables them to search more effectively, at lower cost, and ultimately make more informed decisions on how to best distribute their limited resources.

6 Conclusion

This study seeks to quantify the importance of visible and readily-accessible price information for consumer search and equilibrium price dispersion. We examine the information-search-price dispersion mechanism empirically in an important setting that is familiar to almost all of us, but that has received surprisingly little attention to date – the effect of gasoline price signboards.

The long-standing practice of stations in most areas has been to post the price of regular grade gasoline on large streetside signboards but not the prices of midgrade and premium grade gasoline. The practice creates a natural divide in consumers' ease of collecting price information across the three grades of gasoline – with regular grade gasoline on one side of the divide and higher grades of gasoline on the other. If displaying price information prominently in front of consumers matters for search, this should lead to lower degrees of price dispersion on regular grade gasoline whose price is easily observed and higher degrees of price dispersion on the higher grades whose prices are not. This is indeed what we find.

The result is intuitive, but also surprising given the default assumption in the literature that higher price dispersion on higher grades is likely income related. We find that income matters, but in a secondary way. When consumers are presented with complete signboard information, there is little difference in price dispersion across all three grades of gasoline, even though premium grade gasoline is disproportionately bought by higher income consumers. Only when price information is missing from streetside signboards does price dispersion on the higher grades shoot up in a dramatic way.

Our study adds to the growing body of evidence that search and search costs matter for prices, price dispersion, and market outcomes. Ours is among a handful of studies that examine the causes of gasoline price dispersion in general, and one of very few to examine the impact of highly visible signboard price information in particular. It is also one of the few studies that explicitly examine midgrade and premium grade gasoline prices in their own right. We would argue there is much to learn from a broader analysis of gasoline products beyond just regular grade gasoline, as our results show, and we postulate that it may be worth revisiting some older studies.

It also helps us better quantify a potential benefit of so-called "gasoline price transparency regulations". Gasoline price transparency regulations have been implemented in numerous jurisdictions around the world, and seek to make gasoline prices even more transparent than they already are. Some jurisdictions require stations to post complete sets of prices on price signboards, while others require them to post their prices on a government run website, and some even require retailers to provide advance online notice of future price increases, something largely unheard of with other consumer products.

We recognize that our results may be interpreted as supporting more of these regulations in the retail gasoline industry, but we would advise caution in this regard, for three reasons. First, the gasoline industry would be an unusual place for increased regulatory efforts to promote price transparency. Regular grade gasoline has the most visible price of virtually any consumer product on the street, and higher grade prices seem less visible only in juxtaposition with regular. The price of premium grade gasoline is posted at the spot of purchase, like other brick-and-mortar consumer products, but has all taxes included and is generally viewable without physically getting out of one's car, unlike most brick-and-mortar consumer products. Interested consumers can also look up premium prices on apps designed for that purpose. Second, regulations come with a not-insignificant compliance cost which must be considered in the cost-benefit analysis of any regulation. Third, and importantly, there can be unintended consequences of increased price transparency on the higher grades because of the nature of the gasoline price structure. Gasoline retailing is competitive, and higher margins on premium grade and midgrade gasoline are often used to subsidize lower margins on regular grade gasoline (as a loss leader), while still allowing stations to cover fixed costs and break even. A regulation that would require complete signboard information could potentially lower margins on higher grades of gasoline but at the expense of lower income consumers whose regular grade gasoline prices would rise in the rebalancing. These issues are beyond the scope of this study, but should give the reader pause before interpreting our results as necessarily a call for more regulation in the industry.

Having said this, we feel there are situations outside the gasoline industry where price transparency is especially lacking and where a cost-benefit analysis might well be favorable in the final analysis. Two obvious such situations are "drip pricing" practices and "ex post pricing" practices. Well-known examples of drip pricing include hotel resort fees and rental car add-on fees, where the actual price of a service is often substantially higher than the advertised price, and the actual price is not revealed until later in the process when the buyer is more behaviorally committed to buy. Examples of ex post pricing include medical billing in general, and surprise medical billing in its most extreme form, where the actual price of a service is not known with any certainty until after the service is consumed. In these cases, prices are obfuscated and are difficult for consumers to obtain in advance of committing to buy, either literally or behaviorally. Since markets do not appear to fix the issue, discussions about improved price transparency in such cases would surely be appropriate.

