Curtin Business School

Competition in a Spatial Retail Petroleum Market

Nick Wills-Johnson

This thesis is presented for the Degree of
Doctor of Philosophy in Economics
of
Curtin University

November 2010

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: ………………………………………….

Date: ………………………...

Abstract

This thesis examines the behaviour of retail petroleum markets, with a case study examining prices in Perth, Australia. The aim of the thesis is two-fold. Firstly, it aims to extend the Edgeworth Cycles literature by showing how a simple, distance-based model of duopolistic competition can give rise to Edgeworth Cycles. Secondly, it makes use of the results of this model to build a model of the structure of the Perth market and to explore competition in that network.

In the empirical component of the thesis, I explore whether network structure influences both the prices charged by each retail petroleum outlet and the shape of price cycles exhibited by each retail petroleum outlet. In addition, having performed a spectral analysis on prices and finding that most retail petroleum outlets do not follow a single cycle, but in fact use cycles of differing lengths, mostly seven and ten-day cycles, I explore whether network structure influences these choices or not. In the empirical analysis, I find evidence that network structure does, in fact, influence both price and the nature of cycles.

Acknowledgements

I would like to thank my supervisor, Professor Harry Bloch (Curtin University) for his support and patience during the many years, numerous stops and starts and multitudinous iterations that have comprised the history of this thesis. I would also like to thank Associate Professor Felix Chan (also at Curtin University) for his assistance in answering my interminable econometric questions, and Aaron Rayner, Ray Gibson and Warren Adams at *FuelWatch* for providing me with the data upon which the econometric work depends. Finally, I would like to thank my wife Joan for her support during the many frustrations and long hours of extra-curricular work it took to bring this thesis to completion.

Table of Contents

Chapter One: Thesis Overview

Competition in retail petroleum markets is a complex, multi-level phenomenon. Refineries have significant economies of scale and high fixed costs, and are influenced by the transportation options open to them. The former means larger refineries often have significantly lower costs than smaller ones and the latter means that refineries will often seek to maximise outputs, offloading product in other markets or through other distribution channels (independent outlets, which often cluster around refineries for this purpose, for example) when demand in their local markets falls. The potential market which can be serviced by a given refinery depend upon the transport opportunities available to it; Scherer (1996) suggests that the cost of shipping a barrel of petroleum a thousand miles in the US ranges from four cents for a 150,000 ton tanker on a 3,000 mile journey to US$5.11 for a 15 ton truck travelling 50 miles. The wholesale market often also has a complex competitive structure, with wholesalers using price discrimination to charge differential prices in markets often only a few miles wide, in order to maximise profits (see Comanor & Riddle, 2003, for an account of this in California). At the retail level, a diversity of brands and ownership types (including supermarkets) again results in a complex competitive field.

In Australia, the main focus of competition is at the retail level. There are at most two refineries per capital city, and these cities are thousands of kilometres apart, so competition between Australian refiners is rare. The Australian refining market is contestable, however, due to the much larger refineries operating throughout Asia which can export to Australia. Price discrimination at the wholesale level is less prevalent than in other markets, such as the US, and does not exist in the case study Perth. Retail competition, however, is just as complex as it is in Europe and North America, with many similar patterns of ownership and control, and indeed many of the same vertically-integrated players. I thus focus on retail competition.

In Perth, the case study for this thesis, a unique regulatory environment called *FuelWatch* exists. Under its auspices, every retailer must set its price for 24 hours (so there are no intra-daily price movements) and inform *FuelWatch* of that price a day prior to it being set. *FuelWatch* then makes that price publicly available, effectively providing perfect price information for consumers. It also creates a census of prices, which makes it useful in economic analysis, and this is why Perth is chosen as the case study for this thesis.

The prices of most retail petroleum outlets in Perth follow a saw-tooth pattern; rising sharply over a day or two, and then declining slowly over the course of a week. Perth is not unique in this pattern of pricing, Sydney, Melbourne, Adelaide and Brisbane exhibit similar patterns, as do a number of cities in Europe and North America. In fact, there is a growing literature studying such retail petroleum markets, and the pricing patterns are referred to as Edgeworth Cycles, after Edgeworth (1925). It is to this literature that the thesis hopes to make a contribution, by positing a networked model of spatial competition which admits such cycles as an equilibrium, and then examining the extent to which network structure influences both price choice, and the pattern of price paths.

The aim of exploring competition in this way is to inform policy. Competition authorities examining mergers often require the merging parties to divest themselves of particular assets to preserve competition. In perhaps the most pervasive industry reorganisation it has attempted, the Australian Competition and Consumer Commission (ACCC) required Caltex and Ampol to divest themselves of a number of import terminals, retail outlets and other assets before it would allow the merger to proceed (see Walker & Woodward, 1996). It did not specify which retail outlets needed to be divested but, this thesis suggests that it might be possible to do so by exploring a methodology which characterises competition at a fine-grained level.

Chapter Two of the thesis explores the retail petroleum market in Australia, incorporating an analysis of its historical development, its major players and the regulatory structure within which it operates. This includes an in-depth analysis of the Perth market.

Chapter Three reviews the rather large literature which has informed this thesis. This includes not only the Edgeworth cycles literature and the literature on retail petroleum markets, but also parts of the literature on spatial competition and literature from social networks and geography which underpins the technical tools used in this thesis to explore network structure.

Chapter Four develops an analytical model which shows how Edgeworth Cycles can arise when two spatially separated duopolists interact. The relationship between the price minima of each station in this model forms the basis in the later empirical chapters for concluding whether or not two retail petroleum outlets are competing, and thus develops a network which summarises the competitive structure of the market.

Chapter Five provides an overview of the data used in the empirical analysis of the following chapter, and provides an overview of how the network and sub-networks are constructed. It also gives an account of cycles in the Perth retail petroleum market, using spectral analysis to shed light on the issue, and to show how, in fact, most outlets do not follow cycles of a set length.

Chapter Six empirically examines the influence of network structure on prices, utilising Hansen's (1996, 1999, 2000) Threshold Regression Model to examine the influence of network structure on prices, and simple linear regression to explore the influence of network structure on pricing patterns.

Chapter Seven concludes with a discussion of the ramifications of the model for both economic analysis and for policymakers.

Chapter Two: The Australian Retail Petroleum Industry

This chapter provides an overview of the Australian petroleum industry. The first section provides a brief history of the development of the industry, and its current characteristics. This includes a discussion on then upstream refining and distribution sectors, and on the regulatory environment. Since the focus of the case study is the Perth market, the next section focuses on characteristics of the Perth market which differentiate it from other cities in Australia. This includes a discussion on the regulatory environment in Perth and, in particular, the *FuelWatch* scheme.

History and Characteristics

The Australian retail petroleum market has a history which closely matches, albeit at a lag, the development of the industry in the US and Europe.[1] The first refined petroleum products for use in automobiles began arriving in Australian in the latter years of the 19th Century. The first unbranded pumps for dispensing petroleum arrived in 1916, and the first branded pumps, carrying the Neptune brand, in 1924. This marked the first investment in retailing by one of the then Majors of the industry.

Initially, the pumps of several different brands were located in the same garage, but this proved inefficient and, in 1951, Shell and Mobil introduced solus-trading. Other brands followed, and the 1950s and 1960s witnessed a fight for market share which saw the development of considerable over-capacity in the Australian marketplace; by 1970, there were more than 20,000 retail petroleum outlets in Australia, a number which declined by roughly 3.5 percent per annum to reach roughly 6,500 today (ACCC, 2007).

[1] See Wilkinson (1983) for an account of the history of the Australian industry and Dixon (1964) for an account of the first 50 years of development in the US. The parallels between the two are clear.

The most important players in the retail petroleum market in Australia, as elsewhere in the world, are the Majors; vertically-integrated firms with upstream refining and often crude production operations in Australia. Today, the Majors are Shell, BP, Caltex and Mobil,[2] but in the past Total, Esso and Ampol have also been active in Australia. Complementing the Majors are the independents; usually much smaller firms with no upstream operations, and often focussing on price competition. There have been many independent brands through Australia's history, beginning with Golden Fleece in Melbourne in the 1920s. In the 1980s and 1990s, Solo, Burmah and Liberty were the major players, but the former two were taken over by Ampol (in 1990) and BP (in 2000) respectively, whilst the latter has become an independent fuel wholesaler.[3] Today, Gull (particularly in Western Australia), Matilda, United, Neumann Petroleum, 7-Eleven, Peak and Wesco are important independent players. Additionally, a number of single-outlet independents remain, particularly in Sydney, but these are slowly disappearing as they become unviable (ACCC, 2007).

The major supermarket chains, Coles and Woolworths, have developed an increasing presence in petroleum retailing over the past decade, mirroring trends overseas. Woolworths entered the Australian retail petroleum market in 1996 on its own and expanded to 290 sites, before entering into a joint venture with Caltex in 2003 and expanding to 500 sites. Coles entered the market in March 2004 through a joint venture with Shell and now operates around 600 sites Australia-wide. Between the two, the

[2] After its merger with Ampol in 1995, Caltex kept the Ampol branding on some outlets. These are slowly disappearing, but some still remain.
[3] Many of the outlets it supplies carry its branding, but they are independently-owned and operated.

supermarkets have taken a share of roughly 50 percent of the market by volume (ACCC, 2007). Both operate shopper-docket schemes, providing discounts on fuel consequent upon a certain amount being spent in their supermarkets. Other supermarket chains have followed, and the ACCC has records of some 600 schemes operating at around 1000 outlets in addition to those operated by Coles and Woolworths (ACCC, 2007).

In addition to the different brands, there are also a number of different ownership types:[4]

- Branded Independents, who own the service station, but who are contracted to sell a certain brand of petrol and may be supplied either directly by the refinery or by distributors of that brand of petrol. These contracts are typically short term. All of the Majors and some of the independents make use of this form of contract.
- Franchisees, with greater ties to the brand owner whose brand they sell and which has generally contributed substantially to the capital costs of the service station. Such contracts are typically for longer periods of time. They may cover a single site or, as is becoming more common, be multi-site franchises. BP, Mobil and Shell all use multi-site franchises, but Caltex does not, as it was prohibited from doing so under the terms of its 1995 merger with Ampol.
- Distributor retailers, who purchase petroleum products in bulk from a refinery and sell some (or all) of it in service stations they own, either under their own brand, or under the brand of one of the Majors. These have largely disappeared from cities, but are still prevalent in rural and regional areas.

---

[4] These often reflect historical solutions to the principal-agent problems associated with fuel-brand owners endeavouring to effectively monitor their retail petroleum outlets. Shepherd (1993) examines similar issues in the US context in some detail.

- Outlets owned and operated by the brand owners. All of the supermarket-branded sites use this form of ownership, and it is widespread amongst independents too. However, the Majors make scant use of it, due in part to the restrictions of the *Sites Act* discussed below.

Regardless of the type of ownership used, the brand owner is able to influence prices charged through the wholesale price. In particular, the Majors operate price support schemes (see Wang, 2005a, for an illustration). Under these schemes, the wholesaler provides rebates or discounts to a retailer who sets price below a certain level. The schemes are used to support outlets during price wars, so that the brand-owner does not lose market share. The ACCC has yet to prohibit price supports as resale price maintenance, but has examined them extensively (see ACCC, 1996 or 2007 for details).

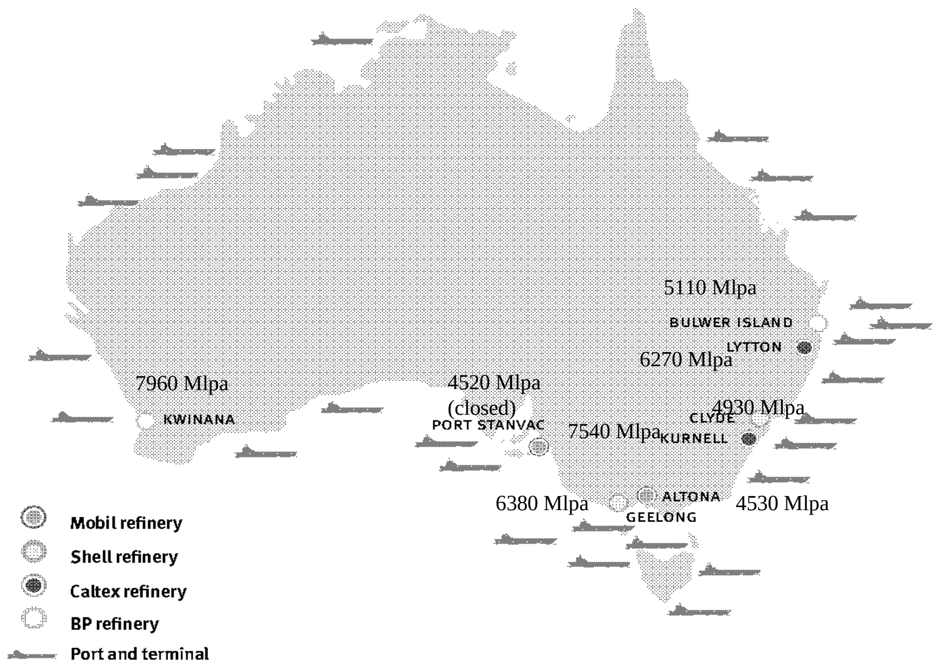
The result of this diversity of players, ownership structures and pricing schemes is a complex and dynamic retail market. Before turning to the prices which result from this interaction, however, it is worthwhile pausing for a moment and examining three other factors which influence retail markets, the upstream activities of refiners and importers, the activities of distributors and wholesalers, and regulatory regimes imposed by government.

Refining and Imports

Australia's first refineries were established in the 1920s, and for the next 40 years (until 1966) new refineries were added to each state as demand grew, and crude oil was discovered in Australia in the 1960s. Today, each capital city (with the exceptions of

Hobart, Darwin and Canberra) has at least one refinery, and Brisbane, Melbourne and Sydney have two.[5] These are shown in Figure 2.1.

Figure 2.1: Australian Petroleum Refineries



Source: Australian Institute of Petroleum (2007) p4

In the past, Australian refineries were required by law to process Australian crude for Australian markets, but these laws were rescinded in the 1980s as Australia's crude output began to slow. Now, overseas crude has become far more dominant, and this has required considerable investment, as it is commonly far heavier and contains more sulphur compared to Australia's domestic crude.

[5] Adelaide's refinery has been closed.

No Major has refining capacity in more than two states, but all have retail operations across Australia. Until 2002, the Majors operated refinery exchange agreements which allowed BP (say) to swap petroleum refined in Perth and sold by Shell-branded retail outlets in Perth, for petroleum refined by Shell in Sydney and sold by BP through its retail outlets there. These agreements allowed the Majors to avoid the cross-border transportation costs, and are common around the world. They rely, however, upon fuel standards being similar or at least similar in the cost of processing and a change in WA emissions laws in 2002 meant that this was no longer the case. BP therefore abandoned them in 2002. They have been replaced by long-term buy-sell contracts, which operate in a roughly similar fashion, but with the value of the fuel taken into account. The ramifications of these buy-sell contracts, as well as competition concerns raised by them, are discussed in detail in ACCC (2007).

Although competition between refineries in Australia is rare, this does not mean they face no competition at all. Throughout Asia, though most particularly in Singapore, there are a number of refineries much larger than those in Australia. Moreover, independently-owned importing terminals are located in Perth, Sydney, Melbourne and Brisbane. Whilst actual importing of fuel into these terminals is rare, they render the refinery market contestable, if not competitive, and act to cap the refinery prices.

Wholesaling and Distribution

The wholesale and distribution markets in Australia are generally much less complex than in more densely populated markets such as the US or Europe. Most population centres are on the coast, and are served by coastal ships operating in “milk runs” from the nearest refinery to the various coastal terminals in the relevant state (see Figure 2.1). Inland towns are generally smaller, and are served by rail or, increasingly, by large trucks operating along similar milk-runs.

In all capital city markets, terminal gate prices (tgps) are used at the wholesale level, allowing anyone with the requisite trucking equipment to purchase a tanker-load of fuel at the published price. The tgp schemes are legislated in Victoria and WA, but voluntary elsewhere, and they do not preclude discounts. An earlier, failed attempt at tgps is reviewed by the Industry Commission (1994).

Regulation

In the past, price regulation was pervasive in the petroleum industry, with the last retail price controls (in South Australia) disappearing in 1973, and wholesale price caps only in 1998 (see ACCC, 1996). However, regulation of other kinds still pervades the industry, influencing competition.

One important influence comes from environmental regulation. During the early part of this century, Australian emissions standards were stricter than those elsewhere in the world, and within Australia, WA, SA and Queensland had stricter standards than the rest of the country and different standards from each other. The result was isolation of each market from others, both here and overseas. If, for example, a much larger, highly efficient Singapore refinery wished to produce fuel for the WA market, it would have to produce a relatively small batch, given the size of the market, and might not thus be able to reach the same economies of scale as are possible if it is producing fuel at its capacity level. This limits, to some extent, the ability of Singaporean (and other) refineries to render the Australian refining market contestable. The SSCE (2006), which provides further details on Australian fuel standards and their potential to island markets within Australia, notes that Australian fuel standards had largely been harmonised by 2006, and that international standards were also approaching the Australian norm. However, during the period of analysis covered in this case study, islanding due to environmental restrictions may have been affecting fuel markets in Australia.

Perhaps the two most important direct controls over the industry in recent years have been the *Petroleum Retail Marketing Sites Act 1980* (the *Sites Act*) and the *Petroleum Retail Marketing Franchising Act 1980* (the *Franchising Act*). Both came out of the recommendations of the Royal Commission on Petroleum (1976), which heard complaints of price discrimination by the Majors against lessees in favour of branded resellers and of unfair practices by the Majors. Each Act was intended to curb this behaviour; the *Franchising Act* was intended to set basic fair conditions for retail petroleum franchisees, and the *Sites Act* limited the numbers of outlets the Majors could own directly in order to prevent them from substituting ownership for franchising. Both Acts were repealed in 2007 and replaced by a mandatory industry code, the *Oilcode*, under Section 51D of the *Trade Practices Act*.[6] Industry and government had been attempting to do this since 1989, but could not agree on an appropriate framework. The *Oilcode*, administered by the ACCC, is described in detail in ACCC (2007).

[6] In part due to the growing power of the supermarkets, which are not bound by the *Sites Act*.

The *Sites Act* restricted the Majors (collectively) to direct ownership of no more than five percent of retail outlets; roughly half their share prior to the passage of the Act. However, in more recent years, the Majors have not taken up even this limited quota. In 2001, they had direct ownership over only 300 sites, or three-quarters of their quota, and by 2006, this had fallen to only 189 sites, or half their quota for that year.[7]

Between 2001 and 2006, BP maintained roughly the same number of directly-controlled sites, but the other Majors reduced their holdings. Caltex and Shell did so as part of their joint ventures with Woolworths and Coles (respectively). Mobil moved a single multi-site franchise (held by Strasburger Enterprises) that now covers all sites formerly owned by Mobil around the country. This move to multi-site franchising, practised by BP and Shell as well (though not Caltex) was perhaps driven to some extent by the requirements of the *Sites Act,* although the fact that it emerged almost 20 years after the Sites Act suggests that other factors are also at play, such as the inability of the Majors to price discriminate amongst their franchisees due to the requirements of the *Franchising Act*.

The *Franchising Act* was introduced to redress power imbalances between the Majors and their franchisees, and the harsh conduct sometimes exhibited by the Majors,[8] by providing certain minimum terms for franchising agreements, including restrictions upon price discrimination between like-branded retail outlets by the Major which supplied them. The Industry Commission (1994) suggests that it has not been particularly

[7] Data supplied in a personal communication from the Department of Industry, Science and Tourism, which collected such data prior to the repeal of the *Sites Act*.

[8] Shepard (1993) provides details on the US Federal *Petroleum Marketing Practices Act 1978* which provides similar kinds of protections to dealers in the US.

effective in achieving its aims, and that, even then, it had largely been superseded by the advent of multi-site franchises and a franchising Code of Practice under the auspices of the *Trade Practices* Act.

The final piece of regulation which is of crucial importance in WA and thus to the case study of this thesis is the *FuelWatch* scheme. *FuelWatch* operates under the auspices of the *Petroleum Products Pricing Regulations 2000* which sit under the *Petroleum Products Pricing Act 1983*, which gives the Government broad powers to regulate retail petroleum prices and obtain information from petroleum retailers. It came about as one of the recommendations of the Select Committee on Pricing of Petroleum Products (SCPPPWA, 2000), reacting to a perception of motorists' anger over frequent intra-daily price fluctuations in WA.[9]

Under the *FuelWatch* scheme, each retail petroleum outlet in WA must report the price it will charge each day by 2pm of the previous day. The price is then made public at 6pm (when it is available on the *FuelWatch* website), and the price change itself occurs at 6am the following day. That price is then fixed for 24 hours. *FuelWatch* has operated since January 2001. At the wholesale level, regulated wholesale price caps were introduced in April 2001, but proved unworkable. They were replaced in December 2001 by tgp arrangements whereby wholesalers must publish their tgp, but its level is not subject to regulation. The practical upshot of these changes is that, from the beginning of 2003, one

[9] The Committee also made a number of other recommendations, such as retail price caps in regional areas, which were not implemented by government.

has both a daily retail price for every outlet in Perth, and also a proxy for their marginal cost; the tgp. It is for this reason that I use Perth as a case study in this thesis.

The *FuelWatch* scheme has been widely studied by government bodies around Australia since its inception (ACCC, 2001, 2002, 2007 and SSCE, 2006). In its first studies, the ACCC (2001, 2002) found that *FuelWatch* had increased prices in WA relative to what they would have been in its absence and in comparison with prices on the East Coast, but it had reversed its position by its third study (ACCC, 2007). This lead to the new Labor government of Kevin Rudd considering a nation-wide rollout of *FuelWatch*. However, the econometric modelling upon which the ACCC (2007) had based its conclusions came in for considerable criticism (see, for example, Harding, 2008a,b, or Davidson, 2008 for a review) and the Federal Government has since backed away from its earlier plans, instead creating a Petrol Monitoring Section in the ACCC.

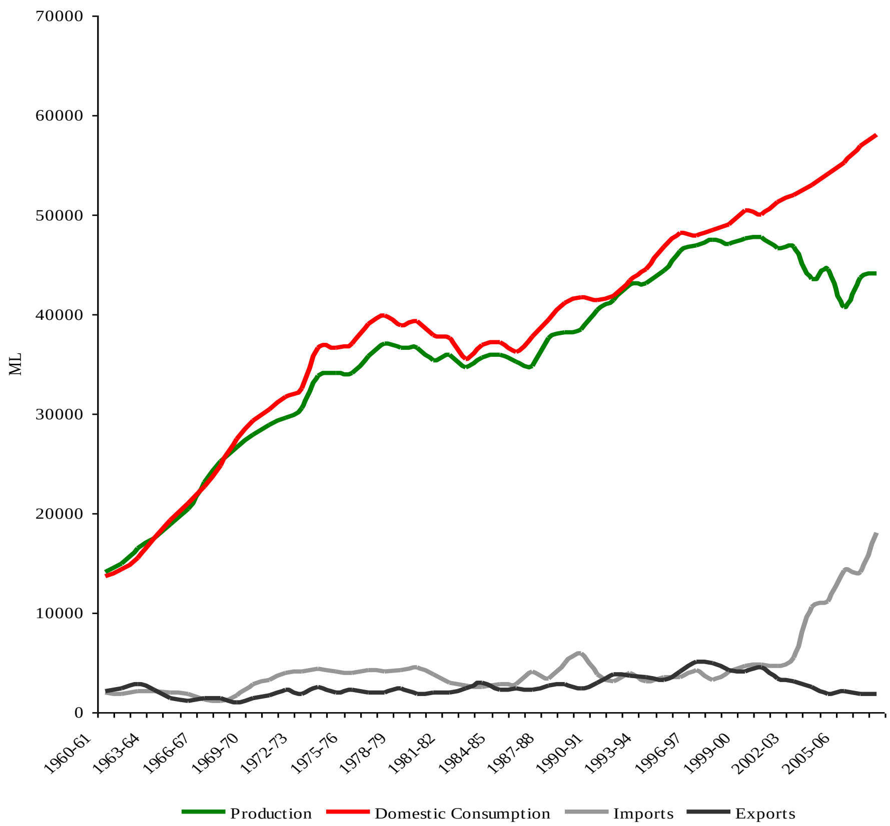
The Retail Petroleum Market at Present

In this section, I provide a brief overview of the market as it exists at present, focusing on demand, supply, prices and profitability. I close with a more in-depth overview of the Perth market, which is supplemented by a much more comprehensive overview for the period under analysis in Chapter Five.

