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Station level gasoline demand in an Australian market with regular price cycles*

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Regular and frequent gasoline price cycles are being observed in many Australian and Canadian markets. What is driving these price cycles has been the subject of academic studies and government investigations. The existing explanations for these price cycles all rely on the presumption that drivers are intensively sensitive to gasoline price differentials at the station level. However, no empirical evidence exists in the literature to support this presumption. This paper provides the first piece of empirical evidence. This paper uses a unique price and quantity data set and novel instruments to estimate the station level gasoline demand in the cycling market of Perth, Australia. The elasticity estimates confirm that drivers in the Perth area are indeed very sensitive to gasoline price differentials.

Key words: Edgeworth cycle, gasoline demand, gasoline price cycle, price elasticity.

1. Introduction

The retail gasoline prices in many markets of Australia and other countries exhibit frequent cycles in which prices increase rapidly and substantially and then decline gradually over a longer period. What is driving these regular price cycles has been the subject of academic research, government investigations and even price-fixing court proceedings. The existing explanations for these price cycles all rely on the presumption that drivers in these markets are very sensitive to gasoline price differentials at the station level. To date, however, this presumption is not supported by any empirical evidence in the literature. The purpose of this paper is to empirically examine the validity of this presumption. For this purpose, we use a unique price and quantity data set and novel instruments to estimate the demand functions for a sample of gasoline stations in the Perth metropolitan area, a market with regular price cycles.

A growing empirical literature has found that regular gasoline price cycles are well characterized by the Edgeworth price cycle equilibrium in Maskin and Tirole's (1988) dynamic oligopoly model. This theory, to be reviewed, presumes that gasoline is a relatively homogenous product. Various

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government and industry reports claim many consumers are very sensitive to gasoline price differentials, and the price sensitivity has contributed to the observed price volatility. For example, Australian Competition and Consumer Commission (ACCC 2001, p. 20) argues that '[gasoline] is a relatively homogenous product and thus competition is based primarily on price,' and that this fact 'may make [gasoline] more susceptible to price volatility.' (Conference Board of Canada 2001, p. iv) states that 'the volatility in gasoline prices [in cycling Canadian markets] … is enhanced by the sensitivity of Canadian consumers to price differentials, a lack of brand loyalty as well as the accepted perception that gasoline from one outlet is basically identical to that from any other dealer.'

If many drivers are indeed intensely sensitive to gasoline price differentials, we would expect very elastic demand for those gasoline stations that are located in competitive areas. This raises the interesting research question: How elastic is the station level gasoline demand in a cycling market? I am not aware of any study that has estimated station level gasoline demand in Australian markets. A key reason for the lack of empirical studies is the challenge of collecting appropriate quantity data. Although price data are publicly available, quantity data are difficult to collect because of commercial sensitivity and, more importantly, the price volatility in the cycling gasoline markets. As it is common for gasoline stations in such markets to change price several times within a single day, the prices of two nearby stations are likely to differ at a given time. However, the two stations' average prices over a fixed period (say, a day) could be identical. Therefore, quantity data that exactly matches the timing of price changes is necessary for precise estimation.

In this paper, we are able to collect station-specific price and quantity data that matches in timing from the Perth gasoline market because of a special timing restriction in that market. A regulation, called the 24 h rule or the Fuelwatch scheme, requires that (i) all the gasoline stations in the Perth area must notify to the government their next day's retail prices by 2.00 p.m. each day and (ii) the notified prices must be posted on the price board at the beginning of the next day and must remain unchanged for 24 h. This regulation essentially forces gasoline prices to be set once a day, thus generating price and quantity data that matches in timing. Our sample includes eight gasoline sites in the Perth metropolitan area, representing three brands, eight locations and various levels of local competition.

We use both the ordinary least squares method and the instrumental variables approach to estimate station level gasoline demand. A novel feature of the estimation is that we use the timing of the regular gasoline price cycles as instruments for the price variables. The elasticity estimates confirm that the station level gasoline demand in the Perth market is indeed highly elastic. For example, the estimated own price elasticity is −6.20 for a sample site whose closest competitor is 4.2 km away and −18.77 for a sample site located right next to its closest competitor. Statistically significant intertemporal elasticities are also found for half of the sample stations, suggesting the possibility of intertemporal substitution. The overall results suggest that many drivers in the Perth area are indeed very sensitive to station level gasoline price differentials, and that most gasoline sites have little market power in gasoline retailing.

2. Properties of the regular gasoline price cycles

This section summarizes briefly the properties of the regular price cycles. These properties have important implications for estimating station level gasoline demand.

2.1 Edgeworth cycle characterizes gasoline price cycles

A growing empirical literature has presented mounting evidence that the regular gasoline price cycles observed in many markets are well characterized by the Edgeworth cycles in the Maskin and Tirole (1988) model. For studies of regular gasoline price cycles in Canadian markets, see Eckert (2002), Eckert and West (2004), Noel (2007a,b) and Atkinson (2007). See Wang (2008a,b) for studies of the regular gasoline price cycles in the Australian cities of Ballarat and Perth. As many readers may not know this literature well, this subsection briefly summarizes the theory and the empirical evidence that the gasoline price cycles in the Perth market are well characterized by the Edgeworth price cycles.