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8 Appendix

Price dispersion is linear in search cost s also when price dispersion is measured as standard deviations instead of max-min ranges. Let $\sigma^2(p)$ be the variance of the price distribution. Then

$$\begin{aligned}
\sigma^2(p) &= E(p^2) - [E(p)]^2 \\
&= \int_0^1 p^2 \cdot dF(p) - \left[\int_0^1 p \cdot dF(p)\right]^2
\end{aligned} \tag{16}$$

where F is defined in the text. Taking

$$z = 1 - F(p) = \left(\frac{1}{N}\frac{1-\mu}{\mu}\frac{\overline{p}-p}{p-c}\right)^{\frac{1}{N-1}} \tag{17}$$

we have

$$\begin{aligned}
\sigma^2(p) &= \int_0^1 \left[\frac{\overline{p}-c}{1+\frac{\mu}{1-\mu}Nz^{N-1}} + c\right]^2 dz - \left[\left(\int_0^1 \frac{\overline{p}-c}{1+\frac{\mu}{1-\mu}Nz^{N-1}} + c\right) dz\right]^2 \\
&= (\overline{p}-c)^2 \cdot \left(\int_0^1 \left[\frac{1}{1+\frac{\mu}{1-\mu}Nz^{N-1}}\right]^2 dz - \alpha^2\right)
\end{aligned} \tag{18}$$

where α is defined in the text. Taking

$$\beta = \int_0^1 \left(\frac{1}{1+\frac{\mu}{1-\mu}Nz^{N-1}}\right)^2 dz \tag{19}$$

we have

$$\begin{aligned}
\sigma &= \sqrt{\beta-\alpha^2}\,(\overline{p}-c) \\
&= \sqrt{\beta-\alpha^2}\frac{s}{1-\alpha} = \kappa s
\end{aligned} \tag{20}$$

so σ and s are linear.

Table 1. Summary Statistics

	Num. Obs.	Mean	Std. Dev.	Minimum	Maximum
Houston	6131	200.67	31.94	148.0	319.0
Regular Grade	3505	179.57	13.62	148.00	249.0
Midgrade	1282	214.44	22.44	174.00	294.00
Premium Grade	1344	242.56	24.35	180.00	319.00
Los Angeles	14496	332.34	26.50	249.00	439.00
Regular Grade	5410	318.52	24.05	249.00	409.00
Midgrade	4450	335.13	23.09	269.00	409.00
Premium Grade	4636	345.78	24.46	279.00	439.00
Pheonix	6462	252.91	27.02	194.00	354.00
Regular Grade	3093	230.01	11.15	194.00	309.00
Midgrade	1572	261.25	12.52	229.00	334.00
Premium Grade	1797	285.03	16.68	228.00	354.00

All prices in cents per gallon.

Table 2. Price Dispersion Across Stations by Grade of Gasoline, Houston

Dep. Var.: PDISP	(1)	(2)	(3)	(4)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	9.900***	0.702**	28.585***	2.132**
	(1.764)	(0.278)	(5.070)	(0.781)
PREMIUM	10.790***	0.694**	30.222***	2.115**
	(1.665)	(0.335)	(4.503)	(0.998)
SCOUNT	-0.070	0.072**	1.374**	0.477**
	(0.111)	(0.031)	(0.279)	(0.112)
Concavity Test	-9.010***	-0.711***	-26.947***	-2.148***
H_0: *2*MIDGRADE=PREMIUM*	(2.020)	(0.305)	(6.188)	(0.858)
Perfect Concavity Test	0.890	-0.009	1.637	-0.016
H_0: *MIDGRADE=PREMIUM*	(0.561)	(0.160)	(1.892)	(0.505)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.686	0.428	0.691	0.383
Num. Obs.	4722	4722	4722	4722

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table 3. Price Dispersion Across Stations by Grade of Gasoline, Los Angeles