Demand and Supply

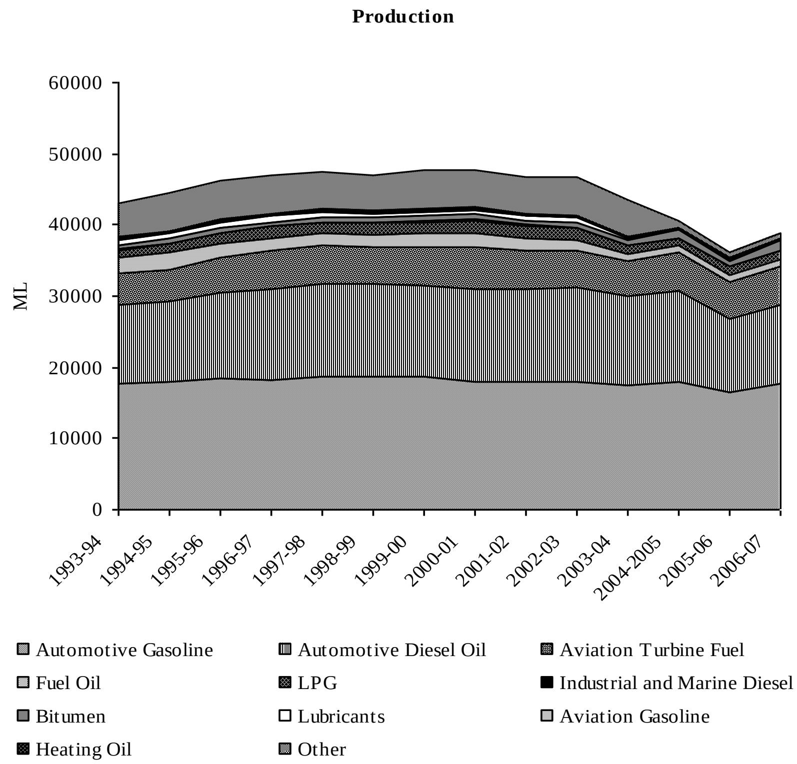
Figures 2.2 and 2.3 provide an overview of production and consumption of refined petroleum products in Australia. Figure 2.2 provides overall results including imports, whilst Figure 2.3 breaks domestic results down into different fuel types. Note that imports have been relatively unimportant for most of the past 40 years, but that they have risen sharply in the last few years. This appears to be due to diesel fuel imports, as diesel consumption has risen, without a concomitant increase in production. Singapore appears to have been the main beneficiary of this trend; its exports of diesel to Australia have risen from 2600 Ml in 2000/01 to 10,000 Ml in 2007/08 (Australian Bureau of Agricultural and Resource Economics, various years a).

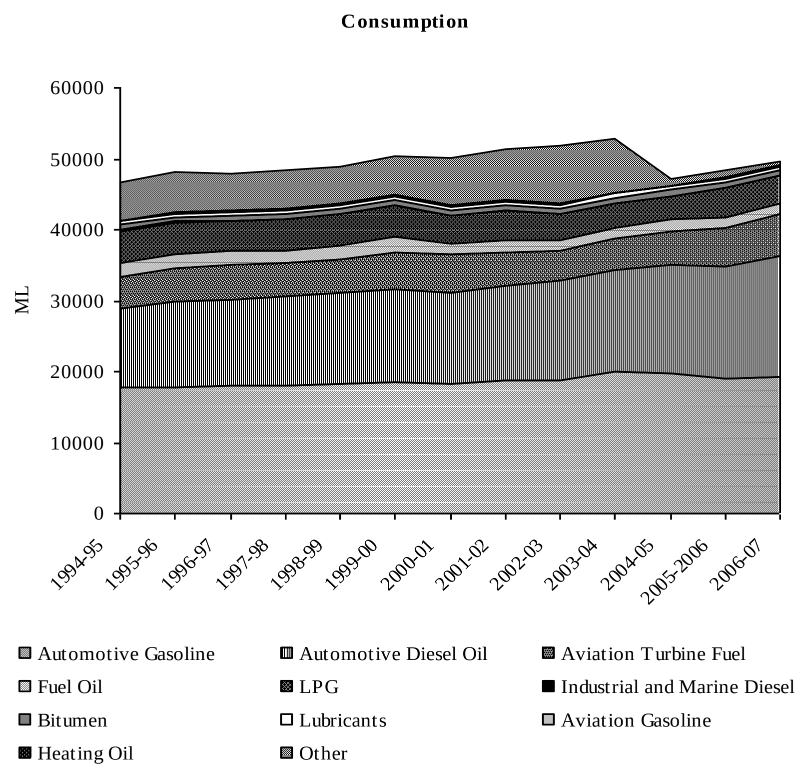
Figure 2.2: Australian Refined Petroleum Production, Consumption, Import and Export - 1960-2008



Source: ABARE (various years a) Table 309.

Figure 2.3: Refined Petroleum Production and Consumption – 1993 to 2007

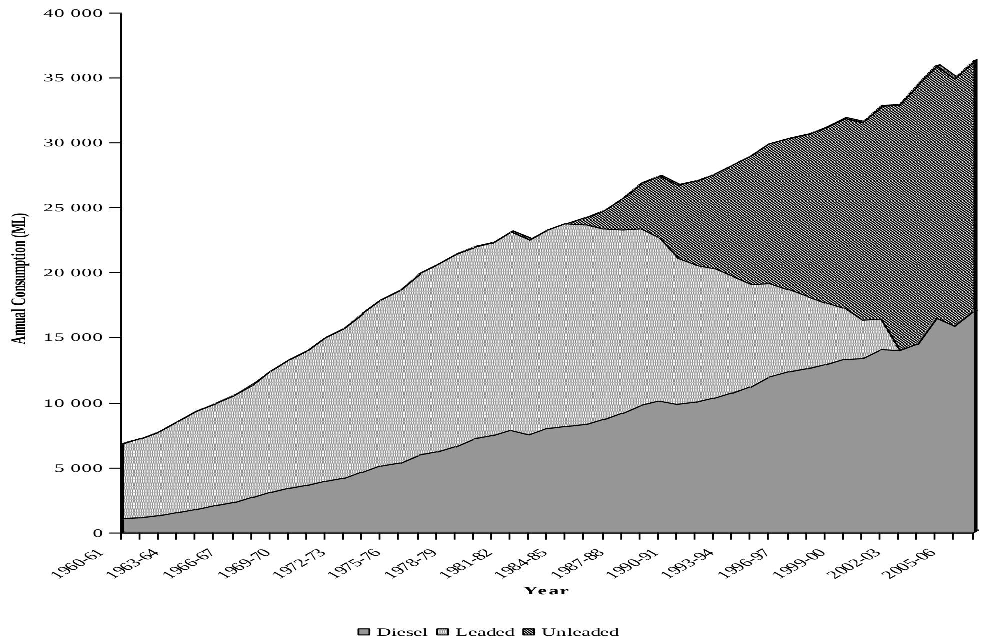




Source: ABARE (various years a) Tables 311 &312

For motorists, petroleum and diesel are the most important fuels. Figure 2.4 shows the rise in consumption of each, highlighting the switch from leaded to unleaded fuels from the mid 1980s. The rise in diesel fuel consumption, by contrast, appears to be linked to the growth of the road-freight industry over the same timeframe.[10]

Figure 2.4: Leaded, Unleaded and Diesel Fuel Sales – 1961 to 2007



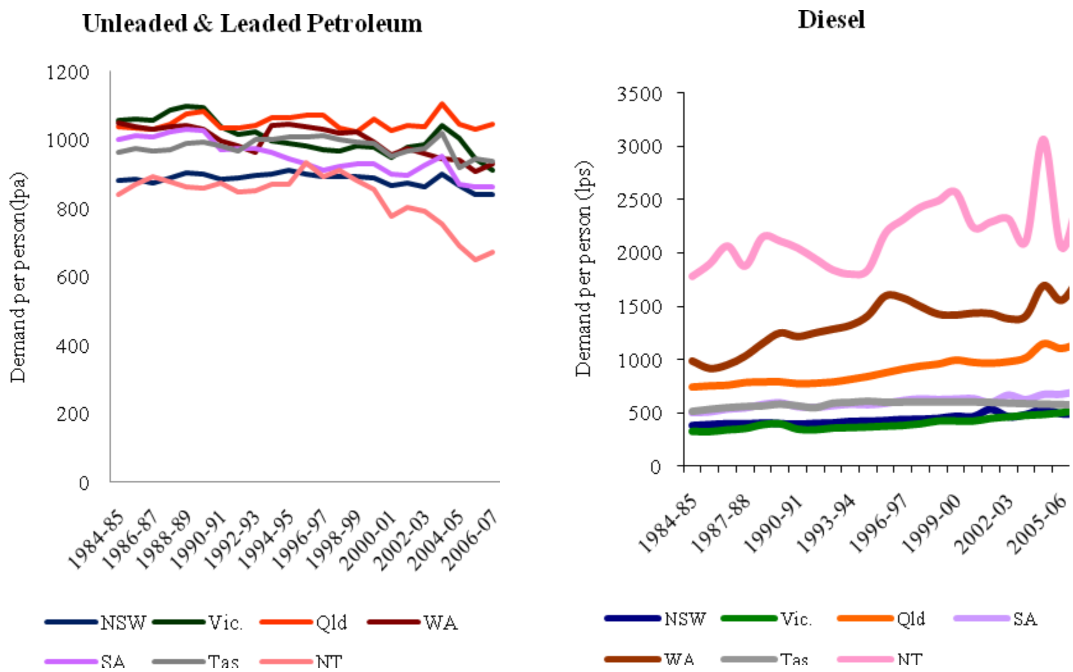
Source: ABARE (various years b) Table K

Figure 2.5 shows the per-capita demand for unleaded and leaded petroleum and diesel on a state-by-state basis since 1984. In general, fuel consumption is steady, until the end of the period, when high fuel prices appear to have attenuated demand somewhat. Diesel sales are more constant, which is to be expected if its main use is in road-freight transport. This is further exemplified by the fact that the states and territories with the

[10] The correlation between diesel fuel sales and road freight net-tonne km (Bureau of Transport and Regional Economics, 2006) from 1960 to 2003 is roughly 97 percent.

largest land area and sparsest populations (WA and the Northern Territory) have the highest per-capita diesel usage.

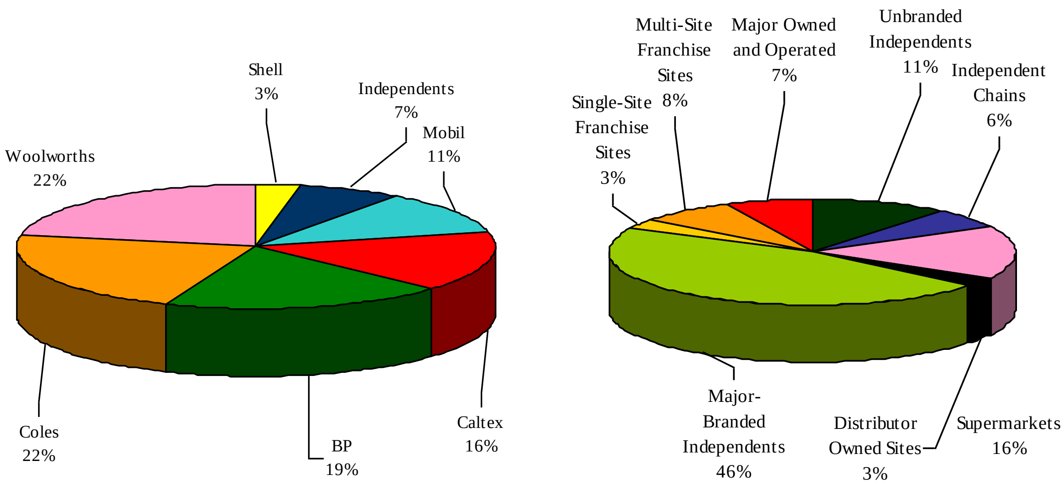
Figure 2.5: Per Capita Demand for Petroleum and Diesel by State – 1984-2007



Source: ABARE (various years b) Tables K2 to K8

There is very little consistent data on market share in Australia, which tends to get surveyed sporadically with each government investigation of the industry, rather than recorded regularly by any statistical agency. Figure 2.6, however, provides a recent overview. The left hand side of Figure 2.6 shows the market share by branding, based upon the volume of fuel sold. The right hand side of Figure 2.6 shows the numbers of outlets of different type.

Figure 2.6: Market Shares



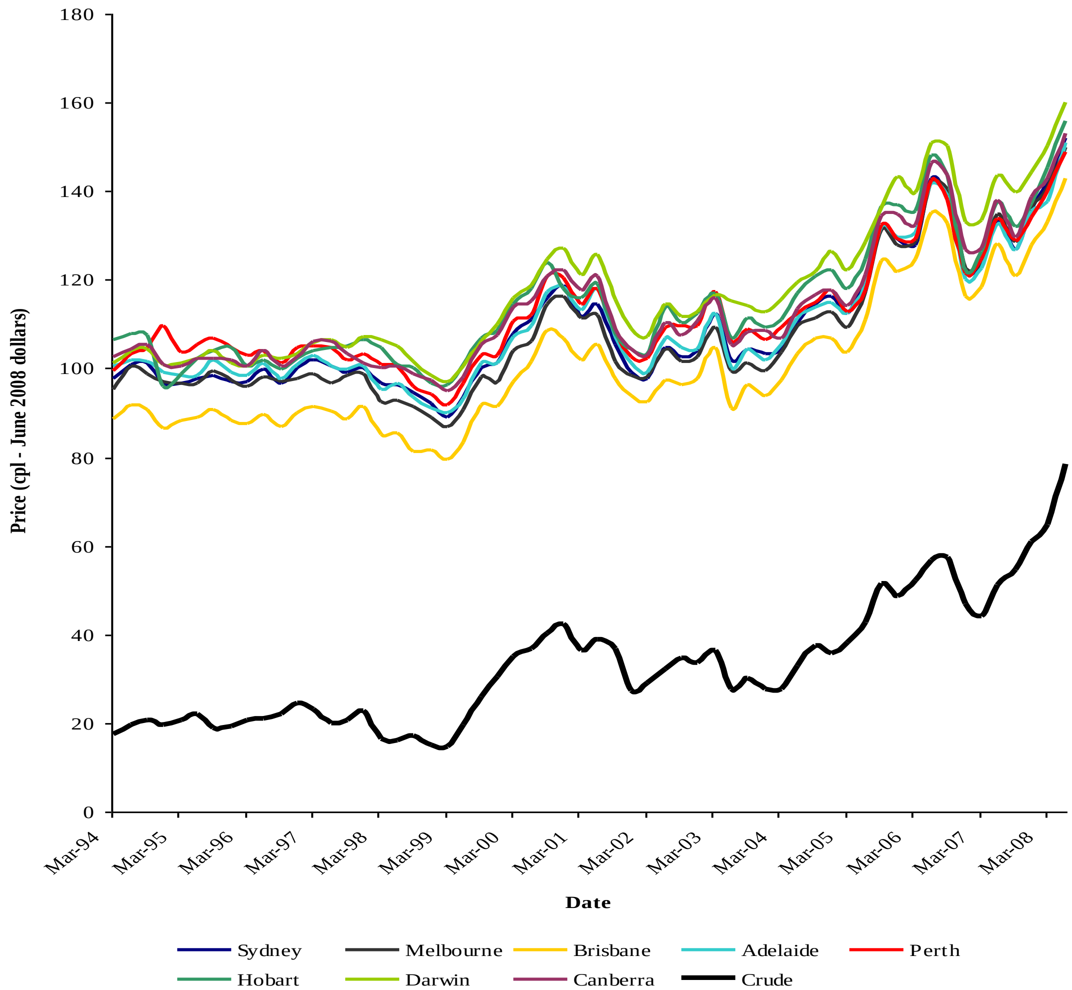
Source: ACCC (2007) p76 *Source: Macfarlane (2006) p6*

The relatively small share of Shell is due primarily to the fact that many of its outlets have become Coles Express outlets. Caltex has also had a number of its sites rebranded, but not as many, and it had more sites than Shell to begin with.

Pricing

I now turn to pricing. Figure 2.7 provides an overview of quarterly prices of unleaded petrol in each of Australia’s capital cities. To remove the effect of inflation, prices are expressed in 2008 dollars. The thick black line across the bottom is the price of the World Trade-Weighted Index for crude oil, converted from US$ to A$, adjusted from dollars per barrel to cpl and expressed in 2008 A$. Australian retail petroleum prices track the world price of crude; the correlation coefficient between each capital city price series and the crude price series is more than 95 percent in each case.

Figure 2.7: Quarterly Petrol Prices (1994-2008)

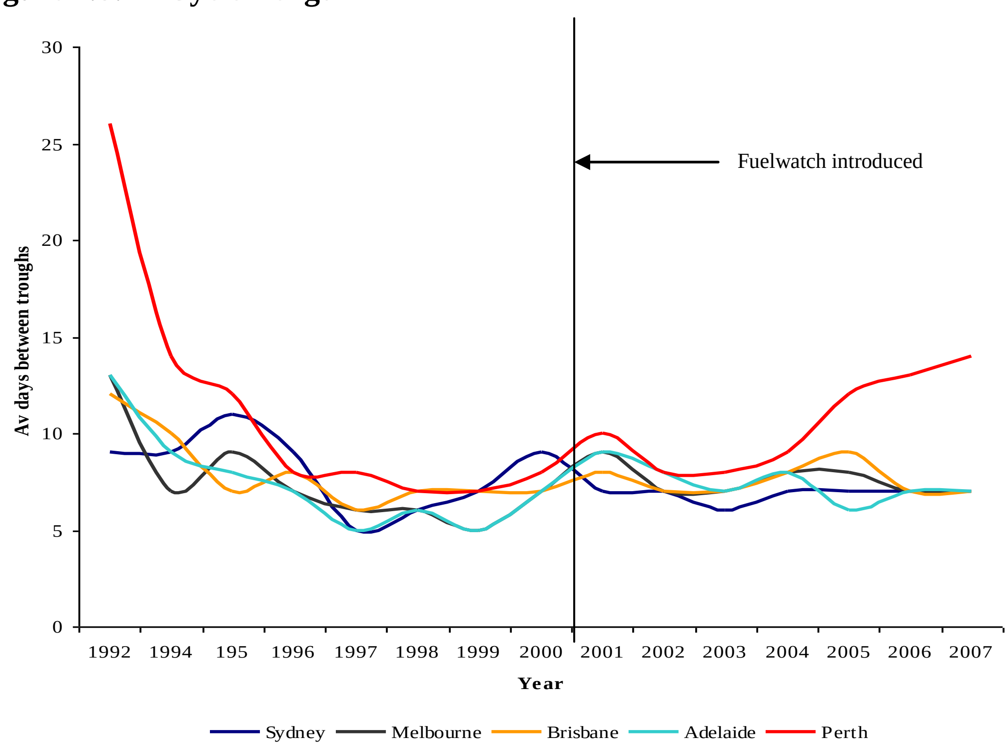


Source: Australian Bureau of Statistics various years) for retail and ABARE (various years a)Table 319 for crude prices.

Although quarterly average prices might be closely linked to crude prices, daily prices are not. In fact, they tend to cycle over the course of roughly a week, shooting upwards in the first day or so, before falling more gently for the remainder of the week. Cycles exist in Perth, Adelaide, Sydney, Melbourne and Brisbane. Moreover, they have existed in Australia for some time. Since these cycles can result in prices shifting upwards by ten percent in a single day, they have been a source of great frustration for motorists, and this has driven an interest in them by policymakers. Perhaps the most comprehensive recent review of price cycles in Australia has come from the ACCC (2007), from which much of the data in this section has been drawn.

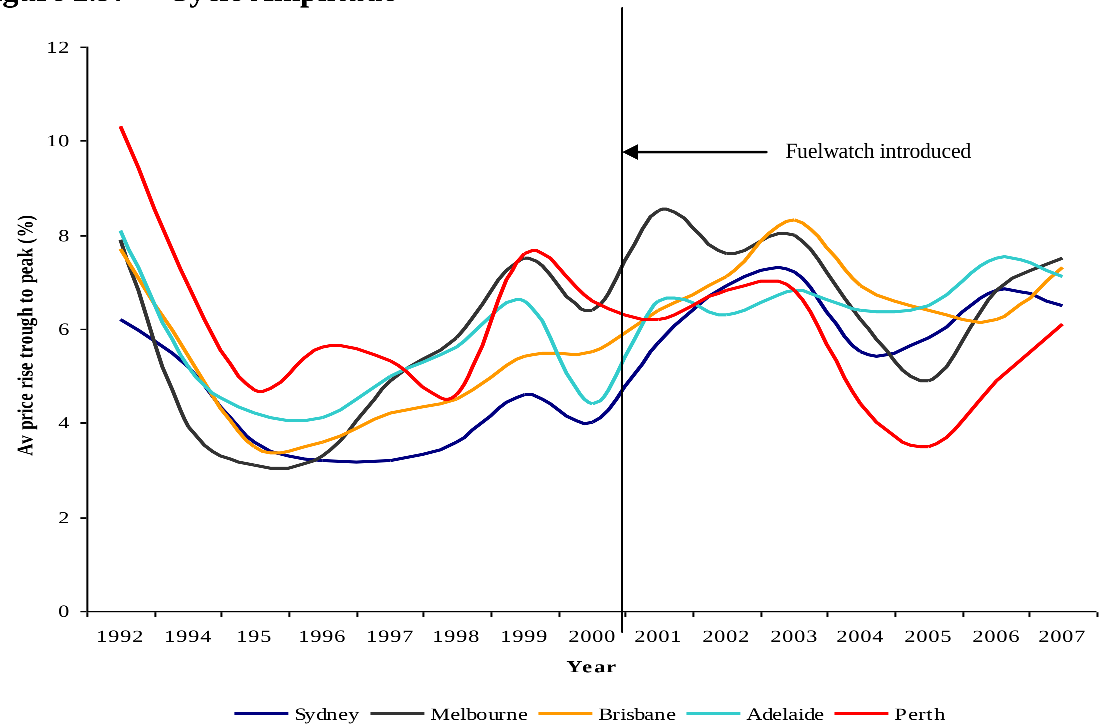
Figures 2.8 and 2.9 show the length and amplitude of price cycles in each of the five cities discussed above from 1993 to the present day. Each figure also shows the advent of *FuelWatch* in WA. After the advent of *FuelWatch*, price cycles lengthened (in WA), and their amplitude decreased. However, the latter is true in each of the five cities, and both occurred at something of a lag from the introduction of the scheme. This is part of the controversy associated with the ACCC's analysis discussed previously.

Figure 2.8: Cycle Length



Source: ACCC (2007) p159

Figure 2.9: Cycle Amplitude



Source: ACCC (2007) p159

A more detailed snapshot for the latter half of 2007 was provided by the ACCC (2007), and is outlined in Table 2.1 below. It shows that cycles exhibit quite a degree of variation in their amplitude, though not in their duration.

Table 2.1: Price Cycles, January to June 2007

	Sydney	Melbourne	Brisbane	Adelaide	Perth
Number of Cycles	24	24	24	24	11
Amplitude (cpl)					
Smallest	1.6	3.8	4.6	1.4	3.1
Largest	13.4	14	13	15.3	10.2
Average	8.6	9.5	8.4	8.8	7.7
Duration (days)					
Average Trough to Peak	2.2	2	1.9	2.1	4.3
Average Peak to trough	5.1	5.3	5.4	5.2	10.9
Average price cycle	7	7	7	7	13
Most common day for peaks	Thursday	Thursday	Thursday	Thursday	Thursday
Most common day for troughs	Tuesday	Tuesday	Tuesday	Tuesday	Sunday

Source: ACCC(2007) p157

The ACCC (2001,2007) has also provided some information on the distribution of days upon which cycles begin. This is reproduced in Table 2.2.