Figure 1 shows Maskin and Tirole's numerical example of an Edgeworth cycle. Market demand in this model does not vary over time, so price variations along an Edgeworth cycle are independent of demand. An Edgeworth cycle has three phases. In the *falling phase*, two firms undercut each other gradually until price reaches marginal cost. At this point, firms are in the *war of attrition phase*: both wish price to be hiked, but neither wants to be the first to hike price. Once a firm eventually relents by hiking its price to a high level, the other firm follows with a smaller increase, and these price hikes constitute the *rising phase* of the cycle. Edgeworth's (1925) original formulation of the

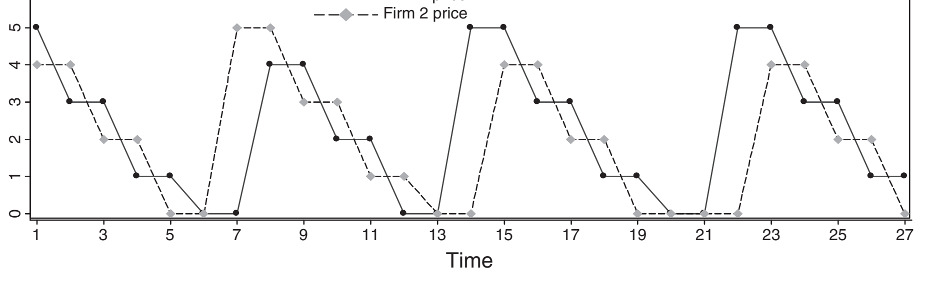

Figure 1 An Edgeworth cycle example.

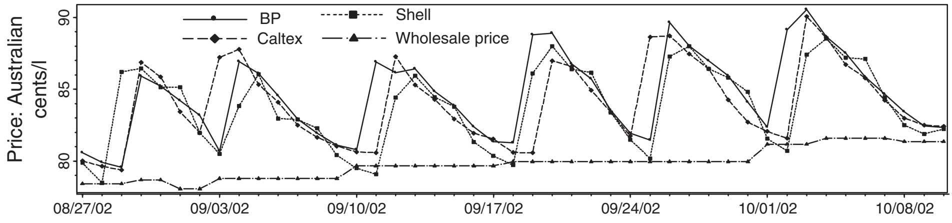

Figure 2 Daily brand average prices over six cycles in the Perth market.

price cycle relies on capacity constraints and does not have a war of attrition phase. This example assumes a homogenous product, but Noel (2006) finds the Edgeworth cycle can arise as long as the product is not too differentiated.

Figure 2 shows the daily brand average retail price of the three largest gasoline firms and the wholesale gasoline price in the Perth market over six representative cycles. The regular gasoline price cycles are captured remarkably well by the Edgeworth price cycle – each of the gasoline price cycles has a quick rising phase, a gradual falling phase, and as the firms hike price sequentially, a war of attrition phase. Wang (2008b) presents further evidence that the gasoline price cycles are consistent with the Maskin and Tirole (1988) theory. The three largest firms are always the first to hike price and these three firms allocate price leadership by playing the stationary mixed strategies presumed in the model. The wholesale gasoline price is much more rigid and does not have a regular cycle.

2.2 Timing of the gasoline price cycles is independent of demand shocks

As the regular gasoline price cycles are well characterized by the Edgeworth cycle, much of the price variations along the cycles appear to be driven by firms' strategic supply behaviour. Indeed, it is hard to think of any demand shocks that could explain the regularities of the price cycles. Yet, we cannot rule out the possibility that some of the price variations along the cycles might be affected by changes in gasoline demand. However, we present evidence that the *timing* of the gasoline price cycles is independent of demand. The timing of a price cycle refers to the dates on which the price cycle starts and peaks, and the order in which firms hike price. Our basic observation is that firms in the market face the same demand shocks every day and yet some firms may hike price on a given day, whereas other firms do not. This variation in the timing of price hikes can only result from firms' supply behaviour. Therefore, we can use the timing of the price cycles as instruments in demand estimation.[1]

Define the day on which one or more firms hike price as the *start day* of a cycle, and the day immediately before as the *last day* of the previous cycle. The start day through the last day is the *duration* of a cycle. There are 102

[1] I thank a referee for suggesting this novel idea.

gasoline price cycles in the Perth market from 10 May 2001 through 21 October 2003. The duration of these cycles, ranging from 3 to 16 days, is unpredictable in that it is characterized by a white noise process. This implies that the start day of a cycle is also unpredictable. Indeed, 7 price cycles start on Monday, 25 on Tuesday, 20 on Wednesday, 19 on Thursday, 5 on Friday and 26 during the weekends. The average retail price in the Perth area always reaches the peak of a cycle either 1 or 2 days after the start day. That is, the cycle rising phase, defined as the number of days from the start day through the peak day, is always 2 or 3 days. This reflects the fact that the three largest firms, if not a price leader, virtually always follow the leader on the second day, and the smaller firms in the market follow on the second or third day. The falling phase of a price cycle starts on the day immediately after the peak day of the cycle and ends on the last day of the cycle. The duration of the cycle falling phase is characterized by a white noise process as well.

Suppose gasoline firms were to respond to demand variations in deciding when to hike price, how would they respond? In the Perth gasoline market, demand is highest on Thursday and Friday and lowest on Sunday.[2] In generating the price cycles, firms are reluctant to serve as a price leader, because the leader has to lose market share for at least 24 h before rival firms can follow. Therefore, one might expect price leaders to always hike price on days when demand is the lowest. However, only 26 of the 102 price cycles are observed to start during the weekends. In fact, 24 price cycles start on the 2 days of the highest demand (Thursday and Friday). There is no evidence to suggest gasoline price cycles in the Perth market tend to be hiked just before the start of public holidays and long weekends.