Dep. Var.: PDISP	(5)	(6)	(7)	(8)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	-0.128	-0.028	0.487	-0.104
	(0.136)	(0.068)	(0.532)	(0.263)
PREMIUM	0.311*	0.008	2.278***	0.002
	(0.168)	(0.070)	(0.682)	(0.285)
SCOUNT	0.044	0.077**	1.589**	0.623**
	(0.039)	(0.017)	(0.205)	(0.067)
Concavity Test	0.568***	0.064	1.303***	0.211
H_0: *2*MIDGRADE=PREMIUM*	(0.162)	(0.077)	(0.575)	(0.295)
Perfect Concavity Test	0.440***	0.036	1.791***	0.106
H_0: *MIDGRADE=PREMIUM*	(0.094)	(0.029)	(0.338)	(0.123)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.626	0.535	0.602	0.541
Num. Obs.	22986	22986	22986	22986

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table 4. Price Dispersion by Grade, Houston v. Los Angeles Difference-in-Differences

Dep. Var.: PDISP	(9)	(10)	(11)	(12)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	-0.128	-0.028	0.487	-0.104
	(0.136)	(0.068)	(0.532)	(0.263)
PREMIUM	0.311*	0.008	2.278***	0.002
	(0.167)	(0.070)	(0.682)	(0.285)
INCOMPLETE	-15.393**	-0.465**	-44.655**	-1.928**
	(1.252)	(0.209)	(3.563)	(0.647)
MIDGRADE*INCOMPLETE	10.028**	0.731**	28.097**	2.236**
	(1.716)	(0.278)	(4.946)	(0.802)
PREMIUM*INCOMPLETE	10.479**	0.686**	27.944**	2.113**
	(1.624)	(0.332)	(4.420)	(1.009)
SCOUNT	0.041	0.079**	1.576**	0.621**
	(0.037)	(0.016)	(0.187)	(0.063)
Concavity Test	-9.578***	-0.776***	-28.250***	-2.359***
H_0: *2*MIDGRADE=PREMIUM*	(1.966)	(0.306)	(6.029)	(0.883)
Perfect Concavity Test	0.450	-0.045	-0.153	-0.123
H_0: *MIDGRADE=PREMIUM*	(0.552)	(0.158)	(1.866)	(0.505)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.675	0.520	0.672	0.536
Num. Obs.	27708	27708	27708	27708

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table A1. Standardized Price Dispersion by Grade, Difference-in-Differences Houston v. Los Angeles

Dep. Var.: PDISP	(13)	(14)	(15)	(16)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	-0.039	-0.009	0.147	-0.031
	(0.041)	(0.020)	(0.160)	(0.079)
PREMIUM	0.094*	0.002	0.685***	0.001
	(0.050)	(0.021)	(0.205)	(0.086)
INCOMPLETE	-3.797**	0.337**	-11.900**	0.653**
	(0.612)	(0.101)	(1.679)	(0.296)
MIDGRADE*INCOMPLETE	4.974**	0.359**	14.103**	1.094**
	(0.854)	(0.136)	(2.457)	(0.386)
PREMIUM*INCOMPLETE	5.285**	0.343**	14.381**	1.054**
	(0.807)	(0.163)	(2.187)	(0.490)
SCOUNT	0.013	0.024**	0.497**	0.192**
	(0.012)	(0.005)	(0.058)	(0.019)
Concavity Test	-4.662***	-0.374***	-13.826***	-1.134***
H_0: *2*MIDGRADE=PREMIUM*	(0.978)	(0.149)	(2.997)	(0.424)
Perfect Concavity Test	0.311	-0.015	0.277	-0.040
H_0: *MIDGRADE=PREMIUM*	(0.272)	(0.078)	(0.921)	(0.247)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	Y	Y	Y	Y
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.682	0.503	0.648	0.494
Num. Obs.	27708	27708	27708	27708

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table A2. Price Dispersion Across Stations by Grade of Gasoline, Phoenix