Table 2.2: Trough days

City	**1998**		**2001**		**2007**
	Day	*% of troughs*	*Day*	*% of troughs*	*Day*
Sydney	Sunday	50	Monday	60	Tuesday
Melbourne	Tuesday	41	Wed/Thurs	37 (each)	Tuesday
Brisbane	Monday	50	Monday	43	Tuesday
Adelaide	Monday	63	Wednesday	47	Tuesday
Perth	Tuesday	42	Tues/Sun	33 (each)	Sunday

Source: 1998 and 2001 data; ACCC (2001p19&20), 2007 data; ACCC (2007, Appendix P)

In its earlier publication, the ACCC (2001) provides details on the proportion of cycles which begin one each day, and rarely does a single day exceed more than half of the total cycles. By the same token, the distribution of starting days is not random; some days are more frequent than others. This is taken up in Chapter Five.

A key question is why such price cycles occur. It does not appear to be due to information advantages enjoyed by the Majors. In all states, the Majors subscribe to an information service provided by Informed Sources, which gives them high-frequency, real-time data on some 3,500 retail petroleum outlets around Australia. This gives them a considerable informational advantage. However, cycles exist in WA, where they enjoy no such informational advantage, so this cannot be the sole reason. Moreover, the downward phases of cycles are often initiated by independents, who do not have access to Informed Sources data. Market size also does not appear to be crucial either, as cycles exist in almost all of the capital cities, regardless of size differences.

As part of its study, the ACCC (2007, pp170-4) asked market participants their views about why cycles occur. Each of the Majors expressed similar views, suggesting that cycles are due to competition. BP suggests that prices reduce to gain market share, and then increase when there are no further benefits to be had from increasing volume. It suggests that in the past, independents drove prices downwards, but that now all competitors do so. Caltex suggests they are due to two different groups of competitors in the marketplace; the discounters and the non-discounters; the former leading prices down and the latter following until price reductions cannot be sustained. Shell suggests that high fixed costs drive a need to maximise throughput, leading to cycles. It also suggests that cycles may persist even now that they are not driven by independents as much, due to some form of entrenched behaviour. Woolworths suggests that independents drive prices downwards because they do not have the brand recognition of the Majors, but that the Majors follow them downwards, until margins are no longer profitable for them.

One independent suggested they had tried to post and hold a given price, but that this did not work, as others simply matched prices and then pushed them lower. Another said that if it did not follow the Majors upwards, its prices were simply matched and it received no benefits from lower prices.

A number of commentators give examples where independent new entry has caused previously stable prices to start cycling, and one independent operator suggests that cycles in Victoria were triggered by the entry of Solo into the market 15 years ago and have persisted even though it has now left. Some independents suggest that price supports drive cycles, because Majors withdraw them, driving prices back upwards again, and Coles suggests that local refineries with excess refined fuel to sell can also initiate cycles by discounting such fuel.

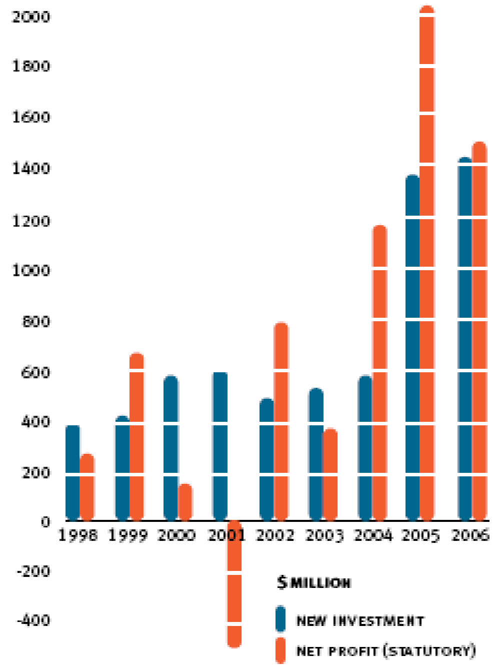
With such a diversity of views, it is difficult to pin down a causal factor, and indeed the ACCC (2007) fails to do so, noting that they are an enigma. In the academic literature, Maskin and Tirole (1988) introduce the notion of Edgeworth Cycles; price cycles are the equilibrium which markets with certain characteristics will obtain, and they are no more enigmatic than any other kind of equilibrium. This thesis (Chapter Four) introduces a model of spatial competition which admits Edgeworth cycles as an equilibrium, suggesting that small amounts of localised market power may facilitate their creation.

Profitability

There is very little reliable information on the profitability of an individual retail petroleum outlet; even gross margins based on the difference between tgps and retail prices provide only limited information, as wholesale prices are often discounted However, the Australian Institute of Petroleum does collect some data on profitability for its members (the Majors) and their profitability. This is summarised briefly below, from the AIP's most recent version of its *Downstream Petroleum Industry (2007)*. Note that the figures are for refining and retailing; no separate figures are available publically.

The industry has substantial assets, valued at $16.6 billion in 2007, an increase of roughly six billion dollars (in nominal terms) from a decade previously. It's annual investment, and profits, tend to fluctuate quite substantially, as Figure 2.10 shows.

Figure 2.10: Australian Petroleum Industry, Investment and Profits ($ mil)



Source: AIP(2007) p11

With profits fluctuating, much of this investment is funded by debt. In 2006, total borrowings fell to $5.65 billion, down from almost $7 billion the previous year, but up from the ten year average of $4.9 billion.

In terms of its profitability, the industry does less well, with average EBIT being only slightly above the bond rate over most of the past decade (AIP, 2007 p12). Profitability is largely driven by overseas capacity and crude prices. When overseas capacity is loose (as in the late 1990s), the contestability of the Australian market means that domestic refiners are wary of raising margins for fear that overseas refiners will export refined product to Australia. When it is tight, margins increase, aided by rising crude prices, which increase the value of crude stocks held by the Majors.

The Perth Market

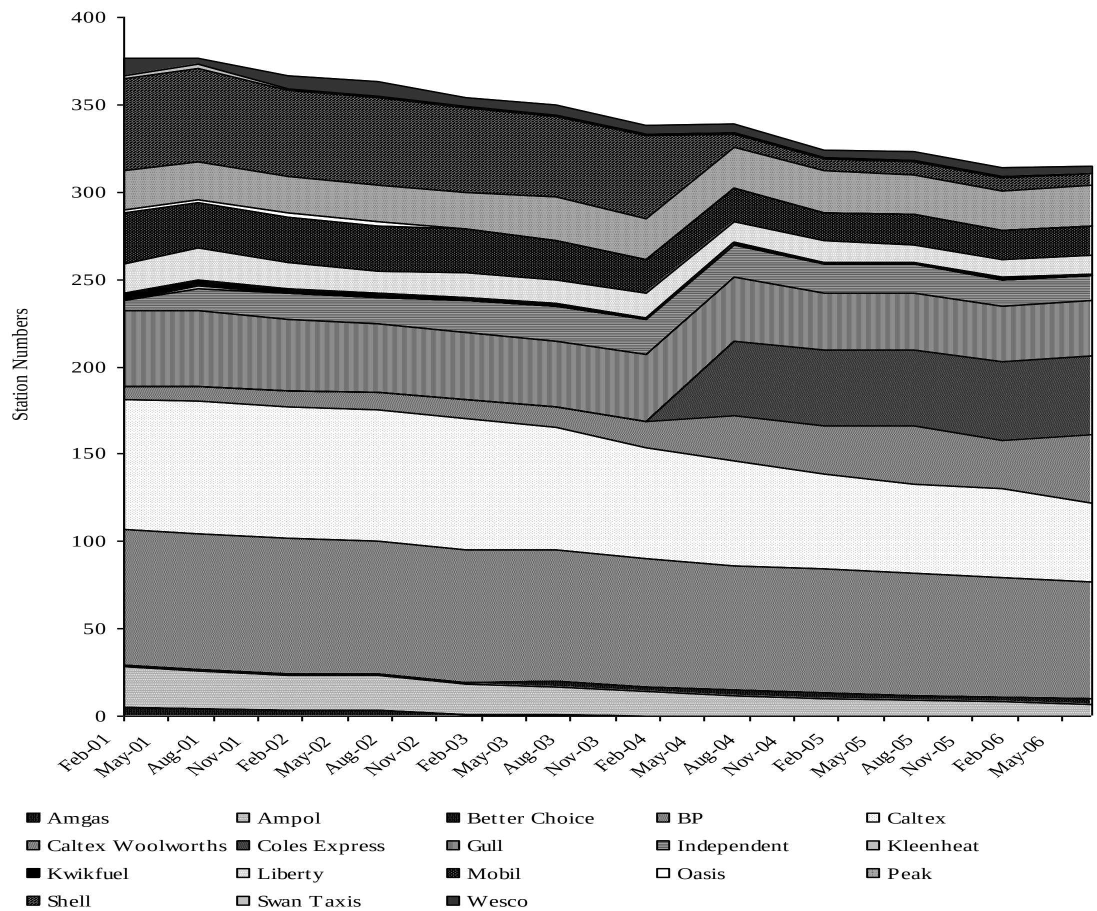
I turn finally to the Perth market, which is also summarised in more detail for the period of the case study in Chapter Five. Perth is the most isolated capital city in the world; it is too far to receive competitive supply from elsewhere in Australia and is thus supplied almost exclusively by the BP refinery in Kwinana[11]. It is thus unaffected, largely, by refinery competition from other markets. At the wholesale level, Perth has six wholesale terminals, all of which are supplied by the BP refinery in Kwinana, most of them by pipeline. Four of them (owned by Caltex, BP, Shell and Mobil) are located in the same place; North Fremantle. BP has an additional terminal in Kewdale, an industrial area, and Gull has a terminal at Kwinana which can take fuel imports. There is, however, very little variation between tgps, with the correlation between each pair of terminals exceeding 99 percent during the period under study (see Table 5.12).

Competition is focussed at the retail level. There are, at present, roughly 350 retail petroleum outlets in Perth. Each of the Majors have a presence, as do Woolworths and Coles, which each operate their own shopper discount scheme. There are also three relatively large chains of independents, Gull, Peak and Liberty.[12] Gull is particularly important, both for its relatively large network of outlets (roughly 50) and for the fact that it owns an import terminal, providing some degree of independence from the BP refinery. Finally, there are a collection of smaller independent brands, Amgas, Better Choice, Kleenheat, Kwikfuel, Oasis and Wesco, as well as a small number of independent stores

[11] Singaporean refineries can contest the Perth market, and restrain the refinery pricing of the incumbent to some degree. There is also occasional import from overseas through Gull's independent terminal.
[12] Peak was taken over by Gull in 2008, but continues to operate as an independent brand.

with no branding. Figure 2.11 provides an overview of the changing brand profile in Perth over a five year period.

Figure 2.11: Numbers of Stations by Brand in Perth – 2001 to 2006

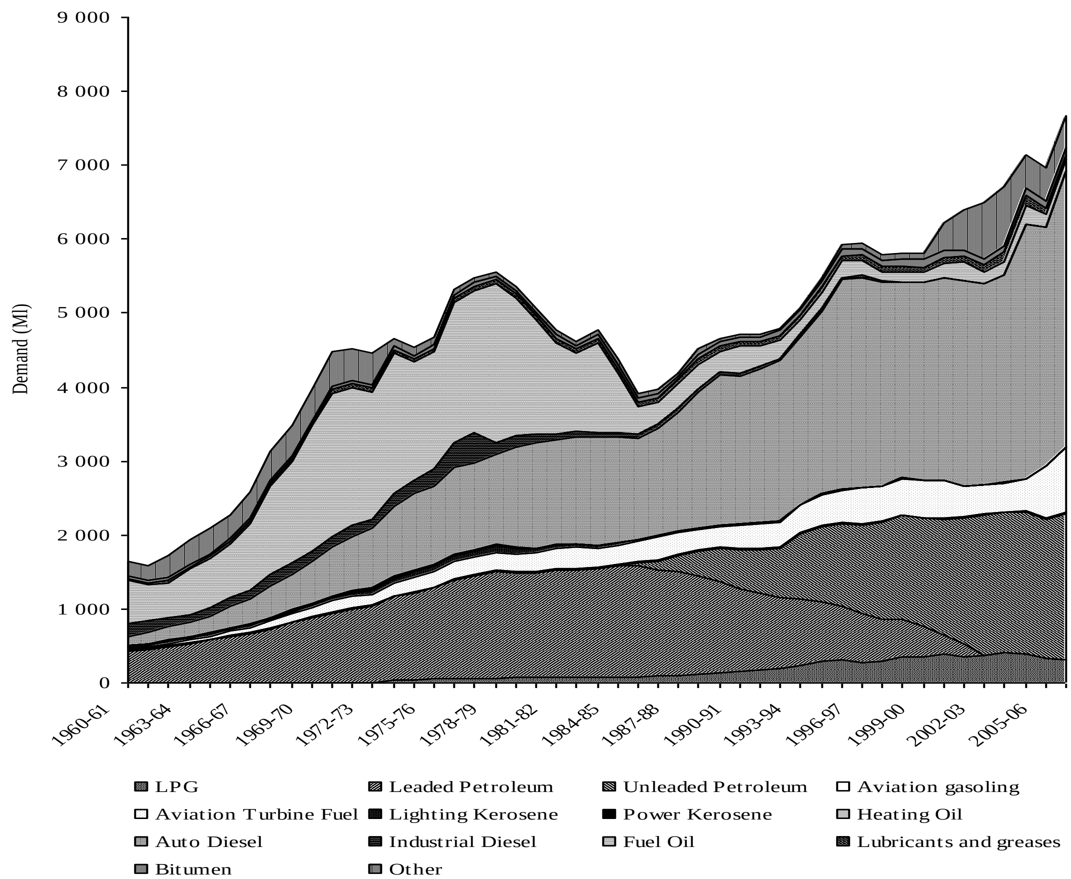


Source: FuelWatch data

BP, Mobil and Shell all make use of multi-site franchising in Perth. All of the Shell and Mobil sites in Perth that they do not own outright, and which are not branded independents, are controlled through a single head lease. BP has three such head-leases (Wang, 2006).

Compared with the Eastern States, Perth is a relatively small market, comprising less than one-fifth of overall Australian fuel sales. Figure 2.12 provides an overview of fuel sales in recent years in WA, broken down into different fuel types. The picture is similar to the Australian total, except for marginally more usage of aviation fuels and fuel oil, associated with WA's sometimes remote industrial locations.

Figure 2.12: Fuel Use by Type WA – 1961 to 2007



Source: ABARE (various years b) Table K5

Chapter Three: Literature Review

The analytical and theoretical models explored in this thesis draw upon a rather wide literature, from both within economics and outside it. This chapter summarises the relevant literature, under four broad headings:

- General literature on retail petroleum market behaviour
- Edgeworth cycles
- Spatial competition
- Literature from outside economics

The wide focus of the literature review reflects the breadth of the inputs into the analytical and empirical models used in this thesis. The literature on petroleum market behaviour contributes to the analysis here and also guides expectations about empirical findings. I also focus on the Australian literature, most of it from government studies, which provides important contextual background for the empirical work later in the thesis. The Edgeworth cycle literature is particularly important because price paths at most of Perth's retail petroleum outlets match those predicted by Edgeworth's (1925) theory. The section on spatial competition is very brief and is intended only to provide background to the spatial model developed in Chapter Four, that admits Edgeworth cycles as an equilibrium. Finally, I make use of a number of empirical techniques in Chapter Six which are not commonly used in economics, particularly network centrality. I thus devote some space to explaining the literature underpinning these techniques.

Retail Petroleum Market Behaviour

A major focus of this thesis is on Edgeworth Cycles in retail petroleum prices as an explanation for their movement. The literature on Edgeworth Cycles is relatively recent, and is addressed as a separate topic below. However, there is also a large literature positing other influences of retail petroleum prices that largely predates the Edgeworth Cycle literature, and offers important insights of its own. I summarise this literature here under five sub-headings:

- **Regulation:** and its effect on retail petroleum prices.
- **Rockets and Feathers:** a literature which explores how shocks in upstream prices are transmitted through to retail prices.
- **Elasticity:** with a special focus on the drivers of elasticity, and hence demand.
- **Market Behaviour Models:** a very brief overview of a very large literature positing different models for retail petroleum markets.
- **Australian Government Studies:** A brief overview of key studies by government bodies in Australia, which provide background information for the current study.

Regulation

The literature on regulation and its impacts on retail petroleum markets focuses largely on case studies from the US. Not only is US data comparatively good, but there is considerable heterogeneity amongst US states in terms of their regulatory structure, which provides important variation for estimating regression coefficients.

Chouinard & Perloff (2004, 2007) undertake wide-ranging studies incorporating many differences in markets and regulatory structures in the US including crude prices, heating degree days (to assess the impacts of special fuels required in cold weather), monthly and seasonal dummies, demographic factors, taxes and fuel emissions standards. At the national level, they find that only crude prices and seasonal dummies are important. However, they find considerably more sources of variation at the state level, with demand and supply factors being important in explaining differences between fuel prices in different states

Regulation is often employed to protect smaller independent operators from the anti-competitive practices of their larger rivals. Three forms of regulation common in the US are divorcement, self-service bans and the prohibition of sales below cost. [13] Blass & Carlton (2001) find that divorcement legislation leads to less investment in retail petroleum by the Majors, whilst Vita (2000) finds that it adds two to three cents per gallon (cpg) to the price of fuel. Vita (2000) also examines the impacts of self-service bans, finding that they add a further three cpg to the price of fuel, whilst Johnson & Romeo (2000) find that such bans reduce the number of self-service outlets compared with market preferences, but do not prevent the Majors from dominating the given market at the expense of smaller independents.

Sales below cost laws are designed to prevent larger operators from predating upon smaller ones, but Blair & Dougherty (2003) present anecdotal evidence from Florida that

[13] Divorcement prohibits firms with refining interests from owning retail outlets. The Royal Commission on Petroleum (1976) whose recommendations led eventually to the *Sites Act* and *Franchising Act* also examined the possibility of divorcement, but instead opted for restricted ownership of retail outlets by the Majors. Self service bans prohibit customers from pumping their own petroleum at a retailer, and sales below cost laws prevent retailers from selling petroleum at a price below the efficient cost benchmark determined by a regulator.

in fact the Majors often use such laws to bring cases against independents engaging in fierce price competition. Anderson & Johnson (1999) find that these laws add 1.6 cpg to the price of fuel, which is less than the 6.3 cpg they find for self-service bans. Skidmore, Peltier & Alm (2005), who use a larger dataset and test for longer-term effects, find that prices actually reduce by one cpg five years after the introduction of sales below cost laws, an effect they ascribe to such laws preserving more independent operators.

Environmental regulations can result in markets being "islanded" when differing fuel standards mean refiners from outside the jurisdiction in question can no longer sell their fuel there. The result is market power for the refiners which are active in the market. Two studies that focus on this effect are Brown, Hastings, Masur & Villa-Boas (2008) and Chakravorty, Naughes & Thomas (2008). Although each uses different methods, they both find that prices rise when environmental standards isolate markets. Chakravorty et al (2008) find that price increases are greater when surrounding states do not follow the state tightening its standards, leading them to suggest that higher, uniform standards impose costs initially as the refineries re-tool, but might lead to lower prices in the longer-term than piecemeal changes in standards by differing jurisdictions at different times.

Government policy changes can also influence retail petroleum markets. In the Australian context, Delpatchirya & Beal (2001) suggest that wholesale price deregulation in 1998 reduced slightly the degree to which Australian retail prices follow the Singapore benchmark and increased the time it takes for shocks to that benchmark to be passed through to Australian retail prices.

In some cases, policy does not need to change to have an effect. Driffield & Ionnadis (2000) find that the 1979 inquiry into the UK petroleum industry by the Monopolies and Mergers Commission depressed industry profits when it was announced, and continued to do so for two and a half years; longer than the inquiry itself, which in any case suggested no major changes to industry structure. The authors find no similar effects for later inquiries, and suggest that the large effect for the 1979 inquiry was due to uncertainty about its outcomes.

Merger policy can have significant effects when it prevents or allows vertically integrated firms to merge. Hastings (2004), examining a merger between an independent and a vertically-integrated refiner in California, finds that the merger increased prices by four to six cpg in the markets where the two firms previously competed. Gilbert & Hastings (2005) find that another Californian merger between two vertically-integrated firms raised wholesale prices by three cpg in markets where the merged firm faced strong retail competition. Outside the US, Coloma (2002, 2003) finds that the merger between Repsol and YPF in Argentina increased prices by five percent, whilst Hyde (2002) finds that successive mergers in Australia may have simultaneously decreased efficiency and increased market power.[14] However, Simpson & Taylor (2008), examining the effects of a merger between Ashland and Ultramar Diamond Shamrock on prices in Michigan

[14] Although his data make firm conclusions difficult to make, as Hyde himself suggests.

compared with prices outside the state not affected by the merger find that the merger had no appreciable effect.

The primary aim of merger policy is to increase competition in the market concerned. However, government often resorts to more direct means of increasing competition. One proposed scheme in California (which did not become legislation) would have required a branded wholesaler to supply any retailer carrying its brand at the same price from a given wholesale rack. This would have removed the ability of wholesalers to price discriminate across markets in California through the delivered prices they charge to their lessee dealers. A special issue of the *International Journal of the Economics of Business*, which centres on an article by Comanor & Riddle (2003), examines the law.

Comanor & Riddle (2003) look at its effects by assuming that, at each rack, the wholesalers using that rack would adopt Ricardian pricing, and by using information on transport costs, they establish that the new rack price plus transport costs would increase existing delivered prices to lessee dealers by between 1.5 and 1.8 cpg for branded retailers, with effects being three times as large for unbranded retailers. Commentary on the article is given by Keely & Elzinga (2003) (who examine the welfare consequences of uniform pricing), Langenfeld, Li & Schink (2003) (who examine the consequences of the legal changes which would remove scope for price discrimination) and Marvel (2003) (who shows how allowing arbitrage by retailers can actually increase prices).

Rockets and Feathers

One area which has attracted a great deal of attention in the literature is the question of whether retail prices respond more quickly to an increase than to a decrease in crude prices. The issue is the topic of a recent special issue of the *Journal of Industrial Economics* (see Hubbard, 2008, Verlinda, 2008, Deltas, 2008, Balmaceda & Soruco, 2008 and Lewis, 2008a) and is known as the "rockets and feathers" debate. The first to notice this pattern was the UK Monopolies and Mergers Commission (1990), but the first to put it to an analytical test, and to coin the phrase, was Bacon (1991). Bacon (1991) uses a quadratic adjustment model, but most of the literature follows the error correction model, of Borenstein, Cameron & Gilbert (1997).

As the literature has developed, the empirical models have become more complex. Balke, Brown & Yucel (1998) allow for changes in the short and long-term relationship, Bachmeier & Griffin (2003) develop the error-correction term via a two-stage least squares approach whilst others use a single step, often incorporating threshold regression to account for differences in positive and negative shocks (see Godby, Lintner, Stengos & Wandschneider, 2000 or Chen, Finney & Lai, 2005) or incorporate state variables (Radchenko, 2005a). Recent studies have used vector auto-regression models (Balke et al 1998 and Radchenko, 2005b) or models that incorporate momentum in the pass-through of price shocks (Al-Gudhea, Kenc & Dibooglu, 2007).

Findings are sensitive to model specification (see, for example, work by Bachmeier & Griffin, 2003 and Balke et al, 1998) and to the periodicity of data; more frequent data generally providing less evidence of asymmetry. Sometimes, the day of the week upon which data are collected matters, as Bettendorf, Van De Geest & Varkevisser (2003) find with Dutch data. Noel (2009) points out that one must first disentangle the effects of Edgeworth Cycles from high frequency data, and presents a methodology for doing so.