2.3 Price cycle dynamics generates extraordinary sales volatility

This subsection illustrates how the timing of the gasoline price cycles affects a site's gasoline sales. The basic point is that price cycle dynamics leads to dramatic changes in the relative price of nearby gasoline sites, and the changes in relative price, in turn, lead to extraordinary volatility in station level gasoline sales.

The extraordinary volatility in station level sales can be seen from Figure 3a, which presents the daily sales quantity for a sample station (coded as B2) for a 10 month period. The large and frequent upward sales spikes in Figure 3a take place on those days when site B2 posted a considerably lower price than its competitors. To see this clearly, consider Figure 3b. The top part of this figure shows site B2's daily sales over a 2 month period, and the bottom part shows the corresponding retail prices of B2 and its two closest competitors'.

[2] This is reported by the Western Australia Department of Consumer and Employment Protection in its submission to the ACCC inquiry into the price of unleaded petrol.

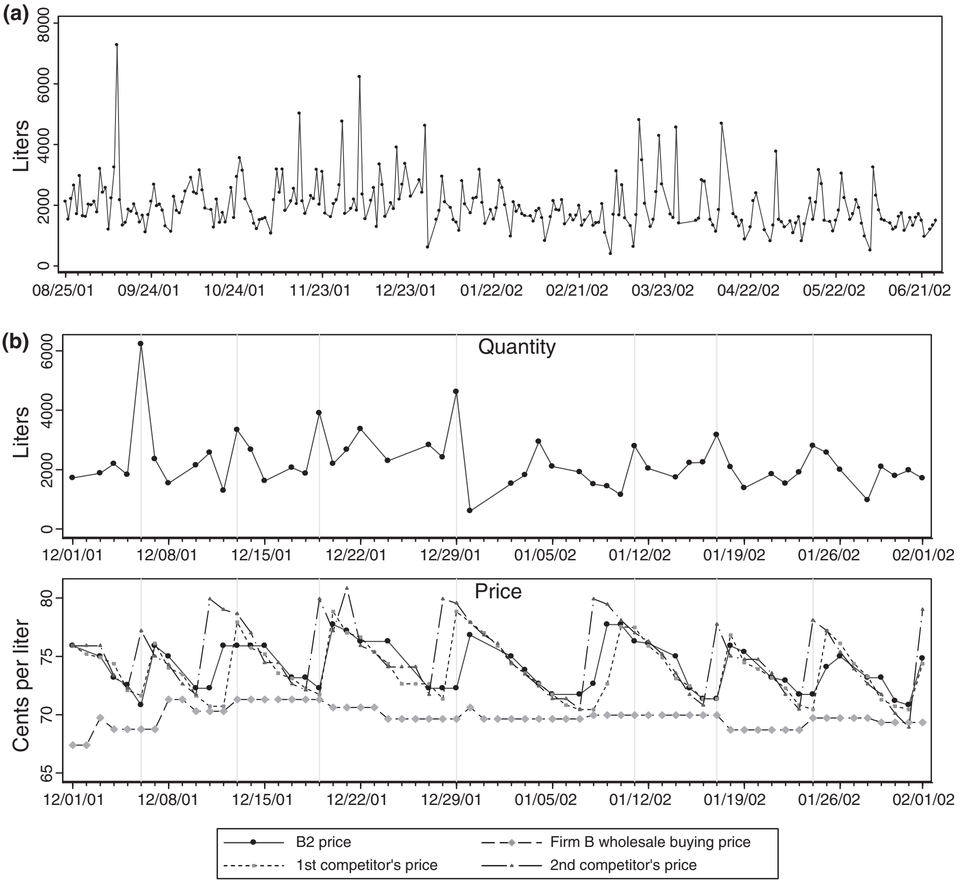

Figure 3 (a) Daily sales quantity for site B2: 08/25/01 to 06/26/02. (b) Daily sales quantity for site B2 and prices: 12/01/01 to 02/01/02.

Consider, for example, the quantity spike on 6 December 2001 when site B2 sold 6228 L of regular unleaded gasoline, which is over three times its sales volume the day before. This quantity hike, like the other quantity hikes, is caused by the change in the relative price between site B2 and its competing sites. On 5 December, site B2 and its two closest competitors posted roughly the same price, but on 6 December, site B2's second closest competitor's price was hiked by 4.9 cents, whereas site B2 and its closest competitor decreased price by 1.7 and 0.5 cents, respectively. As a result, for the entire day of 6 December, site B2's price was lower than its first and second closest competitor's by 0.8 and 6.4 cents, respectively. If a large number of drivers are indeed highly price sensitive, site B2 is expected to experience a hike in its sales volume on that day. It is hard to think of any demand shocks that would cause this dramatic change in the relative prices of site B2 and its competitors, as these sites are in the same local market and face the same demand shocks. The only reasonable explanation for this dramatic change in relative price, therefore, is firms' strategic supply behaviour.