Dep. Var.: PDISP	(17)	(18)	(19)	(20)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	2.705***	0.571***	7.304***	1.634***
	(0.401)	(0.108)	(1.166)	(0.304)
PREMIUM	4.008***	0.727***	11.003***	2.025***
	(0.613)	(0.147)	(1.591)	(0.414)
SCOUNT	-0.074	0.038	1.168**	0.476**
	(0.124)	(0.039)	(0.346)	(0.132)
Concavity Test	-1.402***	-0.414***	-3.605***	-1.243***
H_0: *2*MIDGRADE=PREMIUM*	(0.515)	(0.139)	(1.660)	(0.401)
Perfect Concavity Test	1.303***	0.157	3.699***	0.391
H_0: *MIDGRADE=PREMIUM*	(0.400)	(0.093)	(1.133)	(0.271)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.561	0.322	0.551	0.346
Num. Obs.	6012	6012	6012	6012

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table A3. Price Dispersion by Grade, Difference-in-Differences Phoenix v. Los Angeles

Dep. Var.: PDISP	(21)	(22)	(23)	(24)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	-0.128	-0.028	0.487	-0.104
	(0.136)	(0.068)	(0.531)	(0.262)
PREMIUM	0.311*	0.008	2.278***	0.002
	(0.167)	(0.070)	(0.680)	(0.284)
INCOMPLETE	-13.315**	-1.598**	-43.854**	-4.983**
	(0.479)	(0.158)	(2.133)	(0.558)
MIDGRADE*INCOMPLETE	2.833**	0.599**	6.817**	1.739**
	(0.416)	(0.126)	(1.262)	(0.397)
PREMIUM*INCOMPLETE	3.697**	0.720**	8.725**	2.023**
	(0.625)	(0.160)	(1.703)	(0.496)
SCOUNT	0.019	0.077**	1.503**	0.619**
	(0.039)	(0.016)	(0.196)	(0.063)
Concavity Test	-1.970***	-0.478***	-4.908***	-1.454***
H_0: *2*MIDGRADE=PREMIUM*	(0.530)	(0.157)	(1.727)	(0.491)
Perfect Concavity Test	0.864***	0.121	1.908	0.284
H_0: *MIDGRADE=PREMIUM*	(0.403)	(0.096)	(1.162)	(0.293)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.779	0.492	0.762	0.528
Num. Obs.	28998	28998	28998	28998

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.

Table A4. Price Dispersion by Grade, Difference-in-Differences All Cities

Dep. Var.: PDISP	(25)	(26)	(27)	(28)
	Standard Deviation	Standard Deviation	Max-Min Range	Max-Min Range
MIDGRADE	-0.128	-0.028	0.487	-0.104
	(0.136)	(0.068)	(0.532)	(0.263)
PREMIUM	0.311*	0.008	2.278***	0.002
	(0.167)	(0.070)	(0.681)	(0.285)
INCOMPLETE	-12.904**	-0.493**	-37.537**	-1.942**
	(0.894)	(0.121)	(2.615)	(0.416)
MIDGRADE*INCOMPLETE	5.998**	0.657**	16.178**	1.957**
	(1.211)	(0.148)	(3.574)	(0.453)
PREMIUM*INCOMPLETE	6.680**	0.705**	17.180**	2.063**
	(1.157)	(0.179)	(3.257)	(0.559)
SCOUNT	0.018	0.077**	1.498**	0.615**
	(0.037)	(0.015)	(0.181)	(0.060)
Concavity Test	-5.317***	-0.609***	-15.177***	-1.852***
H_0: *2*MIDGRADE=PREMIUM*	(1.354)	(0.170)	(4.178)	(0.520)
Perfect Concavity Test	0.682*	0.048	1.001	0.105
H_0: *MIDGRADE=PREMIUM*	(0.346)	(0.093)	(1.123)	(0.294)
Using Price Residuals	N	Y	N	Y
Using Standardized Prices	N	N	N	N
Daily Indicator Variables	Y	Y	Y	Y
Market Indicator Variables	Y	Y	Y	Y
Only with All Grades Reported	Y	Y	Y	Y
R-Squared	0.750	0.485	0.748	0.521
Num. Obs.	33720	33720	33720	33720

*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. Robust standard errors in parentheses.