The rockets and feathers response also seems to differ across countries. Bacon (1991) finds that it exists in the UK. Borenstein et al (1997) find evidence in the US of asymmetries in the link between crude and gasoline spot markets and wholesale to retail but not between spot and wholesale markets, whilst Balke et al (1998) find rather more mixed results. Kirchgasser & Kubler (1992) find evidence from Germany in the 1970s of a reverse asymmetry (a faster response to crude price decreases than increases). Duffy-Deano (1996) finds evidence of asymmetries in Salt Lake City. Godby et al (2000) find no evidence of asymmetry in Canada and Galeotti, Lanza & Manera (2003) find evidence of both long and short-run asymmetries in Germany, the UK, Italy and Spain.

There is considerable debate about what might cause the asymmetric adjustments. Noel (2009), suggests that retail price cycles might play a role. Borenstein et al (1997) suggest that focal point equilibria (based upon Green & Porter's, 1984, trigger price model) might slow the response to downward cost shocks, or that inventory effects might be asymmetric, or that volatile crude prices might cause a signal extraction problem for consumers that lowers the payoff from search and thus the incentive to lower retail prices. Brown & Yucel (2000) suggest that inventory effects might be credible but that, if they are, then market power is not the main issue, and endeavours to ameliorate asymmetries might have unforeseen effects on responses to crude price shocks. Johnson

(2002) makes use of the fact that diesel buyers (in the US at least) are usually commercial operators who buy in volume and are thus better informed that petroleum buyers to test whether diesel prices have less asymmetric responses to crude price shocks, and finds that they do, supporting a signal extraction explanation. Radchenko (2005b) adopts a more complex Bayesian updating model for consumer search, and finds that both this and a tacit collusion model are credible explanations, based upon the inverse relationship he finds between asymmetries and the variability of input prices.

Elasticity of Demand and Drivers of Petroleum Demand

Limited literature exists on elasticity of demand at the level of the individual retail petroleum outlet. Slade (1986) estimates own and cross-price elasticity for 13 outlets in Vancouver in 1983, finding that the own-price elasticity ranges from -0.4 to -7.7 (mean -4.5) and the cross-price elasticity ranges from 0.8 to 8.8 (mean 6.9). Barron, Umbeck & Waddell (2002) estimate own price elasticity of between -2.012 and -5.045 and cross-price elasticity of between 2.0 and 4.9, depending upon the grade of petroleum and whether the retail petroleum outlet was in a low density, medium density or high density area (based upon the number of nearby alternative sellers) in Los Angeles. More recently, Wang (2009) uses data from eight outlets in Perth and estimates own price elasticities ranging from -5.51 to -18.41 (mean -8.99) and cross price elasticities range from 0.21 to 11.39 (mean 3.46).

The literature on the elasticity of demand for retail petroleum at the level of the market is much larger. Dahl & Sterner (1991) conduct a meta-analysis based on more than 100 studies, and Graham & Glaister (2002) update the work with studies undertaken since

1992. Epsey (1996,1998) and Goodwin, Dargay & Hanly (2004) also conduct meta-analyses, and Brons, Njiekamp, Pels & Reitveld (2006) and Breunig & Gisz (2009) are two more recent examples that include Australian data.

The market-level literature is useful because it provides an understanding of which demand-side factors influence elasticity, and hence demand for retail petroleum. This then forms an input into Chapter Six. Table 3.1 provides an overview of demand-side factors which have been found to be important in the elasticity literature.

Table 3.1: Factors Driving Elasticity of Demand for Petroleum

Study	**Factors**
Archibald & Gillingham (1980)	Monthly expenditure on fuel, total household expenditure, number of cars per household, number of cylinders per car, fuel prices, prices of other goods, female/non-white/unemployed household head, age and education of household head and others in family, number and age of children, location (rural or urban).
Baltagi & Griffin (1983)	petroleum price and consumption, income, number of cars per capita.
Gallini (1983)	fuel efficiency, vehicle speeds, petroleum price and consumption, income, car prices, unemployment rates, characteristics of the automobile stock (such as weight, age and proportion of new cars), fuel efficiency of cars, wage rates, scrap values of cars.
Puller & Greening (1999)	Price of fuel, income, female/non-white/unemployed/retired household head, age, employment status and education of household head and others in family, vehicle miles travelled, car maintenance costs, price of new cars, number of wage-earners in household
Kayser (2000)	petroleum price and consumption, income, non-white/unmarried/female/unemployed household head, location (rural or urban and what part of the US), number of (employed) adults and children in the house, number of cars, quality of public transport, fuel efficiency, automobile stock.
Nicol (2001)	household type, household expenditure, housing tenure type, age and employment of household head and members, tobacco consumption, consumption of other goods (in six categories), immigration, vehicle ownership, price of fuel and other goods, occupation type, income, number of children, location.
Storchman (2005)	per-capita income, annual fixed cost of new cars, price of petroleum, population density, country dummy, income distribution by country, fuel consumption, levels of urbanisation, private per-capita income, cars per head of population, new car registrations, share of imported cars.
Li, Von Haefen & Timmins (2008)	New vehicle sales, vehicle registrations by location and model, household income, population, average household size, depth of snow in winter, fuel prices, fuel taxes, vehicle fuel efficiency.
Breunig & Gisz (2009)	Volume and price of petroleum sold, population, price of other goods, household income.

Market Behaviour Models

There is a large literature which develops models of retail petroleum markets and their behaviour. Hosken, McMillan & Taylor (2008) explore five different models (static pure strategy, static mixed strategy, dynamic collusion, dynamic path-dependency and Edgeworth Cycles) but find that none explain the Washington market they study adequately. Similar work has been done by Borenstein & Shepard (1996), Rotemberg & Saloner (1986) and in a series of papers by Slade (1986, 1987, 1989, 1990 & 1992), who all examine different dynamic models of market behaviour in retail petroleum markets, finding rather more support for their models than Hosken et al (2008) do.

The spatial nature of retail petroleum markets has also been explored to some extent. Spiller & Huang (1986) examine arbitrage between geographic areas in the North-Eastern United States and endeavour to separate out distinct markets. Cooper & Jones (2007) take a more micro-view, examining competition along radial commuter routes in Lexington Kentucky, and ascertaining whether outlets compete more fiercely with rivals located closer to the centre than themselves. Netz & Taylor (2002) look specifically at spatial models in the tradition of Hotelling (1929) to explore whether agglomeration or dispersion is prevalent in retail petroleum markets, finding that the latter dominates in the Los Angeles market they study. Many authors examine seller density and its effects on market interaction, including Sen (2003) in Canada, Clemenz & Gugler (2006) in Austria and Van Meerbeck (2003) in Belgium. These three authors find that seller density has an impact on pricing, and it has been used by others as a proxy for the competitiveness of local markets by other authors, including Hastings (2004) and Barron & Umbeck (2000).

Some authors have also examined whether the presence of convenience stores influences price, and whether fuel is a loss-leader for higher-margin convenience store items. Adams (1997) finds that it is not, by examining the correlation between fuel prices and the prices of convenience store items.

Fuel is generally considered to be an homogenous product, but retail petroleum outlets can make use of price discrimination. Barron, Taylor & Umbeck (2000) examine the differences in pricing of premium and regular petroleum in the US, finding evidence that the two have different elasticities of demand, and that the latter is more responsive to competitive pressures. Borenstein (1991) examines price differences between leaded and unleaded fuel prices in the US in the 1980s, when the former was being phased out. He finds some evidence that the differences in retail prices between the two types of fuel, are due to rising search costs for leaded fuel as the number of suppliers decreased. Shepard (1991) examines the differences in prices of full service and self-service at outlets which offer only one of these services compared with those which offer both, finding that the differences are greater at the latter, suggesting that such outlets are using the price of the different levels of service to sort customers.

Australian Government Studies

Retail petroleum pricing is an issue of great concern to consumers and voters. It has thus been subject to many inquiries by different Australian government departments over the past few decades, as Table 3.2 shows.

Table 3.2: Government Petroleum Industry Inquiries (1970-2008)

National Petroleum Pricing Inquiries		
Year	*Name of Report*	
1984	PSA, *Inquiry in Relation to the Supply of Petroleum Products*	
1988	TPC, *Study into Market Practices and Government Regulation in the Petroleum Industry*	
1989	PSA, *Inquiry into Petroleum Product Prices*	
1990	PSA, *National Inquiry into Petroleum Product Prices*	
1990	PSA, *Review of LPG Pricing*	
1991	PSA, *Report to Government on the Recommendations of the Caucus Special Committee of Inquiry (the Wright Committee) into Aspects of the Australian Petroleum Industry*	
1996	ACCC, *Inquiry into the Petroleum Products Declaration*	
1999	ACCC, *Increase in the Average Retail Prices in Australia Compared with the Rise in International Prices*	
2000	ACCC, *Report on the movement in fuel prices in the September Quarter 2000*	
2001	ACCC, *Reducing fuel price variability*	
2004	ACCC, *Assessing shopper docket petrol discounts and acquisitions in the petrol and grocery sectors*	
2007	ACCC, *Petrol Prices and Australian Consumers: Report of the ACCC inquiry into the price of unleaded petrol*	
Regional Petroleum Pricing Inquiries		
Year	*Name of Report*	
1987	PSA, *Inquiry in Relation to the Supply of Petrol in the ACT*	
1990	PSA, *Inquiry into Tasmanian Petrol Prices*	
1991	PSA, *Regional Study of Petrol, Distillate and LPG Prices in Mildura*	
1992	PSA, *LPG Pricing in Western Australia*	
1994	PSA, *LPG Pricing in Tasmania*	
1994	PSA, *Inquiry into the LPG Declaration in Western Australia*	
1997	ACCC, *Autogas Pricing in Geelong*	
1998	ACCC, *Victorian LPG Autogas Prices*	
1999	ACCC, *Review of LPG Autogas Prices and LPG Cylinder Prices in Western Australia*	
2002	ACCC, *Terminal gate pricing arrangements in Australia and other fuel pricing arrangements in Western Australia*	
State & Territory Inquiries		
State	*Year*	*Name of Report*
NSW	1995	Commission of Inquiry into Petrol Prices in Rural NSW
NSW	1999	NSW Dept of Fair Trading, *Inquiry into Petrol Price Signs*
NSW	1999	Australian Centre for Co-operative Research and Development, *Development of Co-operative-Type Structures for Lowering Petrol Prices in Rural NSW*
NSW	1999	Western Research Institute, *Enhancing Competition in the Petroleum Industry - The Role of Co-operatives*
Vic	1993	Victorian Coalition Backbench Committee, *Discussion Paper on the Disparity between Country and Metropolitan Fuel Prices*
Vic	2001	Consumer and Business Affairs Victoria, *Information on Fuel Price Trends in Victoria: Victorian Fuel Price Monitoring Initiative*
Vic	2001	Economic Development Committee, *Impact of GST in Victoria*
Vic	2006	Consumer Affairs Victoria, *Report on Automotive Fuel Prices in Victoria*
Qld	2000	Fuel Taskforce Report
Qld	2006	Queensland Legislative Assembly, *Inquiry into petrol pricing in Queensland*
Qld	2007	QLD Treasury, Queensland Treasury Fuel Subsidy taskforce Report
Qld	2007	Queensland Fuel Subsidy Commission Inquiry Report
WA	2000	Legislative Assembly of WA, Select Committee on Pricing of Petroleum Products, *Getting a Fair Deal for Western Australian Motorists*
SA	2001	NCP Review of the Petroleum Products Regulation Act 1995
SA	2001	Select Committee on Petrol, Diesel and LPG Pricing Report
SA	2006	Select Committee on the Pricing, Refining, Storage and Supply of Fuel in South Australia Report

Table 3.2: Government Petroleum Industry Inquiries (1970-2008) continued

State & Territory Inquiries continued.		
State	*Year*	*Name of Report*
Tas	1995	Tasmanian Legislative Council Select Committee on Petrol Pricing Report
ACT	1992	ACT Government Working Group on Petrol Prices Report
ACT	1997	ACT Legislative Assembly Select Committee, *Inquiry into Petrol Prices in the ACT*
ACT	2001	ACT Independent Competition & Regulatory Commission, *Summary Report: Inquiry into Motor Vehicle Prices*
NT	2005	Northern Territory Government, *Inquiry into fuel prices in the Northern Territory*

Commonwealth inquiries other than pricing	
Year	*Name of Report*
1976	Royal Commission on Petroleum. Report No. 4. *The Marketing and Pricing of Petroleum Products in Australia.*
1976	Royal Commission on Petroleum. Report No. 6. *The Use of Liquefied Petroleum Gas in Australia,*
1980	Senate Standing Committee on National Resources, *Replacement of Petrol by Alternative Sources of Energy*
1985	Joint Committee of Public Accounts, *Excise and Deferred Customs Duties*, Report No. 224 of 1985.
1986	Industries Assistance Commission, *Certain Petroleum Products - Taxation Measures*, Report No. 397, 5 November 1986
1987	Auditor-General, *Report of an Efficiency Scrutiny - Diesel Fuel Rebate Scheme*, March 1987
1991	Auditor-General, *Australian Customs Service - Diesel Fuel Rebate Scheme*, Audit Report No. 27 of 1990-91.
1994	Industry Commission, *Petroleum Products*, Report No. 40, 5 July 1994.
1996	Australian National Audit Office, *Diesel Fuel Rebate Scheme: Australian Customs Service*, Report No. 20 of 1995-96.
1999	Department of Industry, Science and Resources, *Downstream Petroleum Products Action Agenda*.
1999	Senate Rural and Regional Affairs and Transport Legislation Committee, *Report on the Provisions of the Petroleum Retail Legislation Repeal Bill 1998*
1999	Senate Economics Legislation Committee, *Consideration of Diesel and Alternative Fuels Grants Scheme (Administration and Compliance) Bill 1999*
2000	Senate Economics Legislation Committee, *Consideration of Petroleum Excise Amendment (Measures to Address Evasion) Bill 2000*
2001	Senate Economics References Committee, *Inquiry into the provisions of the Fair Prices and Better Access for All (Petroleum) Bill 1999 and the practice of multi-site franchising by oil companies*.
2002	Commonwealth of Australia, *Fuel Tax Inquiry Report*
2003	Senate Environment, Communications, Information Technology and the Arts Legislation Committee report, *Provisions of the Fuel Quality Standards Amendment Bill 2003*
2005	Report of the Biofuels Taskforce to the Prime Minister
2006	Senate Economics Legislation Committee, *Inquiry into the provisions of the Fuel Tax Bill 2006 and the Fuel Tax (Consequential and Transitional Provisions) Bill 2006*
2006	Senate Standing Committee on Economics, *Petrol Prices in Australia*
2006	Senate Economics Legislation Committee, *Provisions of the Petroleum Retail Legislation Repeal Bill 2006 Report*
2008	Senate Standing Committee on Economics, *Inquiry into the National FuelWatch (Empowering Consumers) Bill 2008*

Source: SSCE (2006) Appendix Four plus author's own research. TPC = Trade Practices Commission, PSA = Prices Surveillance Authority, ACCC = Australian Competition and Consumer Commission.

Although there is considerable repetition in findings, and not all of the studies listed in Table 3.2 are relevant to this thesis, the table is useful as it shows the sheer volume of government inquiries into the industry over the past three decades. Pertinent points from the more important of the studies in Table 3.2 are highlighted below.

The Industry Commission (1994) and ACCC (1996) reports were written prior to wholesale price deregulation in 1998 and during a period of over-capacity in refining in Asia which restricted profits for Australian refiners. They devote considerable space to both issues, and both advocate wholesale price deregulation, whilst the Industry Commission also advocates the abolishment of the Laidley Agreement (abolished in 1997) which restricted access to wholesale terminals. The ACCC (1996) advocates the use of import competition to restrict the ability of refiners to leverage market power downstream. This advocacy may reflect the then recent decision by the ACCC to require Ampol and Caltex to divest themselves of several import terminals in order to facilitate competition, pursuant to their 1995 merger proposal.

Both reports cover retail petroleum prices, and note the presence of cycles, but neither makes firm conclusion as to their genesis. The IC (1994) suggests they are initiated by independents and exacerbated by the use of price supports by the Majors, whilst the ACCC (1996) suggests that they are used by the Majors to squeeze the independents. Neither, however, recommends market intervention to alleviate cycles. A decade later, the Senate Sub-Committee on Economics (2006) reached roughly similar conclusions, suggesting that cycles are driven by competition for market share, demand variation and wholesale price variation.[15] However, in the intervening decade, supermarkets had taken a substantial market share, and the SSCE (2006) suggests that they now drive prices downwards. Like the ACCC (1996) and IC (1994), the SSCE (2006) did not find that

[15] The Labor senators on the committee dissented, suggesting that cycles are driven by market manipulation on the part of the Majors.

cycles were anti-competitive and suggested that, where anti-competitive practices existed in the industry, they could be addressed through the *Trade Practices Act*.[16]

The Department of Industry, Science and Resources (1999) and Department of Industry Tourism and Resources (2002) have released two reports focussing on industry performance. These reports note the low profitability in the 1990s due to overcapacity in Asia and recommend more co-ordination of industry policy to improve efficiency. Part of this policy framework is the industry code of practice, the *Oilcode*, first proposed in 1989 to replace the *Sites Act* and *Franchising Act*, but not actually implemented until 2007. DISR (1999) also addresses the issue of import competition, but is more sanguine about its effectiveness than the ACCC (1996), noting that its effectiveness hinges upon the independent importer having the ability to on-sell the fuel in a reasonable timeframe. This, it suggests, may be difficult given the limited number of independent chains of retailers not tied to the Majors. By 2007, the ACCC (2007) is also less enthusiastic about import competition, given that very little independent importing had occurred in the decade since its 1996 report.

The IC (1994), ACCC (1996), DISR (1999) and DITR (2002) reports are all written by Federal Government agencies, and each advocates roughly similar positions, particularly in respect to regulation of the industry, which none support. The report by the Western Australian Parliamentary Select Committee on Petroleum Prices (2000) takes a rather different tone, describing the WA context thus:

[16] Several of the senators on the Committee disagreed with these findings.

> *"The marketing and pricing of fuel is fraught with deeply entrenched problems which seriously restrict competition, resulting in market manipulation and excessive prices, especially in country areas" (p.ix)*

Its response was also quite different, strongly advocating considerable re-regulation of the industry including metropolitan price monitoring, regional retail price controls, maximum wholesale price caps, price monitoring of the refineries and a prohibition of Majors owning retail outlets. Few of its recommendations became law, however; the only lasting legacies of the report are the *FuelWatch* scheme and a watered-down version of its envisaged wholesale price caps (the tgp scheme described in Chapter Two). Each is very important for the WA retail petroleum market, but neither is as far-reaching as the committee wished.

The *FuelWatch* scheme and tgps (the latter also implemented in Victoria at roughly the same time, and adopted voluntarily around Australia during 2002) attracted considerable interest around Australia, and the ACCC released two reports (ACCC, 2001, 2002) addressing these issues. The 2001 report focuses more on *FuelWatch* and the 2002 report more on tgps, but both reports cover both issues. The ACCC (2001, 2002) did not support *FuelWatch*, finding that it likely contributed to a rise in fuel prices in Perth relative to the period prior to its imposition and compared with Sydney and Melbourne, and also that it was largely unnecessary to restrict price changes given that there was only an average of 1.16 price changes per day prior to the implementation of *FuelWatch*. It was, however, more optimistic about tgps, suggesting they had likely improved transparency in the industry, without adversely influencing retail prices.

In 2007, the ACCC released its most comprehensive review of the retail petroleum since its 1996 report.[17] This report (ACCC, 2007) finds a basically competitive industry, particularly at the retail level, which had undergone considerable structural change over the past decade as supermarkets increased their market share. It notes concentration in the refining sector but also notes that prices still followed the Singapore benchmark and generally react symmetrically to shocks to this benchmark.

From the perspective of this thesis, perhaps the most important aspect of the ACCC's (2007) report is its focus on price cycles. Many of its findings are presented in Chapter Two, and the report represents the first time the term "Edgeworth cycles" has entered the Australian policymaking lexicon. It finds that the extent of cycling in Australia is quite distinctive internationally,[18] but it does not find that the cycles are caused by the activities of any of the Majors, nor by price-support schemes. It does find, however, that the Major with a refinery in the city in question is often the one which initiates a price rise. Moreover, the Majors are, in general, not aggressive in reducing price, preferring to price-match rather than undercutting.[19] This accords with Eckert's (2003) prediction

[17] It is this report which formed the basis of the Federal Government's proposal to expand Fuelwatch across the country. However, as noted in Chapter Two, the econometric modelling upon which this conclusion is based is subject to considerable criticism, and the policy roll-out has stalled at the time of writing.

[18] Though it does not reach any firm conclusions as to why this might be the case, citing a number of possible reasons, but clearly identifying none of them.

[19] However, the ACCC also notes that both the supermarkets and independent retailers follow strategies of price matching, and one is left wondering who precisely drives cycles downwards. The only candidates appear to be the larger independent chains, but even they appear to temper their reactions for fear of retaliation by the supermarkets (ACCC, 2007, p137).

about large firms, which is discussed further below. Beyond that, the ACCC makes few strong conclusions about cycles. In fact, it concludes that the cycles are an “enigma”. It is likewise unable to conclude whether the cycles benefit retailers or consumers.[20]

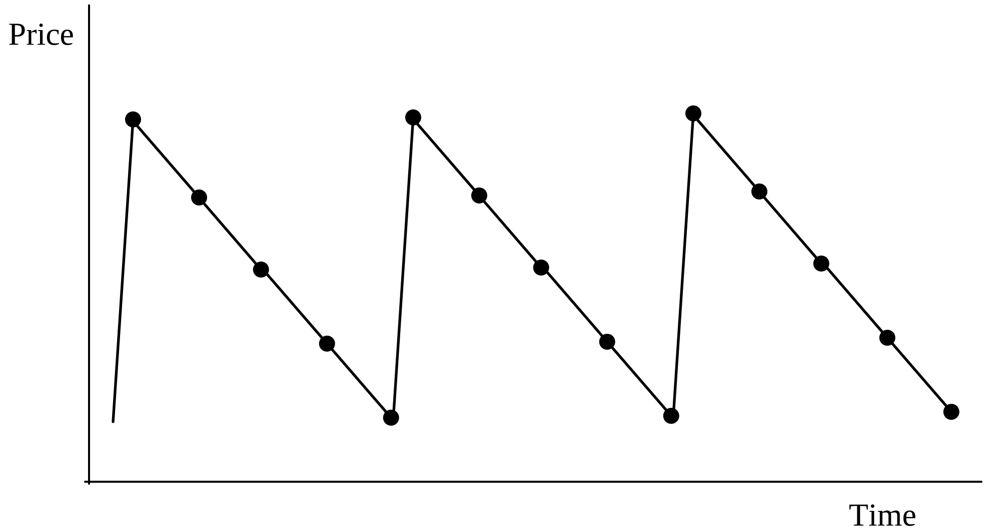
Edgeworth Cycles Literature

In 1925, Edgeworth published his *Theory of Monopoly*, in which he addresses Cournot’s model of duopolists competing to sell an identical good.[21] He explores the case of decreasing returns, where each firm can produce up to a limit and no further. In the case of these two capacity-constrained firms, instead of reaching equilibrium as Cournot suggested, prices will instead oscillate. This oscillation has subsequently become known as an “Edgeworth cycle”. It has a distinct saw-toothed pattern, as shown in Figure 3.1, where prices increase rapidly over one time period, and then decrease slowly.

[20] The survey commissioned by the ACCC for its 2007 study found that around three quarters of consumers try to buy when petrol is cheapest, but 28 percent bought when they needed it. 55 percent of motorists buy their petrol on a particular day, because they believe that day is cheapest.

[21] The 1925 publication, which is widely cited in the literature (including by Maskin & Tirole, 1988), is a translation of Edgeworth’s *Teoria Puradel Monopolio,* published in the *Giornade degli Economisti* in 1897.