Table 1 Basic information of the eight sample sites

Site code	Brand information	Urban area	Distance of the two closest competitor (km)		No. of competitors within 4 km	Operating days per week
			First	Second		
A1	Major oil	Bull Creek	1.4	1.7	5	7
A2	Major oil	Manning	0.4	1.5	4	7
A3	Major oil	Redcliffe	0.6	2.2	6	7
A4	Major oil	Lesmurdie	4.2	5.6	0	7
B1	Small independent	Bayswater	0.9	1.7	6	6
B2	Small independent	Eden Hill	1.0	2.2	5	6 or 7
B3	Small independent	Gosnells	0.0	0.4	6	6
C1	Large independent	Bellevue	0.9	1.3	6	7

Note: The major oil brands in the Perth market include BP, Caltex, Shell and Mobil. Gull and Peak are the two large independent brands. The small independent brands include Liberty and Wesco, among others.

3. Data collection and basic statistics

To estimate station level gasoline demand, I collected a representative sample of eight sites from three gasoline firms in the Perth metropolitan area. To protect their identity, we code these three firms as A, B and C. The eight sample sites include four firm A sites (coded as A1–A4), three firm B sites (coded as B1–B3) and one firm C site. The data for the firm A sites were provided in the form of computer printouts, the data for the firm B sites were collected from hand-written record books and the data for the firm C site were provided in the form of excel files. All three firms set their own retail prices and buy gasoline from major oil firms. Table 1 summarizes the basic information of the eight sample sites.

Station level gasoline demand depends critically on the level of local competition. Our sample is representative of the Perth market in that it covers gasoline sites of different brands, location and levels of competition. First, four of our sample sites (A1–A4) carry a major oil brand, three sites (B1–B3) a small independent brand and one site (C1) a large independent brand. Second, the eight sample sites are located in eight different urban areas (Bull Creek, Manning, Redcliffe, Lesmurdie, Bayswater, Eden Hill, Gosnells and Bellevue), thus allowing us to study eight local submarkets with varying market conditions. These eight urban areas are representative of the Perth market. Some of the urban areas are quite close to the central business district (CBD) of Perth: Manning is about 7 km to the south and Bayswater is about 6 km to the northeast. Some of the urban areas (Lesmurdie, Gosnells and Bellevue) are between 20 and 25 km from the CBD area. Redcliffe is near the entrance of the Perth airport. The sample sites' level of local competition is also representative. At one extreme, site B3 is located at the same crossroad as its closest competitor, thus facing extremely strong competition. At the other extreme, site A4's first two competitors are, respectively, 4.2 and 5.6 km away, thus facing relatively low competition. Site A4 is more isolated than the vast majority of the gasoline sites in the Perth area. The other seven sample sites have four to six competing sites within 4 km of travelling distance, which is typical of the gasoline sites in the Perth area.

Third, conversations with the firms' owners also suggest that our sample is representative of the Perth area. According to firm B's owner, site B3 faced extremely strong competition not only because of the proximity of its competitor, but also because it 'did not have a large convenience store to speak of.' In fact, B3 was closed at the end of its sample period because of competitive pressures. Therefore, site B3 represents those gasoline sites in the Perth area that have the most elastic demand. The other two firm B sites faced more or less an average level of competition. According to firm A's owner, sites A1–A4 faced an average or below average level of competition because of their major oil brand and their favourable locations (e.g. site A3 is near the entrance of the airport and site A4 is quite isolated). According to firm C's owner, site C1 faced an about average level of competition among firm C's gasoline sites or among all sites in the Perth area. Our sample does not include any sites whose primary business is not fuel retailing (e.g. auto repair). There are a limited number of such sites in the Perth area and such sites are expected to have less elastic demand than our sample sites.

In addition to price and quantity data, the actual wholesale transaction price paid by each of the three firms to their gasoline suppliers was also collected to measure each site's local market power. These three firms pay very similar wholesale price, and the wholesale price shown in Figure 2 is the average of the three firms'. The retail price for the competing sites of each sample site was downloaded from the internet website (http://www.fuelwatch.wa.gov.au).

Table 2 shows the sample period for each site's quantity data and the relevant summary statistics. The daily sales quantities have large standard deviation (SD), further evidence that these sites' sales are *highly volatile on a daily basis*. The retail margins are also very volatile on a daily basis and the volatility in sales is highly correlated with the volatility in margin. The retail margins are quite low, especially considering that they are the upper bound of the retail sites' gasoline profit margin, as the wholesale transaction price is the lower bound of marginal cost. Lerner index, a standard measure of market power, is computed as the daily retail margin divided by the daily after-tax retail price. Site B3 has by far the smallest Lerner index and most volatile sales, which supports the argument that this site should have the most elastic demand.

The daily sales quantity for each site is measured for each calendar day. For the period since 24 August 2001, retail prices are fixed by the law for the 24 h from 6.00 a.m. to 6.00 a.m. To match the price and quantity data, it is important to verify each station's operating hour. Six of the eight stations operate within the hours between 6.00 a.m. and midnight, so price and quantity data is precisely matched. For these six stations, the price downloaded