Figure 3.1: A Diagrammatic Representation of an Edgeworth Cycle



The driving force behind this pattern of pricing is the trade-off inherent in the capacity limits each firm faces. When prices are high, each firm can serve most, or even all of the market demand at the higher prices and hence, if each moves sequentially, it pays to try and undercut one's rival, and thus steal their market share. However, as prices diminish, the firms are no longer able to serve all of market demand alone at the prevailing price. The lowest-priced firm captures as much demand as is it can serve at the prevailing price, and the other firm then faces the residual demand. Since the first firm is already producing at capacity, the second firm is a monopolist for the residual demand. The second firm will thus find it profitable to price as a monopolist, hence its price rises to the top of the cycle. The first firm can then raise its price to a level just below the second firm's high price and still maintain market share, and hence it does so. Now one is back at the top of the cycle, and each firm has an incentive to undercut again. The result is not a pure-strategy equilibrium, but rather one in mixed strategies (see below).

Levitan & Shubik (1972) provide a formal model of this form of capacity constraint basis for Edgeworth Cycles, and show how a mixed strategy equilibrium involving relenting to the higher price can emerge. Other authors have also explored mixed-strategy games with Edgeworth Cycles, and Vives (1993) explores this literature in some detail, but the contribution which is most frequently cited, at least within the literature dealing with empirical evidence of Edgeworth Cycles in retail petroleum markets is that of Maskin & Tirole (1988). In this paper, the authors provide theoretical foundations for Edgeworth Cycles and kinked demand curves as equilibia to an infinite, alternating move game between two symmetric duopolists producing the same good for the same marginal cost with sufficiently high discount rates who use Markov-Perfect strategies, and who choose prices from a finite grid (rather than an assumption of continuous prices, which would not give the same results). Unlike supergame models (see for example, Green & Porter, 1984, which assumes demand uncertainty and asymmetric information), Maskin & Tirole do not require exogenous shocks in order to generate price variation, which is driven by the alternating move and Markov strategy assumptions. In contrast to Edgeworth (1925) and Levitan & Shubik (1972), Maskin & Tirole (1988) do not require the firms to be capacity-constrained in order for prices to cycle.

In the Markovian framework of Maskin & Tirole's model, each player moves alternately (which the authors explain proxies the use by firms of strategic commitment in a simultaneous-move game), and the set of payoff-relevant state variables consists just of the price last charged by the rival firm. Profits are determined as follows:

$$\pi_t^i\left(p_t^1, p_t^2, c_t\right) = D^i\left(p_t^1, p_t^2\right)\left(p_t^i - c_t\right) \text{ where}$$

$$D^i\left(p_t^1, p_t^2\right) = \begin{cases} D\left(p_t^i\right) & if \quad p_t^i < p_t^j \\ \vartheta_i D\left(p_t^i\right) & if \quad p_t^i = p_t^j \\ 0 & if \quad p_t^i < p_t^j \end{cases} \tag{3.1}$$

Where c_t are marginal costs (set equal by Maskin and Tirole, 1988), the profit function is strictly concave, *D(.)* refers to market demand and θ_i is the share of the market served by firm *i* when prices are equal, and is equal to 0.5 in Maskin and Tirole's (1988) model. The form of the model shown here is a slightly generalised version of that shown in Maskin & Tirole (1998), and can be found in Noel (2008).

Instead of the higher-priced firm serving residual demand as occurs in Levitan & Shubik (1972), in this environment of no capacity constraints, it serves no demand at all. This, along with assumptions on discount rates and on price choices being discrete, is the source of the cycle. If prices are currently high, and it is the turn of Firm One to choose its price, it will choose a price just below that which it has observed for Firm Two last round, in the expectation that for a single period, it will serve the entire market at a price above marginal cost, before its rival does the same to it the following period. Since there are no capacity constraints, each firm needs to undercut their rival by only a very small amount (one square on the grid) in order to capture the whole market. Moreover, each will do so, in preference to price matching, because capturing the whole market is better than capturing only half of it, when prices differ by only one unit. This, then, gives rise to the gradual downward movement of prices. As prices trend downwards in small increments, the returns from being the lowest-priced firm diminish, and hence there is pressure for prices to rise. The firms play a “war of attrition” at the minimum of the price cycle, each waiting for the other to raise prices. They do not wait because they fear their rival will not follow the price rise upwards; to the contrary, since a price only slightly below that just set will capture the whole market, each firm knows that, if it relents, the rival firm will follow. Instead, they wait because any price increase will be followed by two periods of zero profits; one when the firm raising price does so and one when its rival chooses a price just below that which the relenting firm had initially raised the price to. For this reason, there is value in making large increases in price, so that the third-period profit (when the original relenting firm is finally able to recoup benefits from its strategy) can outweigh the two periods of zero profit. By the same token, this strategy is in itself only valuable when discount factors are high, and hence the value of third-period returns outweigh two periods of zero-returns.

The dynamic reaction functions R^1 and R^2, are defined by:

$$\left(p_t^i\right)^* = R^i\left(p_{t-1}^j, c_t\right) \qquad (3.2)$$

These functions contain the optimal responses in each round of the game for each firm. The functions will be Markov-perfect equilibria when they satisfy (Noel, 2008):

$$V^i\left(p_{t-1}^j\right)=\underset{c}{E}\left(\max_{p_t}\left[\pi_t^i\left(p_t, p_{t-1}^j, c_t\right)+\delta_i W^i\left(p_t\right)\right]\right) \text{ and}$$

(3.3)

$$W^i\left(p_{s-1}^j\right)=\underset{c}{E}\left(\underset{p_{st}}{E}\left[\pi_s^i\left(p_{s-1}^j, p_s, c_t\right)+\delta_i W^i\left(p_s\right)\right]\right)$$

Where *V* indicates the forward-looking value in the period where Firm *i* makes the pricing decision, and W indicating forward-looking value in the period when it does not, and the subscripts *t* and *s* refer to the time periods when Firm *i* is and isn't the one choosing price respectively. In Noel (2008), the expectation over *c* incorporates a stochastic element associated with marginal cost (see discussion of extensions below) which is not present in Maskin & Tirole's (1988) original model, and δ refers to the discount rate.

Maskin & Tirole (1998) go on, within this framework, to show that there is a certain interval of prices within which there will be a focal price (where firms will earn two-thirds of the monopoly profits), corresponding to the kinked demand curve, and that there exists an Edgeworth Cycle that comes about from the best-response functions, wherein each party earns a quarter of monopoly profits. They also show that there is only one focal-point Markov Perfect equilibrium, and that a given Markov Perfect equilibrium cannot contain both a focal point and an Edgeworth Cycle.[22] Thus, a Markov Perfect equilibrium to the duopoly game outlined above is either a kinked demand curve or an

[22] They do not show that it cannot contain more than one Edgeworth Cycle.

Edgeworth Cycle; it does not degenerate into the standard Bertrand result whereby profits are zero, and nor does it degenerate into a collusive outcome with monopoly prices.

Eckert (2003) extends Maskin & Tirole's (1988) framework by considering firms of differing size; in the context of retail petroleum markets, the independents and the Majors. Like Maskin & Tirole (1988) he assumes the lowest-priced firm will serve the entire market, regardless of size. However, if the two firms have the same price, he suggests that their market share will be a reflection of their relative size (number of outlets) rather than the even split Maskin & Tirole (1988) assume. The result is that, as the large firm becomes larger, the differences in rewards from price matching and undercutting to serve the whole market diminish. At a market share of greater than three-quarters, price matching becomes the dominant strategy for prices in the lower range of the cycle, and this strategy becomes dominant at progressively higher prices as the market share of the large player increases further. Eckert (2003) thus suggests that larger firms will be more likely to relent and to price match on the downward phase of the price cycle, whilst smaller independents will be more likely to undercut, a finding he tests empirically.

Eckert also finds that Maskin & Tirole's (1988) focal point equilibrium will disappear at a market share of two-thirds for the larger firm. This occurs because, when capacity shares are sufficiently skewed, there is no randomisation between the focal price and a lower punishment price that the smaller firm can make which will leave the larger firm indifferent between these two prices in the following period.

Noel (2008) introduces a number of extensions to Maskin & Tirole's (1988) model. Firstly, instead of a constant marginal cost, he allows marginal cost to vary according to a random draw.[23] This means that there are now two payoff-relevant variables; the price charged last round by the firm's rival and the firms' current marginal cost. The added complication of variable marginal cost means that Noel (2008) does not prove his results per se, but the computational approach he follows leads, in all cases, to an Edgeworth Cycle.

Noel (2008) also allows for differing elasticities of demand, asymmetric strategies, differentiated products (a more general approach than my spatial competition in Chapter Four) and capacity constraints. He finds that elasticity of demand influences the aggressiveness with which firms undercut each other, with higher elasticity inducing smaller cuts. Asymmetric strategies have the effect of one making one firm consistently relent, whilst the other consistently begins the process of leading prices downwards. Finally, capacity constraints limit the ability of a firm to respond to the price charged by its rival, and thus attenuate cycles until, when the constraints are sufficiently tight, only focal-price equilibria remain.

In the same paper, Noel (2008) examines the consequences of there being three, rather than two firms. Now, in order for a cycle to obtain, the firm which raises price first incurs an extra period of losses, and needs to be sure that both rivals will follow it

[23] Eckert (2004) also explores a model where marginal costs are constant across firms and time, but subject to stochastic shocks.

upwards. The result is still an Edgeworth Cycle, but one with more delayed and false-starts as co-ordination becomes more difficult. He finds this result robust to the perturbations to Maskin & Tirole's (1988) assumptions outlined in the previous paragraph. He also suggests that empirical observations of false and delayed starts may be due to pricing games being played by three or more players.

One final extension is that of Lau (2001) who shows that it is not necessary to assume that the firms play a sequential game. Provided the firms exhibit strategic complementarity, follow Markov strategies and choose price levels, short-run commitment (fixing prices for two periods) can arise endogenously. In fact, he shows that non-synchronisation is the equilibrium for a game where strategic complementarity and positive externalities exist. Intuitively, each firm has an incentive to try and undercut one another when they move simultaneously (hence offsetting each other an moving prices to marginal costs immediately), and this therefore leads to a lower-payoff equilibrium than would be the case if they moved sequentially. Realising this, firms have an incentive to commit to prices for more than one period, and to thus move sequentially, even when not required to do so.

Empirical Evidence for Edgeworth Cycles

Empirical evidence for the existence of Edgeworth Cycles is a small, but growing field, and most of the examples have come from examination of retail petroleum markets.[24]

[24] There is also a small literature in experimental economics, where researchers construct oligopoly games and observe the outcomes when such games are played. One such outcome is Edgeworth cycles. Kruse, Rassenti, Reynolds & Smith (1994), Cason, Friedman & Wagener (2005) and Leufkens & Peeters (2008) are three examples from this literature.

The first paper to explicitly reference the work of Maskin & Tirole (1988) in the context of retail petroleum prices is that of Castanias & Johnson (1993),[25] who note that the Maskin & Tirole model is the only one of several reviewed that is capable of describing the price wars observed in their data (Los Angeles retail petroleum prices from 1968 to 1975). They find asymmetries in retail price cycles, as Maskin & Tirole (1988) predict, and find further that this asymmetry is not due to changes in wholesale prices.

The first paper to explicitly test for Edgeworth Cycles is Eckert (2003), who tests his small-firm, large-firm model discussed above using data from 19 Canadian cities, some of which exhibit cycles and some of which do not.[26] He finds that cities with more small firms exhibit a greater tendency to have Edgeworth Cycles in retail petroleum pricing. Eckert further extends the literature in collaborative work with West (Eckert & West, 2004a,b, 2005) and Atkinson (Atkinson, Eckert & West, 2009). All these papers consider case studies in Canada; Eckert & West (2004a) examine Ottawa and Vancouver, Eckert & West (2004b, 2005) examine Vancouver and Atkinson Eckert & West (2009) examine how prices move across the market in Guelph, Ontario. Eckert & West (2004a,b, 2005) find that firms are facilitating collusion in Vancouver, but fighting for market share in Ottawa, led by maverick independent chains. In Eckert & West (2004b), the authors find that price increases tend to be simultaneous across the city, but that price decreases tend to respond to local factors. A similar pattern is shown for Perth in Figure 5.9.

[25] Alvine & Patterson (1974) note cycle patterns in numerous US cities in the 1960s and 1970s, at a time when vertical controls, ,such as price supports, were widely used.
[26] Eckert (2002) incorporates Edgeworth Cycles into a rockets and feathers model of crude price shock transmission into retail prices using a model similar to that of Borenstein et al (1997). Noel (2009) extends this work.

Atkinson (2009) continues his study of Guelph, Ontario, looking at price cycles and testing whether their shape is most consistent with Edgeworth Cycle theory, or other models of dynamic pricing. He finds greatest support for Edgeworth Cycles, and finds further that the Majors tend to lead prices upwards, whilst independent chains tend to lead them downwards; echoing the earlier work of Eckert (2003).

Another author who has examined Edgeworth Cycles in Canada extensively is Noel (2007a, b).[27] Noel (2007a, b) constructs a Markov-Switching regression and examines switching probabilities between the different states (relenting and undercutting where prices cycles and cost based and sticky pricing where they do not). He uses these switching probabilities to derive information about cycle period, amplitude and the vertical and horizontal asymmetry of prices, comparing these measures with theoretical predictions about the shape of Edgeworth Cycles. Noel (2007a) uses data collected from 19 cities, whilst Noel (2007b) focuses in more detail on Toronto.

Noel's (2007a, b) Markov Switching models allow for considerable flexibility in determining explanatory factors which drive both the change in price within a regime and the switch between regimes. He explores differences between cities, periods of time (days of the week and months), station characteristics (particularly whether an outlet is controlled by the Majors or an independent chain), the market penetration of independents and the position in the cycle on a particular day. The latter is useful for determining, for example, whether the probability of relenting increases as one approaches the minimum of the cycle, something he finds to be the case.

[27] Both Noel's work and that of Atkinson is based on their earlier PhD theses.

Noel (2007a, b) finds evidence that cycles are pro-competitive as the presence of cycles is strongly associated with the penetration of independents in a given market, and weakly associated with seller density and market size. Noel (2007b) tests Edgeworth Cycle theory against other explanatory factors such as changes in demand, asymmetric discounts from rack price or collusion. Like Atkinson (2009) he finds greatest support for Edgeworth Cycle theory.

Despite the predominance of Canadian case studies, Edgeworth Cycles have also been examined in the US, Norway and Australia. In the US, Lewis (2008) examines how retail petroleum prices changed in response to wholesale price shocks brought about by Hurricanes Katrina and Rita in 2005, focussing on 85 cities in the Mid-West, Mid-Atlantic and Southern US. He finds that wholesale cost shocks dissipate fastest in those cities which exhibit Edgeworth Cycles. Lewis (2008) also explore what drives cycles, examining such factors as the market share of independent firms, station density, population, income, number of cars per household and land area, finding that only the market share of independents, population per outlet and the overall number of outlets are significant. Lewis (2008) also develops a measure of the degree of the Edgeworth nature of price cycles; since an Edgeworth Cycle involves lots of small price changes and a few large one, Lewis (2008) reasons that the more negative the median change in price is, the greater the degree of the Edgeworth (or saw-toothed) nature of the cycle.

Doyle, Muehlegger & Samphantharak (2008) use Lewis's (2008) median change in price measure and data from 115 cities across the US to ascertain factors driving cycles, with a particular focus on convenience stores and the market penetrations of independents. They find that convenience stores associated with independents result in more pronounced Edgeworth Cycles than those associated with Majors, particularly when there are two or more such independents in the local market being studied. They also find that greater independent penetration results in more pronounced Edgeworth Cycles, but only up to a point; the markets with the greatest degree of independent penetration exhibited fewer cycles, suggesting they are part of a tacit collusion which can break down. They also find that cities with cycles are one to two cpg cheaper than those without them, confirming, at least in the US context, the hypothesis of the ACCC (1996, 2007) and IC (1994) that cycles are pro-competitive.

Foros & Steen (2008) examine cycles in Norwegian data, but suggest that they are too regular to be Edgeworth Cycles; prices move slowly downwards through the week, but firms almost always relent on a Monday in response to head-office recommendations (most outlets are franchises) rather than as part of a mixed-strategy equilibrium. However, although Monday dominates, the price increases may still be part of a mixed strategy equilibrium, albeit one which allots a very high probability of a change in price to Mondays. The authors do not explore this, and nor do they explore why the dominant price-increase day shifted from Thursday to Monday in recent years in Norway.

Finally, one author has examined price cycles in Australia; Wang (2005b, 2008) examines price cycles in Victoria, and those in Perth (Wang 2005a, 2006, 2007, 2009).

The two papers on Victoria focus on the city of Ballarat, and specifically a case where local petroleum retailers were prosecuted by the ACCC for price fixing. Wang presents evidence from court documents that shows not only prices, but the precise times on each day when the various parties to the cartel contacted each other to discuss future prices. Despite operating as a cartel, the prices of the participants still cycled. Moreover, this cycle has the familiar saw-tooth pattern of an Edgeworth Cycle, with price increases all greater than three cpl, and price decreases around 0.2 cpl. Wang suggests that this is because, even in this collusive environment, a price leader cannot be sure others will follow (indeed, some followers left price boards blank until they could see what others were doing) and hence collusion regularly broke down.

In his five papers on the Perth market, Wang concentrates on three topics; the nature of price cycles, the nature of localised competition using a small sample of firms for which he has price and volume information, and the nature of the strategic game that each firm plays. In his sample period of June 2001 to October 2003, Wang (2005a, 2006) finds 101 price cycles, meaning that each lasts roughly a week. Wang is especially interested in the role of branding, which he suggests overcomes the co-ordination problem which exists with many players. He finds that price increases are highly correlated across stations sharing the same branding, with Shell, BP or Caltex leading price cycles upwards (mostly one or the other, but more rarely, two or three at the same time). All brands usually increase price by the third day after a price increase, and most cycles start on a Monday, Tuesday or Wednesday.

To examine the strength of brand pricing discipline, Wang (2006) conducts a simple regression, decomposing price changes into a series of brand dummies. He finds that the R-squared results tend towards one on price increase days, and zero on price decrease days. This suggests that brands lead prices up, but that something else leads them down. That something else appears to be local competition, which Wang (2009) explores using a small sample of eight outlets scattered across the metropolitan area for which he has price and sales data. Examining cross-price elasticity, he finds that each outlet competes directly with only two or three rivals nearby, a fact which he confirms via anecdotal evidence from the outlets in his sample. This points towards local competition being important during the downward phase of the cycle.

In examining the relationship between cycles, Wang (2005a, 2006, 2007) finds some evidence that firms are playing mixed-strategy games in their decision to raise price, using an empirical model which seeks to predict the likelihood of a particular price-leadership type emerging. Interestingly, Wang (2007) finds that a firm that was the leader in the last cycle is unlikely to lead in this one. Examining the reaction functions of each firm, Wang (2005a, 2006) finds that for the three leading brands, the state of the other leading brands in the last period is the only significant influence on their decision to raise price in the cycles where they are not price leaders. This supports the Markov hypothesis that he suggests drives the cycles. He also find that the non-leading brands

(Gull, Mobil, Peak, Liberty and Woolworths) respond in a similarly Markov fashion, when one allows for a third day in the rising phase.

Spatial Competition

In Chapter Four, I develop a model of spatial competition which admits Edgeworth Cycles as its equilibrium. The model draws upon elements of the spatial competition literature, and this section provides a brief overview of the small part of the literature which underpins this model.

Models of spatial competition posit that location can provide a degree of localised market power if rivals are located some distance away and transport (either through goods being delivered or customers travelling to the store) is costly. The simplest model is a straight line of unit length, explored by Hotelling (1929) in his seminal paper. The equilibrium Hotelling suggested was subsequently shown not to exist under the assumptions of his model (d'Aspermont, Gabszwicz & Thisse, 1979; Osborne & Pitchik, 1987, definitively solve the Hotelling model), and a substantial literature has developed endeavouring to find the equilibria of this game. Anderson and de Palma, in a series of papers (1988, 1992a, and see also Anderson, de Palma & Thisse, 1992 and Anderson & Engers, 1994), have had particular success in finding equilibria by introducing heterogeneous goods via a logit model of demand, Anderson and Neven (1991) find it useful to move from Bertrand to Cournot competition, a move which itself has lead to its own literature (see, for example, Mayer, 2000, Yu & Lai, 2003, Arévalo Tomé & Chamorro-Rivas, 2007 and Gupta, Pal & Sarkar, 1997). Anderson & Thisse (1989) provide an overview of the literature which developed during the 1980s, as do Eiselt & Laporte (1989), with the latter also exploring the questions which remain unanswered in the literature at the time. Kilkenny & Thisse (1999) and Pires & Sarkar (2000) provide two later literature reviews.

The main focus of the literature is on finding equilibria in the two-stage game of location then price.[28] The basic tension in the models is between agglomeration, which allows firms to reach the whole market at lowest cost but intensifies price competition, and dispersion, which increases transport costs incurred by the firm in reaching some of the market but allows localised market power. The type of equilibrium, and indeed the form of pricing which is optimal for the firm and society in general, is often a function of the particular assumptions which underpin each model.

Positing a market as a straight line means that not all points in the market are equal. Vickery (1964) and Salop (1979) extend the model from a line to a circle, on which no location has an advantage over any other. This has sparked a considerable literature as well, since it changes the nature of the game, and equilibria which result, because of this equality between points in the circle. Yu & Lai (2003), Matsushima & Matsumura (2003), Pal & Sarkar (2006),[29] Arakawa (2006) and Yu (2007) are all examples from this literature. Gupta, Lai, Pal & Sarkar (2004) compare and contrast the use of linear and circular models.

[28] Anderson, de Palma & Hong (1992) examine a game where price and location are chosen simultaneously, and Anderson & DePalma, 1992, one where price is chosen first and location second.
[29] They also study multi-plant firms in spatial markets, itself a growing literature. Pal & Sarkar (2002) provide an overview of this literature and highlight how its conclusions differ from models where each firm is assumed to operate a single plant.

Another extension is to allow for competition to occur within the circle. Without some restrictions, this simply becomes a case of perfect competition. Many plausible restrictions have been examined. Gupta et al (2004) posit an upstream monopolist seeking to spatially price discriminate amongst its customers. Others suggest the distribution of consumers might not be uniform; Lederer & Thisse (1990) present a model in which customers are located at nodes on a network and firms compete on plant location, production technology and delivered pricing. Dorta-Gonzales, Santo- Peñate & Súarez-Vega (2004,) extend this work by considering oligopolistic interaction between firms on such a network and a network framework is also used by Braid (1993, 1996), Gupta, Pal & Sarkar (1997) and Granot, Granot & Raviv (2010).[30] Restrictions need not be this complex, however; MacLeod, Norman & Thisse (1988) present a model of equilibrium location and price choice in which the only abstractions from perfect competition are the presence of fixed costs and the ability to price discriminate on a locational basis.

Much of the literature focuses on a two-stage game; firms choose first where to locate and then competition occurs between them. In Chapter Four, the model I introduce is much simpler, considering location to be exogenous and thus focussing on what Anderson, de Palma & Thisse (1989) term the "short-run" (and which they show only has a pure-strategy equilibrium with price discrimination). Moreover, most of the literature focuses on cases where the firm delivers the relevant goods to a consumer, whilst the model I consider has an idiosyncratic structure, whereby customers come to the firm, and can patronise one firm at zero cost but must incur a cost to patronise the other. There are

[30] The latter paper also includes a good review of the literature where the order of entry into a spatial market is considered

thus only a few direct links between this literature and Chapter Four (see below). Elsewhere in the literature on retail petroleum markets,[31] authors have incorporated exogenous location by using measures of distance to competitors (see for example, Netz & Taylor, 2002, Hastings, 2004, Hoskin et. al., 2008 or Cooper & Jones, 2007) or the density of competitors in a given region (see for example Clemenz & Gugler, 2006 and Van Meerbeck, 2003).

The most important part of the spatial competition literature from the perspective of this thesis is that which derives from the work of Hoover (1937). This work was extended by McBride (1983) and formally developed by Lederer & Hurter (1986).[32] Here, I provide a brief overview of the model, as presented by Hoover (1937) as it is from this simple model that the work in Chapter Four derives. The importance of Hoover's (1937) work is that he noticed that firms do no price based upon distance, but rather that, when firms have a degree of market power, they will charge higher prices to those customers located closer to them (and thus further from any rivals) than they will to customers located further from them, but closer to a rival. He provides some empirical support for his model with a case study of Standard Oil.

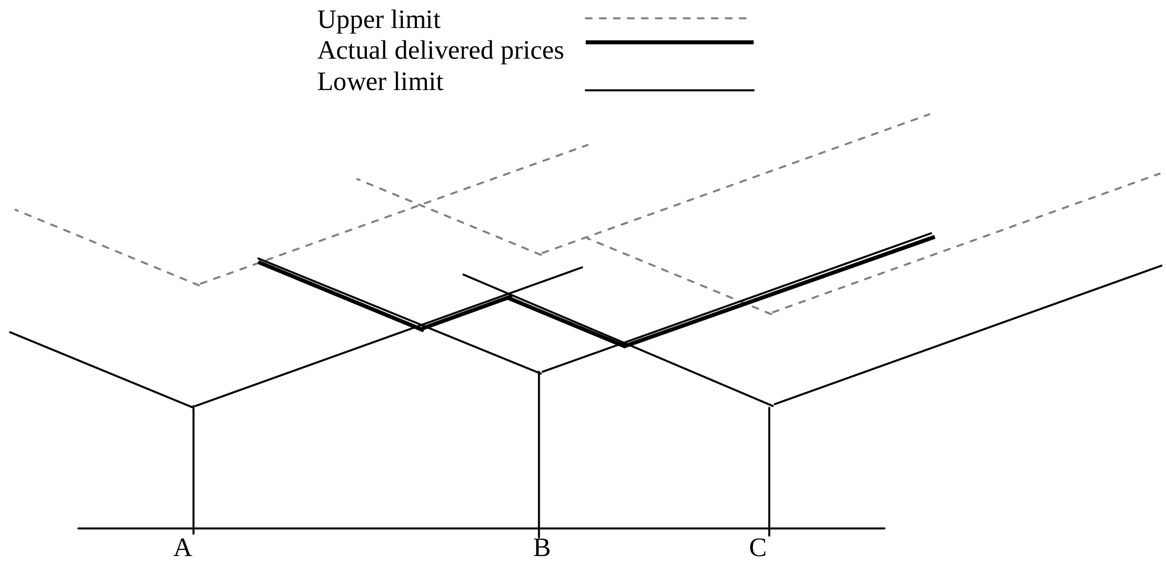
Analytically, Hoover (1937) suggests that elasticity falls as price falls. When demand curves are straight lines, and the seller absorbs the freight costs, the demand and marginal

[31] There is only limited explicit crossover between the spatial economics literature outlined in this section and the retail petroleum literature outlined in the first part of this chapter. Netz & Taylor (2002) is an exception; they set out to empirically test whether retail petroleum markets exhibit agglomerative or dispersive tendencies (finding more evidence for the latter) using a case study in Los Angeles and drawing direct inspiration from many of the papers listed here.
[32] See also Thisse & Vives (1988) and the brief review of the literature in Anderson (1989).

revenue curves of the more distant buyer, as seen from the seller's perspective, are the same as those for the buyers who are nearer, except that they are shifted inwards. This means that, when the seller equates his marginal cost with the marginal revenues of each buyer (seen from the seller's perspective), it charges a higher free-on-board price to the nearby buyer than it does to the more distant buyer. This kind of discrimination is difficult for buyers to avoid.

If there is more than one seller, then elasticity of demand changes according to location. Close by each seller, where it is relatively costly for rivals to supply customers, the elasticity of demand is relatively low. However, on the fringes of the market, where rival supply is a possibility, elasticity of demand will be higher. Thus, if there is but one seller, the price which the seller will charge for the good plus delivery to a specific point will lie between two points; the sum of marginal costs plus freight (the competitive solution), and an upper limit consisting of the reservation price for customers at that location. If, however, there are two or more sellers, each in a fixed location and with overlapping markets, the upper limit changes. It will now be the marginal delivered cost of the next lowest cost rival for each point in the market. This gives rise to a pricing pattern such as that illustrated in Figure 3.2.

Figure 3.2: Delivered Prices in a Spatial Oligopoly with Overlapping Markets



Source: Hoover (1937) p188[33]

The upper limits indicate what the firms *A*, *B* and *C* would like to charge, if they had sufficient market power. The lower limits represent the minimum price they are willing to charge, given their cost structure. Actual prices are a function of the lower limits of rivals.[34] Thus, the firms will have relatively little discretion over the prices they can charge, and customers closest to each of the firms will face the highest prices.

McBride (1983) extends Hoover's (1937) model by developing a more complete specification of marginal revenue and marginal cost curves. The result of his model is a range of customers. Those closer to the firm will face monopoly prices based upon their marginal revenue curves. Further away, when the customers are closer to a rival, both the

[33] Figure 3.2 is reproduced from Hoover (1937). He does not include a vertical axis, the context of his discussion indicates that the vertical dimension is price. The horizontal dimension is described by Hoover (1937) as being elasticity, but this is directly related to distance between firms.
[34] If the market were a cartel, Hoover (1937) suggests that actual prices would follow the lower envelope of the upper limits.

firm and the rival would prefer to continue pricing according to marginal revenue, but can still profit so long as prices are above marginal cost. The result is more competition, whose nature and intensity will be a product of the way in which the two firms to interact. McBride (1983) illustrates his model with a case study from the US concrete industry.

Lederer & Hurter (1986) generalise Hoover's (1937) model, examining different consumer densities (along with relaxation of other assumptions in the original model), as well as exploring the consequences of the pricing game on the first stage of location choice (something McBride, 1983, also considers). They find, in a more rigorous fashion than Hoover (1937), roughly the same result as in the original model; where demand elasiticity is low,the delivered price of the lowest cost firm serving all market demand at a particular point in the market will be the delivered costs of its next lowest rival.

I make use of a model in Chapter Four which incorporates a degree of market power derived from fixed locations in space, as Hoover (1937) does, and I show that this variant gives rise to Edgeworth Cycle equilibria under a variety of circumstances. To the knowledge of this author, this is the first time that a link has been made between spatial models of this type and Edgeworth Cycles.

Network Analysis

When economists speak of networks, it is most commonly in the context of network economies (see, for example, Katz & Shapiro, 1994) or the fact that utility from consuming a good or service can be enhanced by others consuming goods or services of the same type. Internet browsers, computer operating systems, bank ATM networks and

DVD standards are all examples of this. In this thesis, however, I take a more literal interpretation, and consider networks as patterns of interaction between players in a marketplace. This more literal interpretation arises as a logical consequence of the analytical model described in Chapter Four. In so doing, the structure of such networks is important. Much of the literature on network structure has developed in the field of sociology and, whilst there has been some crossover into economics, [35] the author is unaware of any previous endeavours to study a product market via its network structure in the way it is done in Chapter Six.

An important component of the social networks literature is whether the best form of a network is one with dense patterns of interconnection, or whether it should contain what Burt (1992) refers to as "structural holes"; parts of the network which are only joined by a single link between them. Coleman (1988) advocates the first perspective, arguing that a greater number of ties results in more stability for the network and thus a greater potential for the creation of social norms amongst its members that further their collective goals. Burt (1992) on the other hand, argues that individuals in the network are best served by being located at one of the ends of the bridge across the structural hole between two sub-networks, as this allows them to control information flow and thus reap competitive advantage.

[35] See for example Granovetter's (1973) seminal study of job networks, Burt's (1997b, 1999, 2004) many studies on networks inside firms and his (1992) study of macro networks in the US economy, Ter Wal & Boschma's (2009) review of network analysis in economic geography, or other work on intra-firm networks by Granovetter (2005), Zuckerman (2003), Rauch & Casella (2001) or Lie (1997).

Burt's (1992) book touched off a considerable debate in the literature,[36] as authors sought to uncover evidence of dense networks or networks with structural holes contributing to the performance of those in the network or sought to explore the fundamental behavioural notions underpinning Burt's work. In particular, Burt's (1992) notion discounts the possibility of nodes in the network reacting to a given node having a favourable structural position by forming additional linkages of their own (Ryall & Sorenson, 2007, Busken & Van de Rijt, 2008). It seems unlikely nodes would behave so myopically. Moreover, the question of who is in the network matters; Ingram & Roberts (2000) examining social networks amongst Sydney hoteliers suggest that networks containing producers with similar interests are less likely to find benefit from structural holes, a point which Burt himself (1997a) also concedes.

On the empirical side of the debate, authors find evidence of cases where both dense networks and those characterised by structural holes are useful to their participants, and the general direction of findings seems to be that younger industries requiring flexibility can often be best-served by networks containing structural holes, whilst more dense networks better serve more mature industries requiring stability (see Gargiulo & Benassi, 2000, Baum, Calabrese & Silverman, 2000 or Rowley, Brehen & Krackhardt, 2000 for examples) .

[36] There are some 6000 citations for Burt's (1992) book on Google Scholar. Burt himself has conducted many studies (see, for example, Burt 1997b, 1999, 2004, Burt & Ronchi, 2007, Burt, Jannotta, & Mahoney, 1998) and he shows a correlation between being favourably located near a structural hole in an intra-firm network and aspects of corporate success such as promotion, salary and prestige (see Burt, 2000, 2002 or 2005 for reviews of this literature).

If information transfer is important, too many structural holes can be deleterious to the network but, equally, networks which are too dense make it difficult for network participants to keep track of all the information flows. Thus, one often sees the "small world phenomenon" (see the seminal paper by Milgrom & Travers, 1969, or Watts & Strogatz, 1998 for a more recent approach in the physical sciences) of densely connected local networks, supported by sparse connections to distant points in the network. Reagans & Zuckerman (2001) explore the utility of this kind of network structure in research groups.

There is thus no universal answer about which kind of network is better; both play a role dependent upon the nature of the industry/firm/social group within which the network sits and dependent upon the scale of analysis. Burt (2000) himself also argues that the two concepts are not necessarily contradictory, but rather that each has value depending upon the context of what the network is to be used for. Moreover, as Granovetter (2005) points out, there are limits on the number of links an agent can form and, indeed, where budget constraints exist, one might expect said agent to form those links which are most valuable to her, rather than trying to link with everyone. The small worlds literature alluded to above is a consequence of these limitations and it appears to have relevance for this thesis given the shape of the retail petroleum market in Perth (see Figures 5.6 and 5.7).

Network Centrality

The density of the network as a whole is simply the proportion of ties which exist compared to the maximum possible with the number of nodes present. This is useful, but it is arguably more useful to have a measure associated with each node in the network in order to ascertain how network structure influences each participant in the network. The most common measure is centrality; how close the given node is to the centre of the network. Centrality has been associated with trust (Tsai & Ghoshal, 1998); those at the centre of a group will most strongly embody its shared vision and will thus be trusted most by others in the network. Tsai (2000) and Ibarra (1993) suggest that centrality captures the structural dimension of social capital and that a central actor will have greater access to information, people or resources in a network than will a peripheral actor. Ibarra (1993) cites a series of studies which relate centrality to occupational attainment, career mobility, power and external resource acquisition.

There are many different measures of centrality, based upon relative position in the flow of information, numbers of connections and the importance of those connections (Freeman, 1979), and different measures are employed in different contexts. However, there is an underlying mathematical relationship between all of them, and each can be thought of as the end result of a different kind of walk structure within the network. This means that each is a measure of cohesiveness or proximity in a given network, and this is a function of network density. Borgatti & Everett (2005) provide a detailed characterisation of many measures of centrality, and their mathematical interrelationships.

In Chapter Four, I suggest reasons why, for the purposes of this thesis, Bonacich’s (1972, 1987) measure of centrality is perhaps the most useful. It is based upon the elements of the eigenvector of the largest eigenvalue of the adjacency matrix associated with a given network. The adjacency matrix, a workhorse of the social networks literature, is a symmetric, zero-one matrix with a zero in the ij^{th} position if nodes *i* and *j* are not connected, and a one if they are.[37]

To consider Bonacich's (1972,1987) measure in more detail, note first that, if an adjacency matrix is multiplied by itself, the result, rather than describing which nodes are connected to which, describes how many two-step connections exist between the ij^{th} node. If the adjacency matrix is multiplied by itself again, t describes how many three step connections exist and so on. The series of such multiplications is:

$I+A^2+A^3+\ldots\ldots+A^n$

which can be summed as follows:[38]

$$\sum_{i=0} A^i = (I - A)^{-1} \tag{3.4}$$

Bonacich suggests that his measure, which endeavours to obtain the closest measure of the actual 'bond' between two nodes by minimising the sum of the squared differences between the estimated and actual (but unknown) matrices representing bonds, is akin to principal components analysis in statistics, in that the use of a (suitably standardised) eigenvector as the centrality measure preserves as much as is possible, the maximum variance in the original. Mathematically (following Bonacich, 1987), if *R* is the matrix of relationships, and *e* the measure of 'centrality', the centrality of unit *i* is given by:

[37] Generally, they have zeroes down the main diagonal, though this is a convention, rather than a mathematical necessity, see Straffin (1980).

[38] This relationship is true where the eigenvalues of the adjacency matrix are all less than one. If they are not, oscillation, rather than convergence occurs, and the adjacency matrix must be normalised.

$$\lambda e_i = \sum_j R_{ij} e_j \tag{3.5}$$

where λ is a constant, chosen such that the equations have a non-zero solution. In matrix notation, this is expressed as:

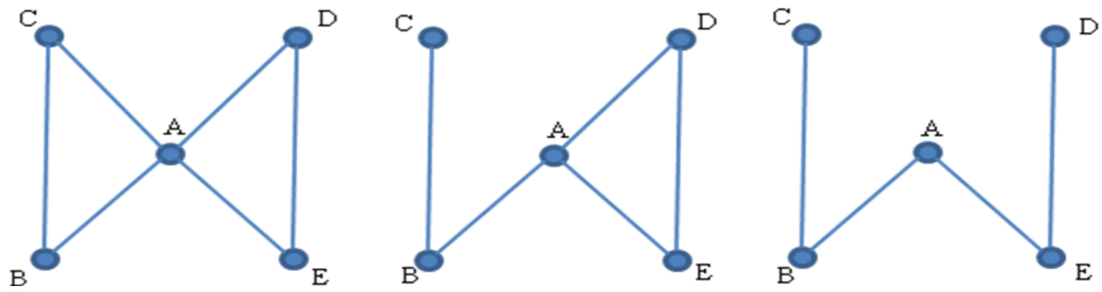
$$\lambda e = \mathrm{R}e \tag{3.6}$$

where λ is the vector of eigenvalues and *e* its associated eigenvector. Bonacich considers the largest eigenvalue and its associated eigenvector as these preserve the most variation from the original data in *R* but, as he notes, any eigenvector/eigenvalue pair can be used as a centrality measure.[39]

Bonacich's measure can perhaps be understood better by examining a simple five node network, summarised in Figure 3.3.

[39] However, in a symmetric matrix, the largest eigenvector will contain all positive entries, whilst remaining eigenvectors will have a mix of positive and negative entries. As discussed further below, this means that they pick up importance in subgroups, rather than importance overall. Hadi & Ling (1998) note that, despite containing the largest amount of variation, the largest eigenvector might not be 'closest' to the underlying data. Indeed, as Borgatti & Everett (2005) point out, Bonacich's measure works best when a network has a single core.

Figure 3.3: Centrality Scores in a Five-Node Network



A	0.615	0.664	0.577
B	0.394	0.342	0.5
C	0.394	0.155	0.289
D	0.394	0.497	0.289
E	0.394	0.497	0.5

In Figure 3.3, we begin with a "bow-tie", where A is connected to all other nodes, and B is connected to C and D to E. We then remove one link, unravelling the left-hand side of the bow-tie such that C is connected to A only through B, and then unravel the right hand side such that D is connected to A only through E. The centrality scores in each case are summarised under the relevant part of Figure 3.3. Node A stays the most central in each case. However, its relative advantage does not. Removing the links between A and C, and then A and D has the effect of making C and D peripheral, as can be seen in the middle and right-most network, where C and then D obtain the lowest scores. However, as links are removed, the advantages of the most central node vis-a-vis the next most central decreases; in the middle diagram, the fact that D and E are connected to each other means that they are more central than B, which is similarly connected to A, but is otherwise only connected to the peripheral node C, rather than another node only one link from the centre. Once B and E become symmetric in the right-most diagram (a straight line, though it is not drawn as such to maintain continuity of shape), A must go through two links to reach the periphery of the network, so its centrality advantage over the next most central nodes deceases. Note that, if we added links to the bow-tie on the left of Figure 3.3, we would also equalise scores as more nodes would have the same structural relationship with the rest of the network as A has. If C is joined to E and B to D, then all nodes obtain the same centrality score.

Bonacich's (1972, 1987) measure is widely used in sociology, with more than 750 citations for his two papers on Google Scholar. An identical measure has also been used in geography, and indeed it was a geographer who first proposed the measure (Gould, 1967) which was later independently discovered by Bonacich.

Structural Holes

Structural holes refer to "gaps" in a network; where two groups of nodes well-connected internally within each group have only a few connections between them. Structural holes are particularly useful for the nodes which sit on either side of the bridge across the whole (the connection between groups), because these nodes can exploit any information flowing between groups to their own advantage. The measures which are most commonly used to quantify structural holes are those developed by Burt (1992). In Chapter Six, I make particular use of three of Burt's (1992) measures; constraint, efficiency and redundancy and in Chapter Four I provide a rationale for the use of these measures. Here, I explain Burt's (1992) measures in some detail.

Consider a network consisting of a number of nodes with a pattern of connection of differing strengths of interaction between pairs. Beginning with a measure of the strength of the contact between two nodes z_{ij}, examine first all of the other nodes, q, connected to i

and also to *j*, who thus represent alternate ways for information from each to reach each other. Define the relationship $p_{iq}m_{iq}$, where *p* represents the proportion of *i*'s network time and energy invested in maintaining the relationship with *q*, and *m* represents the marginal strength of *j*'s relationship with q. The two are defined as follows:

$$p_{iq} = \frac{z_{iq} + z_{qi}}{\sum_j (z_{ij} + z_{ji})} \text{ and } m_{jq} = \frac{z_{jq} + z_{qj}}{\max(z_{jk} + z_{kj})} \tag{3.7}$$

Here, the possibility for a directed graph is allowed by including the connection from *i* to *q* and from *q* to *i*, with similar for *j*. One can then aggregate as follows:

$$\sum_q p_{iq} m_{jq} \; for q \neq i, j \tag{3.8}$$

This measures the portion of *i*'s relationship with *j* which is redundant to its relations with other primary contacts *(q)*. The non-redundant portion of this relationship is simply one minus the above summation, and Burt suggests that the effective size of a node's network is simply the sum of the non-redundant portions of a node's contacts. The effective size of the network ranges from one (which would indicate that the rest of the network is very well connected, and all of the information a given node obtains is redundant, in the sense that it could come from numerous contacts) up to *N*, the total number of contacts a node has in the network. Thus, if one divides the measure of effective network size by *N*, one has a measure of the efficiency of the network, from the perspective of the node being analysed.

Burt then goes on to describe 'constraint', which he suggests occurs in the absence of structural holes. Constraint occurs when there is a great degree of indirect condition between one node and another, which means that, even if the first node severs its direct connections with the second, the amount of paths which will lead it back to the second mean that the second node can constrain its opportunities for entrepreneurial activity with other nodes to which a given node is connected. In effect, a node has invested a great deal of time and effort, directly and indirectly, on ties with another node, and thus that connection tends to drive its actions. Burt defines constraint as follows:

$$p_{ij} + \sum_q p_{iq} p_{qj}, q \neq i, j \tag{3.9}$$

Where *p* is, as previously, the proportion of network time one node spends on relations with another. When this expression is squared, the result measures the constraint on node *i* from a lack of primary holes around j. Constraint is a measure of the lack of structural holes around those connected to a given node. Its maximum is one, and at one, there is no-one in the network to whom *i* could turn to to support it in opposing demands from *j*.[40]

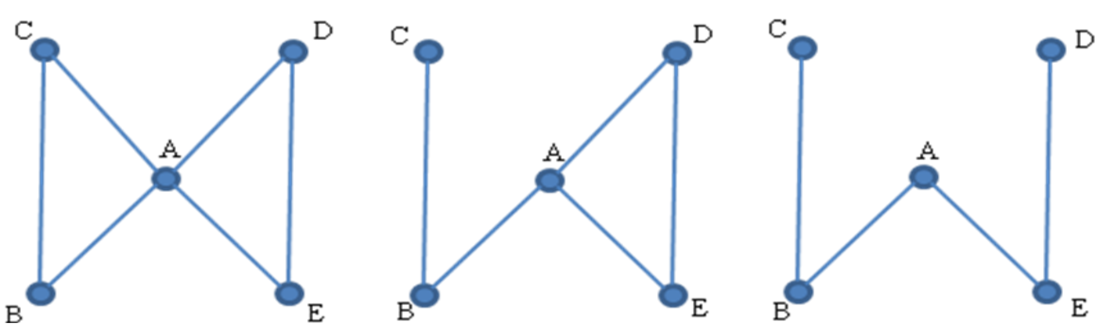
Borgatti (1997) points out an important aspect in relation to Burt's measures above. When one has a simple zero-one adjacency matrix, one can only measure whether two

[40] Busken & Van de Rijt (2008) show that the maximum is actually 9/8, rather than one, but Burt (1992) suggests it is one, and no outlet in the empirical work of this thesis exceeds one.

parties are connected or not, rather than the strength of that connection. In this situation, the measure of redundancy is simply the average degree (number of connections) of all of the nodes connected to the node for which the calculation is being made. Efficiency is therefore the density of the network around the node under consideration, multiplied by *n-1* (where n is the total number of nodes in the network). The relationship between redundancy and efficiency is then one minus this density. Thus, for a fairly small, fairly densely connected network, Burt's (1992) measure of efficiency, when applied to a zero-one adjacency matrix, will be fairly close to being a simple linear transformation of network density.

To obtain a flavour of Burt's measures of efficiency and constraint, which I use in Chapter Six, consider again Figure 3.3; this time with the constraint and efficiency scores, rather than the centrality scores, as shown in Figure 3.4.

Figure 3.4: Efficiency and Constraint in a Five-Node Network



	Efficiency	Constraint	Efficiency	Constraint	Efficiency	Constraint
A	0.75	0.563	0.778	0.611	1	0.5
B	0.5	0.953	1	0.5	1	0.5
C	0.5	0.953	1	1	1	1
D	0.5	0.953	0.5	1	1	1
E	0.5	0.953	0.5	1	1	0.5

The first thing to note is that, in general, the relative values are different from those for centrality; node A is neither the least constrained, nor the most efficient, despite being the most central in all three networks above. Moreover, constraint and efficiency are not directly related; although there appears to be some form of inverse relationship in the bow-tie, this is a function of this particular shape, where four of the nodes have the same number of redundant contacts (B, C, D and E) and are equally constrained by the most central node. However, this is not the case in the latter two networks. Note especially the right-most straight line. The efficiency scores are all the same because no node has a connection with another node that is shares with a third node (like A's connection to B in the bow-tie, which it shares with C). The end-most nodes (C and D) are more constrained than those nodes closer to the centre because they have no ability to pass on or stop any information flow. However, the most central node (A) is no longer better off than B or E, as it is in the centrality scores in Figure 3.3, because, whilst A could decide to stop information flowing from B to E and vice versa (wherever such information had originated), B can stop information flowing from A to C (and vice versa) and E can do the same for information flowing between A and D. They are thus structurally equivalent in the sense of their constraint, even though A is more central than B or E in Figure 3.3, because A is connected to two relatively central nodes (B and E), whilst B and E are connected to only one (A).

Finding Sub-Networks

In many cases, it is not just the whole network which is of interest, but also the various smaller sub-networks contained within it. This is particularly pertinent in the case of

Perth, as I explore further in Chapter Four. It is therefore useful to explore how one might use network structure to uncover important sub-markets.