Table 2 Summary statistics for the eight sample gasoline stations

Site code	Sample period for quantity data	Number of days	Daily quantity mean (L)	Daily quantity SD (L)	Retail price mean (cents)	Daily margin mean (cents)	Margin SD (cents)	Lerner index mean (%)
A1	07/01/03 to 10/31/03	123	6610	1579	91.25	5.16	2.34	6.2
A2	07/01/03 to 10/31/03	123	7761	1515	92.17	6.05	2.29	7.2
A3	07/01/03 to 10/31/03	123	7076	1561	91.46	5.17	2.34	6.2
A4	07/01/03 to 10/31/03	123	5338	1291	89.79	3.68	1.83	4.4
B1	07/01/02 to 10/31/03	385	3307	1248	90.21	4.41	1.79	5.3
B2	08/25/01 to 06/26/02	255	2005	885	85.94	2.94	2.28	3.7
B3	06/01/01 to 11/23/01	149	1487	1157	85.00	1.09	2.55	1.3
C1	03/01/02 to 06/30/02	120	6269	1399	87.22	4.10	1.93	5.1

SD, standard deviation.

from the website is identical to the price recorded by the stations. Site A3 operates 24 h per calendar day, so a 6 h (from midnight to 6.00 a.m.) price–quantity mismatch exists. Site C1 opens at 5.00 a.m., so a 1 h discrepancy exists. The calendar day average price recorded by these two stations is only slightly different from the price downloaded from the website. As the estimated results are very similar whether the calendar day price or the price from the website is used, we will report the estimated equations in which the website price is used to match the quantity data.

4. Estimation and results

The base specification of the demand function for a sample site is given by:

$$q_t = f(p_t, \tilde{\mathbf{P}}_t, \mathbf{Z}_t, \varepsilon_t). \tag{1}$$

A sample site's sales quantity on a given day (q_t) is assumed a function of its own price (p_t), a vector of competing sites' prices ($\tilde{\mathbf{P}}_t$), a vector of exogenous demand shifters ($\mathbf{Z}_t$) and an error term (ε_t). Intertemporal effects will be considered later. We estimate Equation (1) by two approaches: the ordinary least squares (OLS) method and the two-stage least squares or instrumental variables (IV) method.

4.1 The OLS estimates

The OLS estimates of Equation (1) may suffer from two biases. The simultaneity bias arises if the price variables are correlated with demand shocks. In the Perth setting, this bias is not expected to be severe, because much of the variations along the regular gasoline price cycles appear to be driven by firms' supply behaviour. The omitted variable bias arises if a key competitor's price is omitted from Equation (1). A two-step procedure is followed to identify each site's primary competitors whose price should be included in Equation (1). First, we identify the gasoline sites within a chosen travelling distance of a sample site (6.5 km for site A4 and 4 km for the other sample sites). Conversations with the station owners suggest the sample sites compete primarily with other stations in the same local market. We check the correlation coefficients among these sites' prices. If two sites post nearly perfectly correlated prices, we ignore one of them. Second, we use the OLS method to estimate Equation (1) with the remaining competitor sites. Those sites that have a statistically significant and positive coefficient are deemed the primary competitors. No competitor sites are found to have a negative coefficient.

Table 3 reports, for each of the sample sites, the OLS estimates of Equation (1) in which only the primary competitors are considered. The reported estimates are for the log–log functional form. (Other function forms yield very similar results.) The exogenous demand shifters include dummies for the day of the week and a dummy for public holidays.