In principal, communities, or sub-networks, are groupings whereby the number of internal connections is greater than the number of external connections (Freeman, 1993). However, applying this principal raises two issues; it can be very time consuming and the results are not necessarily unique. The time issue can be addressed by incorporating some form of search structure, and Freeman (1993) proposes a genetic algorithm which does precisely this. However, the non-unique nature of subgroups remains, and means that some degree of judgement must always be exercised.

Girvan & Newman (2003a,b) characterise two approaches to finding sub-networks, agglomerative approaches and divisive approaches; summarising the literature on the first and devising a new method for following the second.[41] In an agglomerative approach, one first devises a measure of similarity between each pair of nodes and then, beginning with an empty network, starts adding nodes in decreasing orders of their similarity. Each step taken represents a different submarket characterisation. Girvan & Newman's (2003a,b) divisive approach starts with a measure of 'edge betweenness' (how many paths flow along a given edge connecting two nodes), and then removes edges in descending order of edge betweenness, recalculating the score after each removal. Again, each round of this process will give rise to a different set of subgroups. Girvan &

[41] See Wilkinson & Huberman (2002), Radicchi, Castellano, Cecconi, Loreto, & Parisi (2004) and Gleiser & Danon (2003) for variations on these approaches.

Newman (2003a,b) also derive a test of their model, called modularity, which I describe in more detail and use in Chapter Five.

Agglomerative and divisive approaches are precise, but they are complex, and still require the use of judgement to determine which step is the right one to stop at in order to characterise the appropriate submarket division. There is a literature in geography, however, which uses a much simpler method that, whilst still requiring some judgement, delivers a unique result. This literature stems from a seminal paper by Gould (1967) which also underpins much of the more modern literature on graph-splitting, including Girvan & Newman's (2003a,b) work above. It is Gould's (1967) approach that I use in Chapter Five to determine appropriate sub-market splits. In Chapter Four, I provide some reasons for doing so.

Gould's (1967) approach is based upon the eigenvectors associated with the second to n^{th}-largest eigenvalues of the adjacency matrix describing the network. Since an adjacency matrix is symmetric, the first eigenvector will have all positive entries, and the second to n^{th} eigenvectors, in order that they can be orthogonal to the first, must have a mixture of positive and negative elements. Gould suggests that collections of like-signed elements in each eigenvector might represent particular sub-structures associated with the element indexed with the relevant eigenvalue, or different ways in which one might divide up the network. One can thus choose a collection of eigenvectors that allow one to tell a consistent story about the optimal way in which the network should be divided.[42] He illustrates this approach by considering the road networks of Uganda and Syria, and uses it to pick out regional centres in each country, and the network of towns that surround them.

Despite the seemingly ad-hoc nature of Gould's (1967) approach, it does provide useful results that can be examined in various ways (see Chapter Five). It has been followed by other geographers, most particularly by his students, who use it widely in Africa (see Brookfield, 1973). Cliff, Haggett & Ord (1973) use it to examine airline networks, whilst Boots (1985) shows how the approach gives consistent divisions for cellular networks of different sizes (that is, a landscape divided into cells), provided the number of cells is greater than 20. O'Huallachain (1985) uses a variant of Gould's methodology to reduce the dimensionality of input-output tables, and Hill (1998) uses it to group precincts into electorates. Tinkler (1971, 1975) and Hay (1975) debate an extension by Tinkler (1971) that considers flows of information (which he terms 'rumour' and 'anti-rumour') whilst Straffin (1980) explores the mathematical underpinnings of Gould's (1967) work through the use of the Perron-Freobenius theorem.

[42] The number of eigenvectors to choose is arbitrary. Boots (1985) points out that the signal-to-noise ratio decreases as eigenvalues get smaller and thus, in practical terms, only a few of the larger eigenvectors will provide useful information.

Chapter Four: Analytical Model

Figure 5.9 (p. 178) shows how prices in Perth's retail petroleum market follow the saw-toothed pattern of an Edgeworth Cycle. The observation is not new, but in this chapter I develop a simple spatial duopoly model which admits Edgeworth Cycles as a Markov-perfect equilibrium.

The model is used in the empirical analysis for its predictions on relationships between price minima for two firms that compete. This is the mechanism by which the decision is made to connect two retail petroleum outlets in the network that summarises market structure which I construct in Chapter Five. It is the summary statistics associated with this network that form some of the variables in the regression models of price in Chapter Six. I thus do not directly test the model developed in this chapter empirically. Rather I use it as a guide to the formation of a network, whose attributes are then used as part of an empirical model which seeks to explain pricing decisions.

Model Outline

Consider the situation of two firms, A and B, located on a straight road, and selling an homogenous product to homogenous consumers who enter the road (travelling in both directions) on either side of Firms A and B, but who plan to exit it at some point between them.[43] Assume that the firms' locations are fixed and that no new entry is possible for

[43] Customers who pass both firms can access each without incurring additional transport costs, and hence patronise the firm with the lowest costs. Customers who enter and leave within the interval between Firms A and B behave like those passing both if they enter and leave on different sides of the intersection between the cost of travel curves for each firm by patronising the lowest-cost firm, and those which enter and leave

the duration of the game. Assume that each customer is perfectly informed about the price, and that the points at which they plan to leave the road form a continuous, uniform distribution between the two outlets. Assume further that these homogenous customers have inelastic demand for a single unit of the product provided price is at or below the price a monopolist would charge, taken to be the market reservation price. This stylised model seems apt in the context of a retail petroleum market where retail petroleum outlets are neither right next to each other, nor so far away that the pricing decisions of each is irrelevant to the other.

Each customer will pass one of the retail petroleum outlets first, and thus is able to obtain petrol from that station without incurring any additional transport costs. However, obtaining petrol from the other outlet would require them to deviate from their proposed travel plans, incurring a cost to do so. Customers would only contemplate such a side-trip if the outlet in question had fuel prices which were sufficiently low to warrant the additional travel costs.

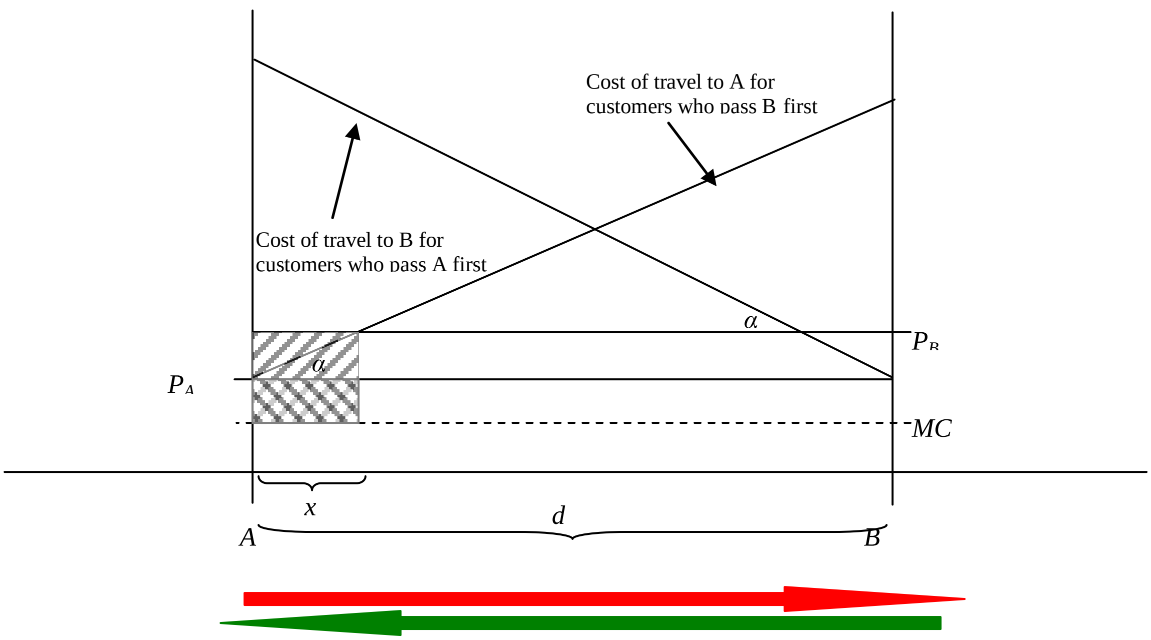
If the outlets have the same prices, each will capture the customers which pass them first. As one prices below the other, it captures a certain share of its rival's "natural" customers (ie – those which pass it first), beginning with those which had planned to leave the road closest to the (now) lower-priced station. However, in reducing its price, the firm reduces the profits it can make from its "natural" customers, and thus it needs to balance these losses against the gains which accrue from increasing its market share.

---

on the same side of the intersection point behave like customers which pass only one outlet, with higher costs of travel.

The model is similar to that of Hoover (1937) in that spatial differentiation and a lack of entry gives rise to a degree of market power, which is greater for those customers located (here, leaving the highway) near the firm in question. However, it differs in one important respect; rather than the firm delivering to customers, the customers come to the firm. Thus, the firm in question has no notion of from whence each customer has come, and must thus set a single market price. The resulting equilibrium of this game is outlined below, beginning with a graphical representation of the discussion above is shown in Figure 4.1.

Figure 4.1: Pricing Game for Two Retail Petroleum Outlets



To specify the model more formally, consider the case whereby the two firms play a sequential move game, with the Markov assumption imposed, as in Maskin & Tirole (1988). Here the payoff-relevant information to which each firm will restrict itself is the price of its rival in the previous period, the quantity of consumers passing each firm first (its "natural" customers) and the marginal cost each firm faces.

In this situation, the demand faced by each firm will be as follows:

$$D_i = \begin{cases} q_i - \delta q_i & if \quad p_i > p_j \\ q_i & if \quad p_i = p_j \\ q_i + \delta q_j & if \quad p_i < p_j \end{cases} \tag{4.1}$$

Where:

p_i = price charged by firm i.

q_i = number of overall customers that are the "natural" customers of firm i.

δ = the proportion of the higher-priced firm's customers that are lost to the lower-priced firm.

In the relatively simple situation shown in Figure 4.1 and described above, it is possible to solve for δ through some straightforward geometry. Note that with a uniform distribution of leaving points for the highway, the probability that a given customer will leave at a given point is $1/d$, where d is the distance between the two firms. Thus, x/d in Figure 4.1 above represents δ; the proportion of customers who pass Firm B first, and who might be induced to travel on to Firm A by virtue of the difference between their two prices (when Firm A has a lower price). Some simple geometry shows that:

$$x = \frac{P_B - P_A}{\tan \alpha} \tag{4.2}$$

Where $\tan\alpha$ = the per-unit cost of travel (cost/distance). Thus, Equation 4.1 can be expressed as follows:

$$D_i = \begin{cases} q_i - q_i\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ q_i & if \quad p_i = p_j \\ q_i + q_j\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \tag{4.3}$$

Note that in this instance, because of the uniform distribution of leaving points, the lower-priced firm will always capture some of the customers which pass the higher-priced firm first, except when the firms are an infinite distance apart. A more realistic distribution of leaving points, which saw all customers leave after a certain point, would be appropriate in a general sense, but for retail petroleum outlets located relatively close to each other, Equation 4.3 seems reasonable. Note also that if the firms are adjacent to each other, they will capture all of their rival's market share through undercutting, and the model collapses to that of Maskin & Tirole (1988).

The profit function for each firm when demand is described by Equation 4.3 will thus be:

$$\pi_i = \begin{cases} q_i(p_i - c_i) - q_i(p_i - c_i)\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ q_i(p_i - c_i) & if \quad p_i = p_j \\ q_i(p_i - c_i) + q_j(p_i - c_i)\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \tag{4.4}$$

Where p_i, q_i and $\tan\alpha$ are defined as previously, and c_i = marginal cost of firm *i*.

The dynamic price path traced out as each firm optimises in response to its rival can be rather complex. To simplify, and ultimately explore the Markov-perfect equilibrium, I thus consider a simplified version of the model, which highlights its important dynamics.

Simple Model

In order to explore the equilibria of this model, I begin with its most simple characterisation; where marginal costs are assumed equal and set equal to zero, and each firm has an equal number of "natural" customers ($q_1=q_2=q$). This gives rise to:

$$\pi_i = \begin{cases} qp_i - qp_i\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ qp_i & if \quad p_i = p_j \\ qp_i + qp_i\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \tag{4.5}$$

To begin the sketch of the Markov perfect equilibrium, consider first the case where Firm B arbitrarily sets its price at p^*, greater than the minimum price that firm is willing to accept. The optimal response for Firm A is found by taking the derivative of the profit function in Equation 4.5 and setting it to zero. Since the firm can always increase its profit by undercutting (most obvious by reference to Equation 4.1) at any price above the minimum, this means that one solves the following derivative:

$$\pi_A = qp_A + qp_i\left(\frac{p^* - p_A}{d\tan\alpha}\right)$$

$$\pi_A = qp_A + \frac{1}{d\tan\alpha}\left(qp_A p^* - qp_A^2\right)$$

$$\frac{\partial\pi_A}{\partial p_A} = q + \frac{1}{d\tan\alpha}\left(qp^* - 2qp_A\right) = 0$$

$$\Rightarrow 1 + \frac{1}{d\tan\alpha}\left(p^* - 2p_A\right) = 0 \qquad (4.6)$$

$$\Rightarrow p^* - 2p_A = -d\tan\alpha$$

$$\Rightarrow p_A = \tfrac{1}{2}\left(d\tan\alpha + p^*\right)$$

Firm B then responds to this optimal price in the same way,[44] since the game is symmetric, and if we express this response in terms of the initial price chosen ($p*$), then Firm B's optimal price response (found in the same way as 4.6 above) is:

$$p_B = \tfrac{1}{4}\left(3d\tan\alpha + p^*\right) \qquad (4.7)$$

The best response to Equation 4.7 is:

$$p_A = \tfrac{1}{8}\left(7d\tan\alpha + p^*\right) \qquad (4.8)$$

The pattern which emerges in subsequent rounds can be summarised for Round *k* as:

$$p = \tfrac{1}{2^k}\left(\left(2^k - 1\right)d\tan\alpha + p^*\right) \qquad (4.9)$$

[44] That is, substitute p_A for $p*$ and p_B for p_A.

At the limit, the equilibrium best response is:

$$p = d \tan\alpha \qquad (4.10)$$

Once one of the firms reaches this point, its opposite number has the same optimal best response in a single-shot game, and thus the two firms reach a static equilibrium. However, this is not a dynamic equilibrium; if one of the firms relents (increases its price), both can increase their prices, and hence profits, over the course of a new cycle. Relenting is, as Maskin & Tirole (1988) suggest, a public good; each would prefer that the other do so first. Thus, at the minimum of each cycle, the two firms will play a mixed strategy 'war of attrition' (provided each has a discount factor (δ) near one)[45] in an endeavour to entice their rival to raise price first.

The exact form of the mixed strategy equilibrium will depend upon the parameters of the game (how far apart the two firms are, the cost of travel and so on) which would dictate profits over a whole cycle. However, one can explore how the game might unfold by using an example. Consider the first four rounds of a game where the initial move is an increase in price to the maximum price possible, $\bar{p}$ (the monopoly or reservation price for the market, beyond which demand is zero). There is good reason to expect that this will be the price to which the firm which relents moves to because each subsequent best-response prices is a fraction of the relenting price. Thus, profits are maximised in the

[45] Where $\delta = \exp(-rT)$ with r being the relevant interest rate and T being the time between successive rounds of the game, as in Maskin & Tirole (1988). A high discount factor will therefore mean that the future has a very similar value to the relevant player as does today.

case where that first price is itself maximised. Also, note that the profits available to each firm in a given round of the game if neither relents will be as follows:

$$\pi_i = qd \tan\alpha \tag{4.11}$$

This is important in calculating the net profits for each firm over the four rounds of the game. In Table 4.1, note that the cells coloured grey indicate which outlet is making a pricing decision in each round of the game. Firm B moves first.

Table 4.1: Four-Round Game Results

	Best Response Price		***Profits***	
	Firm A	*Firm B*	*Firm A*	*Firm B*
Round 0	$d^2 \tan\alpha$	$\bar{p}$	$dq\bar{p}$	$2dq\bar{p} - \frac{q\bar{p}^2}{d\tan\alpha}$
Round 1	$\frac{1}{2}\left(d^2 \tan\alpha + \bar{p}\right)$	$\bar{p}$	$\frac{q\left(d^2 \tan\alpha + \bar{p}\right)^2}{4d\tan\alpha}$	$\frac{q\left(3d^2 \tan\alpha - \bar{p}\right)\bar{p}}{2d\tan\alpha}$
Round 2	$\frac{1}{2}\left(d^2 \tan\alpha + \bar{p}\right)$	$\frac{1}{4}\left(3d^2 \tan\alpha + \bar{p}\right)$	$\frac{q\left(5d^4 \tan\alpha + 4d^2\bar{p} - \bar{p}/\tan\alpha\right)}{8d}$	$\frac{q\left(3d^2 \tan\alpha + \bar{p}\right)^2}{16d\tan\alpha}$
Round 3	$\frac{1}{8}\left(7d^2 \tan\alpha + \bar{p}\right)$	$\frac{1}{4}\left(3d^2 \tan\alpha + \bar{p}\right)$	$\frac{q\left(7d^2 \tan\alpha + \bar{p}\right)^2}{64d\tan\alpha}$	$\frac{q\left(27d^4 \tan^2\alpha + 6d^2 \tan\alpha\bar{p} - \bar{p}^2\right)}{32d\tan\alpha}$
Round 4	$\frac{1}{8}\left(7d^2 \tan\alpha + \bar{p}\right)$	$\frac{1}{16}\left(15d^2 \tan\alpha + \bar{p}\right)$	$\frac{q\left(119d^4 \tan^2\alpha + 110d^2 \tan\alpha\bar{p} - \bar{p}^2\right)}{128d\tan\alpha}$	$\frac{q\left(15d^2 \tan\alpha + \bar{p}\right)^2}{256d\tan\alpha}$
Sum of Profits ***(note that this assumes, for simplicity that any discount factors equal one)***			$\frac{q\left(329d^4 \tan^2\alpha + 294d^2 \tan\alpha\bar{p} - 75\bar{p}^2\right)}{128d\tan\alpha}$	$\frac{5q\left(117d^4 \tan^2\alpha + 214d^2 \tan\alpha\bar{p} - 75\bar{p}^2\right)}{256d\tan\alpha}$
Net Profits ***(sum of profits minus*** $5qd\tan\alpha$ ***– the profits each firm would obtain if both remained at the minimum)***			$\frac{q\left(-311d^4 \tan^2\alpha + 294d^2 \tan\alpha\bar{p} + 17\bar{p}^2\right)}{128d\tan\alpha}$	$\frac{5q\left(-139d^4 \tan^2\alpha + 214d^2 \tan\alpha\bar{p} - 75\bar{p}^2\right)}{256d\tan\alpha}$

Table 4.1 suggests that, depending upon the values of the relevant parameters, there will be cases where cycling gives higher profits than both firms remaining at the minimum price. If the initial price $\bar{p}$ in Table 4.1 is defined as being equal to $\delta d\tan\alpha$, with $\delta>1$ (that is, $\bar{p}$ is a multiple of the minimum price), both firms engaged in the five rounds of interaction shown in Table 4.1 emerge with positive profits for values of δ between 1.1 and 1.9. There thus seems to be scope for suggesting that, rather than the static equilibrium shown in Equation 4.10 being stable in a dynamic game, situations where the two firms instead play a mixed strategy equilibrium designed to facilitate relenting, but to prevent one firm from always relenting first, might not be uncommon.

I now turn to the question of whether the price path shown in Equations 4.6 to 4.10 is an equilibrium. As outlined in Chapter Three, one can construct a dynamic reaction function outlining each firm's optimal response to its rival thus:

$$R^i(\ )=p_t^i=R^i\left(p_{t-1}^j\right) \tag{4.12}$$

Following Maskin & Tirole (1988), a Markov perfect equilibrium in this context is a pair of dynamic reaction functions (R^1,R^2) which satisfy:

$$V^i\left(p_{t-1}^j\right)=\underset{c}{E}\left(\max_{p_t}\left[\pi_t^i\left(p_t,p_{t-1}^j,c_t\right)+\delta_i W^i\left(p_t\right)\right]\right)$$

and (4.13)

$$W^i\left(p_{s-1}^j\right)=\underset{c}{E}\left(\underset{p_{st}}{E}\left[\pi_s^i\left(p_{s-1}^j,p_s,c_t\right)+\delta_i V^i\left(p_s\right)\right]\right)$$

Where (V_i) denotes the value function associated with the round in which firm i makes the pricing decision, and (W_i) denotes the value function associated with the period in which firm j makes the pricing decision. The other variables are as denoted previously

In this instance, the reaction functions comprise the optimal response results summarised in Equations 4.6 through 4.10. Reorganising these into a table similar to Tables I and II in Maskin & Tirole (1988, p575 & 576), beginning with the maximum price of $\bar{p}$ and incorporating the incentive to mix strategies at the minimum price in order to induce a cycle and potentially increase profits, one has reaction functions as outlined in Table 4.2

Table 4.2: (R^1,R^2) for the Simple Game

p_j	$R^i(p_j)$
$\bar{p}$	$\frac{1}{2}(\tan\alpha + \bar{p})$
$\frac{1}{2}(\tan\alpha + \bar{p})$	$\frac{1}{4}(3\tan\alpha + \bar{p})$
$\frac{1}{4}(3\tan\alpha + \bar{p})$	$\frac{1}{8}(7\tan\alpha + \bar{p})$
$\frac{1}{8}(7\tan\alpha + \bar{p})$	$\frac{1}{16}(15\tan\alpha + \bar{p})$
. . . .	. . . .
$\tan\alpha$	$\tan\alpha \quad with \quad pr = \gamma$ $\bar{p} \quad with \quad pr = (1-\gamma)$

I claim that this is a Markov perfect equilibrium, provided that the discount rate is close to one. Formally, this would require that both elements in Equation 4.13 are satisfied by the strategies in Table 4.2 above. This requires verification that deviating at a given step does not result in a higher value for V_i or W_i. Doing so, however, rapidly becomes complicated, even in this simple case, as is seen in Table 4.1.

Arguably, however, one does not need to do so. Take Round 1 in Table 4.2. The optimum response to a price of $\frac{1}{2}(d\tan\alpha+\bar{p})$ is $\frac{1}{4}(3d\tan\alpha+\bar{p})$. If the firm facing $\frac{1}{2}(d\tan\alpha+\bar{p})$ undercuts with a different price (denoted p^*), then the subsequent best response of its rival will be $\frac{1}{2}(d\tan\alpha+p^*)$. This is because, as shown in Equation 4.6, this is the best response to any arbitrarily chosen price. Each subsequent round of best responses will, as in Equations 4.6 through 4.10, be a fraction of this price p^*. Since $p^* < \bar{p}$, the overall value of the cycle will be reduced and Equation 4.13 will not be satisfied.

Now consider the case where the firm in question responds to $\frac{1}{2}(d\tan\alpha+\bar{p})$ with a price increase, denoted p^{**}, where $\frac{1}{2}(d\tan\alpha+\bar{p}) < p^{**} < \bar{p}$. The optimal response could then be denoted $\frac{1}{2}(d\tan\alpha+p^{**})$. Subsequent responses would then depend on this price p^{**}, which again is less than $\bar{p}$, and hence leads to a lower overall profit for the cycle as a whole. Knowing this, the firm in question would in fact choose $p^{**} = \bar{p}$. Once it has done so, provided it can make some credible commitment that it will keep its price at this maximum, each firm will maximise its profits in a dynamic sense by staying at this maximum and splitting the market; in effect, acting as a cartel.

However, this cartel is highly unstable, because each firm can improve its position in a single round by undercutting to the optimal response to the cartel price. Moreover, this incentive is effectively doubled; if it knows that the response of its rival to a price of $\frac{1}{2}\left(d\tan\alpha+\bar{p}\right)$ will be the monopoly price $\bar{p}$, then it will also know that deviating from the monopoly price will give it two periods of increased profits, rather than one. Thus, the stronger the commitment of one party to the monopoly price, the greater the incentive for the other party to use the optimal response to the monopoly price.