Table 3 Estimated demand functions for the eight sample sites

Variables	A1		A2		A3	A4		B1		B2		B3		C1	
	OLS	IV	OLS	IV	OLS	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Own price	**−5.78**	**−6.75**	**−3.23**	**−4.93**	**−4.49**	**−6.20**	**−9.04**	**−4.99**	3.07	**−10.93**	**−7.94**	**−18.77**	**−28.18**	**−7.43**	**−9.70**
	(0.56)	**(1.27)**	**(0.45)**	**(1.08)**	**(0.45)**	**(0.78)**	**(2.98)**	**(0.78)**	(2.15)	**(0.70)**	**(1.53)**	**(1.98)**	**(5.01)**	**(1.09)**	**(3.92)**
Competitor 1	**1.19**	**2.71**	**1.67**	**1.65**	**1.24**	**5.87**	**7.24**	**1.94**	−4.60	**6.96**	**4.96**	**9.78**	**10.89**	**4.09**	**6.21**
	(0.55)	**(1.05)**	**(0.32)**	**(0.43)**	**(0.31)**	**(0.87)**	**(2.82)**	**(0.61)**	(2.60)	**(0.63)**	**(1.34)**	**(1.47)**	**(3.12)**	**(1.09)**	**(3.80)**
Competitor 2	**1.52**	0.78	**1.35**	**1.38**	**1.82**			**1.13**	1.04	**2.72**	**2.27**	**5.29**	**6.16**	**1.73**	**1.86**
	(0.41)	(0.71)	**(0.27)**	**(0.45)**	**(0.40)**			**(0.48)**	(1.72)	**(0.43)**	**(0.50)**	**(0.92)**	**(1.42)**	**(0.44)**	**(0.53)**
Competitor 3	**1.87**	0.86						**2.20**	1.24			**3.81**	**11.35**		
	(0.54)	(1.02)						**(0.40)**	(0.78)			**(1.60)**	**(3.86)**		
Monday	**0.23**	**0.24**	**0.30**	**0.31**	**0.37**	**0.35**	**0.36**	**0.74**	**0.79**	0.10	0.08	0.23	**0.35**	**0.33**	**0.34**
	(0.05)	**(0.05)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**	**(0.06)**	**(0.07)**	(0.06)	(0.06)	(0.15)	**(0.17)**	**(0.05)**	**(0.07)**
Tuesday	**0.17**	**0.17**	**0.32**	**0.32**	**0.40**	**0.33**	**0.32**	**0.72**	**0.78**	0.05	0.05	0.22	**0.35**	**0.44**	**0.44**
	(0.05)	**(0.03)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**	**(0.06)**	**(0.06)**	(0.06)	(0.06)	(0.15)	**(0.18)**	**(0.06)**	**(0.06)**
Wednesday	**0.23**	**0.25**	**0.30**	**0.32**	**0.43**	**0.38**	**0.37**	**0.75**	**0.79**	**0.21**	**0.20**	**0.43**	**0.47**	**0.55**	**0.55**
	(0.05)	**(0.05)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**	**(0.06)**	**(0.07)**	**(0.06)**	**(0.06)**	**(0.15)**	**(0.17)**	**(0.06)**	**(0.06)**
Thursday	**0.26**	**0.29**	**0.35**	**0.37**	**0.43**	**0.36**	**0.36**	**0.81**	**0.82**	**0.24**	**0.25**	**0.58**	**0.71**	**0.55**	**0.55**
	(0.05)	**(0.05)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**	**(0.05)**	**(0.06)**	**(0.06)**	**(0.06)**	**(0.15)**	**(0.18)**	**(0.06)**	**(0.06)**
Friday	**0.31**	**0.33**	**0.44**	**0.46**	**0.54**	**0.38**	**0.39**	**0.80**	**0.84**	**0.20**	**0.21**	**0.38**	**0.49**	**0.53**	**0.55**
	(0.05)	**(0.05)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**	**(0.05)**	**(0.06)**	**(0.06)**	**(0.06)**	**(0.15)**	**(0.17)**	**(0.07)**	**(0.07)**
Saturday	**0.25**	**0.25**	**0.22**	**0.22**	**0.12**	**0.20**	**0.22**							**0.39**	**0.38**
	(0.05)	**(0.05)**	**(0.04)**	**(0.05)**	**(0.04)**	**(0.05)**	**(0.06)**							**(0.06)**	**(0.06)**
Holiday	**−0.38**	**−0.52**	**−0.23**	**−0.34**	**−0.14**	**−0.23**	**−0.35**	**−0.15**	**−0.15**	**−0.51**	**−0.52**	−0.30	−0.19	**−0.42**	**−0.45**
	(0.09)	**(0.11)**	**(0.07)**	**(0.10)**	**(0.07)**	**(0.09)**	**(0.13)**	**(0.11)**	**(0.07)**	**(0.09)**	**(0.10)**	(0.27)	(0.31)	**(0.10)**	**(0.12)**
Observation #	123	123	123	123	123	123	123	385	385	255	255	149	149	120	120
Adj. R-square	0.59	0.51	0.63	0.53	0.80	0.56	0.47	0.62	0.48	0.58	0.54	0.47	0.35	0.65	0.60
Hausman test P-value	0.0004		0.003			0.29				0.003		0.18		1.00	
Endogeneity test P-value	0.0002		0.002			0.29				0.002		0.18		0.89	

Notes: The coefficients for the constant terms are not reported. In parentheses are robust standard errors. Coefficients in bold face are statistically significant at the 5% level or higher.

As expected, the estimated own price elasticities for all the sample sites are negative and highly significant. The own price elasticity estimates for six of the eight sites range from −3.23 to −7.43. The estimated own price elasticity for site B3 is much larger (−18.77). We know site B3 has by far the smallest Lerner index, an indicator that it faces the strongest competition, so it is not surprising that site B3 has by far the largest own price elasticity estimate.

The first competitor in seven of the eight equations is a sample site's closest competitor, and the second competitor in five equations is a sample site's second closest competitor. These findings suggest the sample sites compete primarily in local markets. No sites are found to have more than three primary competitors.

The coefficients on the day of the week dummies clearly indicate that the sales volumes on weekends are much lower than those on the weekdays for all of the eight sample stations. The holiday dummy always has a negative sign, and is statistically significant at the 5 per cent level or above for six of the eight sites.

4.2 Instrumental variables estimation

4.2.1 Instruments

We consider two types of instruments whose definitions are listed in Table 4. The first type, including six binary variables and one discrete variable, indicates various aspects of the timing of the regular gasoline price cycles (e.g. the start day and the peak day). Besides these timing-based instruments, we also consider a cost-based instrument: the daily spot price of the Singapore Mogas 95 unleaded. As Singapore is one of the major refining and trading centres of petroleum products in the world, the price of the Mogas 95 is exogenous of the demand shocks in the Perth area. Nonetheless, the price of Mogas 95

Table 4 Definitions of the instrumental variables

Instrumental variables	Definition
Start day	Equals 1 if a day is the start day of a cycle; 0 otherwise.
Rise day	Equals 1 if the day of the cycle rising phase is 2 and the duration of the cycle rising phase is 3 days; 0 otherwise.
Peak day	Equals 1 if a day is the peak day of a cycle; 0 otherwise.
BP leads	Equals 1 on the day BP is among the first to hike price; 0 otherwise.
Caltex leads	Equals 1 on the day Caltex is among the first to hike price; 0 otherwise.
Shell leads	Equals 1 on the day Shell is among the first to hike price; 0 otherwise.
(Weighted) day of falling phase	The day of a cycle' falling phase divided by the duration of the cycle's falling phase; equals 0 on any days of the rising phase.
Singapore Mogas 95	The spot price of the Singapore Mogas 95 unleaded in Australian (cents/L)

Table 5 First stage regressions for site C1

	C1	Competitor 1	Competitor 2
Singapore Mogas 95	**1.19 (0.06)**	**1.12 (0.09)**	**1.08 (0.06)**
Start day	**−4.88 (0.79)**	**−5.78 (1.18)**	**−6.74 (0.78)**
Rise day	**−5.02 (0.50)**	**−6.28 (0.72)**	**2.11 (0.49)**
Peak day	0.09 (0.47)	−1.29 (0.67)	0.60 (0.46)
BP leads	−0.80 (0.68)	−0.95 (1.02)	−0.44 (0.67)
Caltex leads	−0.33 (0.68)	0.00 (1.01)	**9.79 (0.67)**
Shell leads	−0.85 (0.73)	−0.81 (1.09)	−0.37 (0.72)
Weighted day of falling phase	**−5.56 (0.50)**	**−6.18 (0.71)**	**−7.04 (0.49)**
Observation #	121	120	192
Adj. R-square	0.86	0.74	0.91

Note: Dummies for the day of the week and holidays are included in these equations, but not reported here. Coefficients in bold face are statistically significant at the 5% level or higher.

(converted into Australian cents per litre) is highly correlated with the wholesale gasoline price in Australia.[3]

It is illuminating to see how the instrumental variables are related to the price variables. Consider site C1 as an example. The demand equation for site C1 includes its own price and its two primary competitors' prices. Table 5 reports the three corresponding first-stage regressions. As expected, the retail prices of these sites respond strongly to the Mogas 95 price. The estimates also reveal the three sites' pricing behaviour along the cycles. The negative and significant coefficients on the binary variable *start day* and the insignificant coefficients on the binary variable *peak day* reflect the fact that these sites' average price on the start day of a cycle is smaller than their price on the peak day of the cycle. The variable (*weighted*) *day of falling phase* is defined as the day of a cycle's falling phase divided by the duration of the cycle's falling phase. Suppose the duration of a cycle's falling phase is 5 days, then the variable *(weighted) day of falling phase* takes the value of 0.2 (= 1/5) on the first day of this cycle's falling phase. As this variable equals 1 on the last day of any price cycle, its estimated coefficient indicates a sample site's average price on the last day of the price cycles (relative to the average price on the peak day of the price cycles). Thus, it is not surprising that the two variables *(weighted) day of falling phase* and *start day* have very similar coefficients. The binary variable *Caltex leads* is 1 on the day when Caltex is among the first to hike price. Therefore, this variable is highly significant in the regression for site C1's second competitor, which is a Caltex site, but insignificant for site C1 and its first competitor, which are of different brands.

It turns out that the IV approach does not yield sensible results for two sample sites (A3 and B1). For example, the IV estimate (reported in Table 3)

[3] This is because the oil firms in Australia use the method of import parity pricing to determine the wholesale gasoline price in Australia, and Singapore wholesale gasoline price is the key component of the import parity pricing. See ACCC (2007) for more details.

for site B1's own price elasticity has a positive sign and the cross price elasticity associated with the closest competitor has a negative sign. These highly problematic results are probably because of the fact that site B1 and its closest competitor almost always hiked price on the same day. Because our instruments are primarily based on the timing of price changes, the projected prices of site B1 and its closest competitor becomes too highly correlated – the correlation coefficient is 0.99. In comparison, the correlation coefficient between these two sites' original prices is 0.92.

4.2.2 The IV estimates

The IV estimates of Equation (1) for six sample sites are reasonable and reported next to the OLS estimates in Table 3. The IV estimates of the own-price elasticities are bigger (in absolute value) than the OLS estimates for five of the six sites. This is consistent with the common finding that the OLS estimates of own price elasticity tend to be biased towards zero – this bias is known in some cases to be so severe that it may lead to an 'upward sloping' demand curve. The IV estimates of the cross price elasticities also tend to be bigger. However, the difference in the OLS and IV estimates does not appear to be large except for site B3. We perform the Hausman test to formally check if the estimates are sufficiently different to indicate the OLS estimator is inconsistent for our model. The Hausman test cannot reject the null that the OLS estimator is consistent, thus efficient, for three of the six demand equations, including the equation for site B3. We also perform the standard regression-based *F*-test for endogeneity in the context of IV estimation (see, e.g. Wooldridge 2002), and find essentially the same results. These results support the argument that the potential biases of the OLS estimates are not severe in the Perth market because of the regular gasoline price cycles.

The Hausman test suggests the preferred estimates for sites A1, A2 and B2 are their IV estimates (−6.75, −4.93 and −7.94, respectively), whereas the more efficient estimates for sites A4, B3 and C1 are their OLS estimates (−6.20, −18.77 and −7.43, respectively). The OLS estimates for sites A3 and B1 to which the IV method cannot be applied are −4.49 and −4.99, respectively. These estimated own price elasticities suggest many drivers in the Perth area are indeed highly price sensitive. In particular, note that site A4 has an own price elasticity estimate of −6.20, although its closest competitor, not on the same road, is 4.2 km away.

It is useful to note these estimates are quite in line with the results from two studies of Canadian gasoline markets. Slade (1986) estimated the demand for 13 gasoline sites in the Vancouver area for the 1983 summer period when regular gasoline price cycles did not appear to exist. Ten of Slade's 13 sites have an estimated own price elasticity between −4.1 and −7.7. Using data of bimonthly frequency from Quebec City, Houde (2008) estimated a model of retail gasoline demand. It is not clear if regular gasoline price cycles exist in Quebec City during Houde's sample period (between 1995 and 2001). Houde

(2008) reports station level own price elasticity averages around −15 in Quebec City.

4.3 Intertemporal substitution

This section explores the possibility of intertemporal substitution. Australian Competition and Consumer Commission (2007) reports a large per cent of consumers in Sydney and Melbourne appear to time their gasoline purchase, but a much smaller percentage in Perth appear to do so. Over a number of years, the gasoline price cycles in Sydney and Melbourne have almost always been weekly and reached a trough on Tuesday, a pattern perhaps motivated by firms' incentive to price discriminate intertemporally. This pattern makes it easy for price-sensitive drivers to time their gasoline purchase, as most drivers fill their car on a weekly basis. However, in the Perth market, it is much more difficult to buy gasoline on the day when price is the lowest because the duration and start day of the price cycles are unpredictable during our sample period, although it is easier to engage in spatial substitution within a single day because of the 24 h rule. Nonetheless, we cannot rule out the possibility that some drivers in the Perth market may engage in intertemporal substitution.

There are two possible ways for Perth drivers to engage in intertemporal substitution. First, a driver, if willing, is able to know today if there is a price hike tomorrow through the Fuelwatch website or TV news because of the 24 h rule. However, there do not appear to be many such drivers. In any case, such drivers also know that firms hike their prices sequentially and many gasoline stations do not hike their prices on the first day of a new cycle. This means that even if some firms hike their prices tomorrow, drivers know that they can still buy gasoline tomorrow from some stations at a low price; thus, the incentive to buy gasoline today is small. Indeed, a sample site's next day price, when added in Equation (1), is never statistically significant and often has the wrong sign.

Second, many drivers may learn that a new price cycle has started and, knowing that price will certainly fall, these drivers may delay their purchase of gasoline for a couple of days. The lagged own prices in the past 2 days are added in Equation (1) to capture this possibility. These lagged prices are expected to have a positive sign – higher lagged prices lead some consumers to buy gasoline today. The lagged values of own price for the three firm B sites are not well defined, because they operate 6 days/week. For this reason, lagged values are not considered for these three stations.

Table 6 reports the OLS estimates of Equation (1) with the lagged prices. For four of the five sites considered here, the 2 day lagged prices (but not the 1 day lagged prices) are found to have a statistically significant and positive coefficient. A possible interpretation is that if a consumer waits for price to drop, he or she waits for more than 1 day. For all five sites, the Wald test rejects the null that the lagged price terms are jointly insignificant. This is why

Table 6 OLS estimates with lagged own prices

	A1	A2	A3	A4	C1
Own price	**−8.56 (0.71)**	**−5.61 (0.56)**	**−5.52 (0.57)**	**−7.41 (0.96)**	**−8.80 (0.99)**
Competitor 1	**1.35 (0.48)**	**1.84 (0.27)**	**1.25 (0.30)**	**5.80 (0.87)**	**3.12 (0.91)**
Competitor 2	**1.58 (0.36)**	**1.73 (0.23)**	**2.00 (0.40)**		**2.08 (0.41)**
Competitor 3	**2.44 (0.48)**				
Own price lag 1	0.98 (0.70)	0.75 (0.58)	0.63 (0.54)	−0.19 (1.01)	1.27 (0.85)
Own price lag 2	**2.15 (0.54)**	**1.83 (0.45)**	0.48 (0.40)	**1.95 (0.75)**	**1.67 (0.62)**
Observation #	121	121	121	121	120
Adj. R-square	0.70	0.75	0.82	0.59	0.68

Notes: The day of the week and the holiday dummies are included in the regressions. In parentheses are robust standard errors. Coefficients in bold face are statistically significant at the 5% level or higher.

we did not use lagged prices as instruments in the previous subsection – lagged prices appear to be correlated with the error term in the current period through intertemporal substitution.

In theory, it is possible that the lagged prices may be endogenous. Unfortunately, the identification condition for IV estimation fails after adding the lagged prices (the total number of price variables are bigger than the total number of effective instruments in the first stage regressions). However, the OLS estimates of intertemporal elasticities should be reasonable, as the OLS estimates of own and cross price elasticities are not much different from the IV estimates.

5. Conclusion

This paper estimates the station level gasoline demand in the Perth market. The timing restriction of the Fuelwatch regulation in this market offers a unique opportunity to collect station-specific price and quantity that matches in timing. The estimated own price elasticities are quite large. Statistically significant intertemporal elasticities are also found, suggesting the possibility of intertemporal substitution. In sum, the elasticity estimates suggest drivers in the Perth market are indeed very sensitive to station level gasoline price differentials and that gasoline is indeed a relatively homogenous product in this market. The elasticity estimates along with the computed Lerner indices in this paper suggest most gasoline sites in the Perth market have little market power. The findings in this paper, however, do not suggest all gasoline sites in the Perth area have very elastic demand – a gasoline site's demand depends critically on the level of local competition.

Gasoline and groceries are increasingly linked in Australia and other countries by fuel discount programs (or shopper docket programs) offered by supermarkets such as Woolworths and Coles. The data used in this paper were collected before the entry of Coles Express into the Perth gasoline market. It would be interesting for future research to investigate whether station level gasoline demand is affected by the supermarkets' gasoline discount programs.

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