The above does not constitute a proof, in the strict sense, of the Markov perfect equilibrium. Such a proof is problematic given the number of variables involved.[46] However, it does suggest that Edgeworth cycles are a very likely outcome in a simple model such as this, because the alternative, the cartel price, is unstable.

General Model

The simple model above restricted Equation 4.4 to a case where marginal costs are equal to zero and the number of customer passing each outlet first is the same. I now explore the consequences of relaxing each of these assumptions. The elements of each dynamic reaction function are more complex, but a similar pattern emerges as in the simple model. It seems likely that a Markov-perfect equilibrium still obtains in these more complex models, following the same chain of logic as outlined above.

[46] Maskin & Tirole (1988) undertake their proof with a simpler demand and profit function. Noel (2008), using a more complex function faces a similar issue and instead examines computational solutions.

Consider first the case where marginal costs are different.[47] This gives the following profit function:

$$\pi_i = \begin{cases} q\ (p_i - c_i) - q\ (p_i - c_i)\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ q\ (p_i - c_i) & if \quad p_i = p_j \\ q(p_i - c_i) + q\ (p_i - c_i)\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \tag{4.14}$$

Where each of the variables are defined as previously. :

If Firm B again moves first, setting a price of p^*, at an arbitrary level above the minimum price, which is assumed to exist in equilibrium at this stage and shown to do so below, then the best response of Firm A, from Equation 4.13 above is:

$$p = \tfrac{1}{2}\left(d\tan\alpha + p^* + m\right) \tag{4.15}$$

Where, here *m* denotes the marginal cost of Firm A, and *n* (in Equations 4.16 to 4.23 below) indicates the marginal cost of Firm B. The best response to this price is:

$$p = \tfrac{1}{4}\left(3d\tan\alpha + p^* + m + 2n\right) \tag{4.16}$$

In the next round, the best response to this price is then:

[47] When marginal costs are not equal to zero, but are equal to each other, the best responses are the same as in Equations 4.4 to 4.8, except that marginal cost is added to each.

$$p = \tfrac{1}{8}\left(7d\tan\alpha + p^{*} + 5m + 2n\right) \tag{4.17}$$

The pattern which emerges is similar to the simple case, but with the addition of marginal cost. The equilibrium which emerges is:

$$p = d\tan\alpha + \tfrac{2}{3}m + \tfrac{1}{3}n \text{ for Firm A,}$$

and (4.18)

$$p = d\tan\alpha + \tfrac{1}{3}m + \tfrac{2}{3}n \text{ for Firm B.}$$

Again, this is an equilibrium in a static game, but in a dynamic game where discount factors are high, each firm will have the same incentive to adopt a mixed strategy approach at the minimum price to endeavour to induce the public good of a price increase.

Consider finally the case where neither the marginal costs nor the numbers of customers are the same. This gives the following expression for the profit of firm *i*:

$$\pi_i = \begin{cases} q_i(p_i - c_i) - q_i(p_i - c_i)\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ q_i(p_i - c_i) & if \quad p_i = p_j \\ q_i(p_i - c_i) + q_j(p_i - c_i)\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \tag{4.19}$$

This is the same expression as Equation 4.2 above. Now let Firm A decide to set an arbitrary price of p^*, and observe the chain of best responses. If Firm A sets a price of p^*, Firm B's best response is:

$$p = \frac{1}{2q}\left(nq + d\tan\alpha r + qp^*\right) \qquad (4.20)$$

The best response to this price, when Firm A responds in turn, will be:

$$p = \frac{1}{4qr}\left(d\tan\alpha\left(2q^2 + r^2\right) + qr\left(2m + n + p^*\right)\right) \qquad (4.21)$$

In these two expressions, m and n refer to the marginal costs of Firms A and B respectively, whilst q and r refer to the "natural" customers of each firm. The best response to the above price is:

$$p = \frac{1}{8qr}\left(d\tan\alpha\left(2q^2 + 5r^2\right) + qr\left(2m + 5n + p^*\right)\right) \qquad (4.22)$$

Again, a similar pattern is emerging, and the equilibrium which is eventually reached can be characterised thus:

$$p = \frac{1}{3qr}\left(\left(2q^2 + r^2\right)d\tan\alpha + \left(2m + n\right)qr\right) \text{ for Firm A,}$$

and (4.23)

$$p = \frac{1}{3qr}\left(\left(q^2 + 2r^2\right)\tan\alpha + \left(m + 2n\right)qr\right) \text{ for Firm B.}$$

This static equilibrium is very similar to the different marginal costs case above, but with the quantities of natural customers influencing results. Again, a 'public good' is associated with relenting, and the two firms will play mixed strategies at the minimum, relenting with some positive probability to induce a repeat of the cycle.

Simultaneous Move Case

In most jurisdictions, retail petroleum outlets are not restricted in when they make their pricing choice; they can react to prices charged by rivals whenever they determine it is necessary to do so. In such circumstances, it seems apposite to consider the game as a sequential game, as modelled in the previous section.

However, in the particular case examined in the empirical component of this thesis, the *FuelWatch* regulations require every retail petroleum outlet to provide a price to the regulator at the same time. The fact of prices being reported simultaneously does not necessarily imply that a simultaneous game is being played; Lau (2001) suggests that an equilibrium where price hikes and cycles occur can be sustained provided strategic complementarity exists. This is because changes in the relevant strategic variable (here, price) can produce an externality for the opposing player, which then leads the firms to commit to higher prices for more than one period, even when they move simultaneously. Maskin & Tirole's (1988) assumption of sequential moves make exogenous the strategic commitment to keep prices high for two periods and thus begin a cycle. However, Lau (2001) shows that one does not need to make this assumption, as strategic complementarity means that commitment can arise endogenously. That said, because the

FuelWatch regulations require simultaneous choice of price, rather than assuming a sequential game eventuates regardless of this regulatory restriction, I explore the outcomes of a simultaneous game, within the same framework as the sequential game of the previous section.

To simplify the analysis, I work with the simple model (Equation 4.5) where marginal costs are assumed equal and equal to zero, and each firm has the same number of "natural" customers (q_1=q_2=q). Thus:

$$\pi_i = \begin{cases} qp_i - qp_i\left(\dfrac{p_i - p_j}{d\tan\alpha}\right) & if \quad p_i > p_j \\ qp_i & if \quad p_i = p_j \\ qp_i + qp_i\left(\dfrac{p_j - p_i}{d\tan\alpha}\right) & if \quad p_i < p_j \end{cases} \qquad (4.5)$$

If one makes no further assumptions, and one assumes that firms play the game in a myopic fashion, then the firms move instantaneously through Equations 4.6 to 4.10. However, this is not what one observes empirically; firms in Perth generally follow an Edgeworth cycle in their pricing. Thus, to explore why this might happen, I make an additional assumption; that there is some exogenous limit to the size of their choices of price decrease each time they play the simultaneous game. That is, in terms of choice of price, if the current lowest price amongst the two players is p_t, I assume that each has three choices in the next round of the game:

$P_{i,t+1}=m$

$P_{i,t+1}=p_t$

$P_{i,t+1}=p_t-k$

Here *m* is the monopoly or maximum price, and *k* is the (exogenously imposed) maximum size of any undercut. Thus, each firm can choose to undercut the current price by up to some discrete amount *k*,[48] to play the same price again, or to return to the monopoly price.[49]

I do not claim any proofs in the discussion below, but instead explore the structure of the game in the context of the exogenous restrictions. The result, I suggest, allows the formation of some interesting conjectures as to how Edgeworth cycles might emerge if firms play a simultaneous pricing game. In the discussion, I set $m=5$, and explore the consequences of $k=1$, 2 and 3.

Game with *k=1*

In this instance, since the minimum value of *k* is one, each firm has only one undercutting choice; to undercut by a cent. Consider the case where the current price is 5cpl.[50] There

[48] Maskin & Tirole (1988) make the same assumption that prices are discrete numbers, rather than being part of a continuum, and this same assumption is carried forward in the rest of the literature. This is partially because the model changes with continuous prices, but also because prices are not generally continuous. In the Perth retail petroleum market, for example, the minimum change in price legally allowed is 0.1 cpl.

[49] In the games outlined below, it can be relatively easily verified that the maximum price dominates any other price above that charged by a rival.

[50] Throughout this section, I make reference to "the current price". By this, I mean the current minimum of the two prices being charged by the firms at present. The expression is intended as shorthand to avoid making the text overly difficult to read.

are two choices which each firm can make; they can stay at five cpl, or reduce to four cpl. There are thus four possible situations. These are shown in Table 4.4.

Table 4.3: Price and Profit Outcomes for p_t=5, k=1

	A	B	C	D
	$P_{i,t+1}=5$, $p_{j,t+1}=5$	$P_{i,t+1}=5$, $p_{j,t+1}=4$	$P_{i,t+1}=4$, $p_{j,t+1}=5$	$P_{i,t+1}=4$, $p_{j,t+1}=4$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha+1)$	$4q$

Here *tan α* is the cost of travel, as in the previous section and d is the distance between the two retail petroleum outlets. Note first the nomenclature, as this will carry forward to all examples below, some of which have too many outcomes to place in a table such as this. In each case, we start with $p_{i,t+1}=5$, $p_{j,t+1}=5$. This is labelled "A". Next, $p_{j,t+1}$ is reduced by one, and this is labelled "B". If k were greater than one, as it is in the next two games below, then we would have moved through the other choices of $p_{j,t+1}$, labelling them "C" "D" and so on, before moving to the set of outcomes associated with $p_{i,t+1}=4$, and so on downwards.

Note also the outcomes. Where $p_{i,t+1}=p_{j,t+1}$, The profit is simply the price. If $p_{i,t+1}>p_{j,t+1}$, the resultant profit for Firm i is:

$$\frac{p_{i,t+1}}{d\tan\alpha}\left(d\tan\alpha-\left[p_{i,t+1}-p_{j,t+1}\right]\right) \qquad (4.24)$$

If $p_{i,t+1}<p_{j,t+1}$,the resultant profit for Firm i is:

$$\frac{p_{i,t+1}}{d\tan\alpha}\left(d\tan\alpha + \left[p_{i,t+1} - p_{j,t+1}\right]\right) \tag{4.25}$$

This is consistent through all of the games analysed below. I now compare which of the above situations is preferred by Firm *i*, and under what circumstances. Firstly, A is preferred to D, always. Now compare A with B. Assume first that A<B. This means:

$$5q < \frac{4q}{d\tan\alpha}\left(d\tan\alpha + 1\right) \rightarrow 5d\tan\alpha < 4d\tan\alpha + 4 \rightarrow \tan\alpha < \frac{4}{d} \tag{4.26}$$

If travel costs are relatively small and the outlets relatively close together (the smaller the travel costs, the further apart they can be for 4.27 to hold), B will be preferred to A. Now compare C with D, and assume that C<D, which gives:

$$\frac{5q}{d\tan\alpha}\left(d\tan\alpha - 1\right) < 4q \rightarrow 5d\tan\alpha - 5 < 4d\tan\alpha \rightarrow \tan\alpha < \frac{5}{d} \tag{4.27}$$

If the relationship between travel cost and distance is such that 4.26 holds, then D will be preferred to C. Moreover, since A is preferred to D, one can also say that A is preferred to C, and B is preferred to C and D.

Before going further, it is worth exploring the relationship between distance and travel costs. As travel costs decrease, outlets can be further apart and the above preference relationships will still hold. The key relationship is between A and B above; between undercutting and pricing at the monopoly price. The lower are travel costs, the wider will be the circle of competitors for a given retail petroleum outlet, because customers will be willing to travel further in order to buy at a lower price.[51] This makes intuitive sense, and indeed accords with the findings of Marvel (1976), who finds more intense competition on commuter routes, where travel costs are smaller per unit of distance (in a given direction) than within surrounding local areas, where customers might need to navigate unfamiliar streets to find a competitor. I return to this relationship between undercutting and the monopoly price at the conclusion to this section, as it has important implications for the presence of cycles.

In order to find the Nash Equilibrium of the game described above, I first put all the preferred outcomes into a table, Table 4.4. In Table 4.4, the preference when Situation A is compared to Situation B (say) is shown in the ABth cell in the table. Where the situations are equal, the cell is coloured black. For this very simple game, Table 4.4 is perhaps overly complicated, but the approach is very useful when there are more situations being compared, so I introduce it here.

Table 4.4: Matrix of Preferred Outcomes, p_t=5, k=1

	A	**B**	**C**	**D**
A		B	A	A
B	B		B	B
C	A	B		D
D	A	B	D	

[51] However, beyond a certain distance, undercutting will no longer be profitable, and the firms will act as monopolists, which also seems intuitively sensible.

In Table 4.4, in Row and Column B, all of the entries are “B”, which indicates that B is preferred to each other situation in this game. Thus, we may designate it as the preferred option.[52] If Row B and Column B are removed from the matrix in Table 4.4, then all of the entries in Row A and Column A of this three by three matrix are “A”, meaning that Situation A is preferred to everything except Situation B. If Row A and Column A are now removed, then Situation D is seen to be preferred over the remaining Situation C. Thus, we can write:

B>A>D>C

This is the same outcome that I came to above, and I repeat it here to show the chain of logic in Table 4.4 because, in subsequent games, there are too many pair-wise comparisons to show them all; Table 4.4 represents a way of summarising the work required to obtain a set of ordered preferences, which is then used to calculate the Nash Equilibrium of the game. It is to this Nash Equilibrium that I now turn, in Table 4.5.

Table 4.5: Nash Equilibrium of Game Where $p_t=5$ and $k=1$.

		Station *j*	
		$P_{j,t+1}=5$	$P_{j,t+1}=4$
Station *i*	$P_{i,t+1}=5$	A,A	B,C
	$P_{i,t+1}=4$	C,B	D,D

As is clear from the presentation of the situations in Table 4.4 above, there is symmetry in the game. Thus, Situation B for Station *i* is the same as Situation C for Station *j*.

[52] As noted above, provided travel costs are sufficiently small.

Consider first if Station *i* believes that Station *j* will choose $p_{j,t+1}=5$. If Station *i* believes this will be Station *j*'s choice, it can respond with $p_{i,t+1}=5$, and find itself in Situation A, or it can respond with $p_{i,t+1}=4$, and find itself in Situation B. Since it prefers Situation B to Situation A (provided travel costs are not large), it will choose $p_{i,t+1}=4$. If Station *j* believes that Station *i* will choose $p_{i,t+1}=4$, it can respond with $p_{j,t+1}=5$, to find itself in Situation C, or it can respond with $p_{j,t+1}=4$, and find itself in Situation D. Since it prefers Situation D to Situation D, it will respond with $p_{j,t+1}=4$. If both firms have chosen a price of four, none can deviate unilaterally to improve their payoffs, and we thus have a pure-strategy Nash equilibrium.

Thus, if the game starts at the monopoly price of five, and each firm is able to reduce its price by one cpl, then after one round, the game will result in a Nash Equilibrium whereby the price equals four.

Now consider the next round. Here, each firm has three choices; it can choose a price of five (the monopoly price), a price of four (the current market price) or a price of three (reducing the price by *k*). This gives rise to a slightly more complex situation for prices and profits, which is shown in Table 4.6.

Table 4.6: Price and Profit Outcomes for p_t=4, k=1

	A	B	C	D	E
	$P_{i,t+1}=5$, $p_{j,t+1}=5$	$P_{i,t+1}=5$, $p_{j,t+1}=4$	$P_{i,t+1}=5$, $p_{j,t+1}=3$	$P_{i,t+1}=4$, $p_{j,t+1}=5$	$P_{i,t+1}=4$, $p_{j,t+1}=4$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha+1)$	$4q$
	F	**G**	**H**	**I**	
	$P_{i,t+1}=4$, $p_{j,t+1}=3$	$P_{i,t+1}=3$, $p_{j,t+1}=5$	$P_{i,t+1}=3$, $p_{j,t+1}=4$	$P_{i,t+1}=3$, $p_{j,t+1}=3$	
Profit$_{i,t+1}$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+1)$	$3q$	

Note that the nomenclature of situations matches the pattern in Table 4.3 above, but extends out to nine, rather than four cases. There are too many pair-wise combinations to show all working, so the matrix of preferred outcomes is shown in Table 4.7.

Table 4.7: Matrix of Preferred Outcomes, p_t=4, k=1

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A		A	A	D	A	A	G	H	A
B	A		B	D	E	F	G	H	I
C	A	B		D	E	F	G	H	I
D	D	D	D		D	D	G	D	D
E	A	E	E	D		E	G	H	E
F	A	F	F	D	E		G	H	I
G	G	G	G	G	G	G		G	G
H	H	H	H	D	H	H	G		H
I	A	I	I	D	E	I	G	H	

This gives rise to the following order of preference:

G>D>H>A>E>I>F>B>C

I now turn to the Nash Equilibrium of this game, in Table 4.8.

Table 4.8: Nash Equilibrium of Game Where p_t=4 and k=1.

		Station *j*		
		$P_{j,t+1}=5$	$P_{j,t+1}=4$	$P_{j,t+1}=4$
Station *i*	$P_{i,t+1}=5$	A,A	B,D	C,G
	$P_{i,t+1}=4$	D,B	E,E	F,H
	$P_{i,t+1}=3$	G,C	H,F	I,I

Following the same process as for Table 4.5 reveals just one pure strategy equilibrium, at I,I, or where $p_{i,t+1}=p_{j,t+1}=3$. Thus, the second round of this game will result in the price moving down by one more cent.

I now turn to the next round, where $p_{i,t}=p_{j,t}=3$. Here, each firm has three choices; it can choose a price of five (the monopoly price), a price of three (the current market price) or a price of two (reducing the price by *k*). This gives rise to a situation for prices and profits, which is shown in Table 4.9.

Table 4.9: Price and Profit Outcomes for $p_t=3$, $k=1$

	A	**B**	**C**	**D**	**E**
	$P_{i,t+1}=5$, $p_{j,t+1}=5$	$P_{i,t+1}=5$, $p_{j,t+1}=3$	$P_{i,t+1}=5$, $p_{j,t+1}=2$	$P_{i,t+1}=3$, $p_{j,t+1}=5$	$P_{i,t+1}=3$, $p_{j,t+1}=3$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$3q$

	F	**G**	**H**	**I**	
	$P_{i,t+1}=3$, $p_{j,t+1}=2$	$P_{i,t+1}=2$, $p_{j,t+1}=5$	$P_{i,t+1}=2$, $p_{j,t+1}=3$	$P_{i,t+1}=2$, $p_{j,t+1}=2$	
Profit$_{i,t+1}$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+1)$	$2q$	

Note that the nomenclature of situations matches the pattern in Table 4.6 above, but the prices and profits are different. The matrix of preferred outcomes, shown in Table 4.10.

Table 4.10: Matrix of Preferred Outcomes, $p_t=3$, $k=1$

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A		A	A	D	A	A	G	H	A
B	A		B	D	E	F	G	H	I
C	A	B		D	E	F	G	H	I
D	D	D	D		D	D	G	D	D
E	A	E	E	D		E	G	H	E
F	A	F	F	D	E		G	H	I
G	G	G	G	G	G	G		G	G
H	H	H	H	D	H	H	G		H
I	A	I	I	D	E	I	G	H	

Note that Tables 4.7 and 4.10 are identical. This means that the order of preference, and the pure strategy Nash equilibrium is the same (when expressed in letters). Thus, the game moves to a price of two.

I now turn to the next round, where $p_{i,t}=p_{j,t}=2$. Here, each firm has three choices; it can choose a price of five (the monopoly price), a price of two (the current market price) or a price of one (reducing the price by k). This gives rise to a situation for prices and profits, which is shown in Table 4.11.

Table 4.11: Price and Profit Outcomes for $p_t=2, k=1$

	A	**B**	**C**	**D**	**E**
	$P_{i,t+1}=5, p_{j,t+1}=5$	$P_{i,t+1}=5, p_{j,t+1}=2$	$P_{i,t+1}=5, p_{j,t+1}=1$	$P_{i,t+1}=2, p_{j,t+1}=5$	$P_{i,t+1}=2, p_{j,t+1}=2$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$2q$
	F	**G**	**H**	**I**	
	$P_{i,t+1}=2, p_{j,t+1}=1$	$P_{i,t+1}=1, p_{j,t+1}=5$	$P_{i,t+1}=1, p_{j,t+1}=2$	$P_{i,t+1}=1, p_{j,t+1}=1$	
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+1)$	q	

The matrix of preferred outcomes is shown in Table 4.12.

Table 4.12: Matrix of Preferred Outcomes, p_t=2, k=1

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A		A	A	D	A	A	G	H	A
B	A		B	D	E	F	G	H	I
C	A	B		D	E	F	G	H	I
D	D	D	D		D	D	D	D	D
E	A	E	E	D		E	G	H	E
F	A	F	F	D	E		G	H	I
G	G	G	G	D	G	G		G	G
H	H	H	H	D	H	H	G		H
I	A	I	I	D	E	I	G	H	

Note that this matrix is different to Table 4.10; it is more profitable to charge a price of two when the opponent charges five than it is to charge a price of one. Thus, in a more general sense, there will eventually be a price level where the deepest undercut is no longer most preferred. This does not change the pure strategy Nash equilibrium in this case, but it also points towards the dominance of the undercutting strategy weakening as prices move closer to marginal costs. This should perhaps be expected, as with less profit available from undercutting, one would expect the incentive to undercut to weaken. The order of preference in this case is:

D>G>H>A>E>I>B>F>C

I now turn to the Nash Equilibrium of this game, in Table 4.13.

Table 4.13: Nash Equilibrium of Game Where p_t=2 and k=1.

		Station *j*		
		$P_{j,t+1}=5$	$P_{j,t+1}=2$	$P_{j,t+1}=1$
Station *i*	$P_{i,t+1}=5$	A,A	B,D	C,G
	$P_{i,t+1}=2$	D,B	E,E	F,H
	$P_{i,t+1}=1$	G,C	H,F	I,I

Although the deepest undercut is no longer preferred, following the same process as for Table 4.5 reveals just one pure strategy equilibrium, at I,I, or where $p_{i,t+1}=p_{j,t+1}=1$ Thus, this round of this game will result in the price moving down by one more cent, to just one cent above marginal costs.

I now turn to the next round, where $p_{i,t}=p_{j,t}=1$. Here, each firm has three choices; it can choose a price of five (the monopoly price), a price of one (the current market price) or a price of zero, or marginal cost (reducing the price by k). This gives rise to a situation for prices and profits, which is shown in Table 4.14.

Table 4.14: Price and Profit Outcomes for $p_t=1$, $k=1$

	A	**B**	**C**	**D**	**E**
	$P_{i,t+1}=5, p_{j,t+1}=5$	$P_{i,t+1}=5, p_{j,t+1}=1$	$P_{i,t+1}=5, p_{j,t+1}=0$	$P_{i,t+1}=1, p_{j,t+1}=5$	$P_{i,t+1}=1, p_{j,t+1}=1$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-5)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	q

	F	**G**	**H**	**I**
	$P_{i,t+1}=1, p_{j,t+1}=0$	$P_{i,t+1}=0, p_{j,t+1}=5$	$P_{i,t+1}=0, p_{j,t+1}=1$	$P_{i,t+1}=0, p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{q}{d\tan\alpha}(d\tan\alpha-1)$	0	0	0

The matrix of preferred outcomes is shown in Table 4.16. Three outcomes have a profit of zero (G, H and I) and if Firm *i* has the higher price, it cannot have negative profits, meaning B, C and F are bounded at zero, and there are many shaded cells in Table 4.15.[53]

Table 4.15: Matrix of Preferred Outcomes, $p_t=1$, $k=1$

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A		A	A	D	A	A	A	A	A
B	A			D	E				
C	A			D	E				
D	D	D	D		D	D	D	D	D
E	A	E	E	D		E	E	E	E
F	A			D					
G	A			D	E				
H	A			D	E				
I	A			D	E				

The effect of some of the outcomes giving rise to a profit of zero changes the order of preference quite markedly. It is now:

D>A>E>G=H=I=F=B=C

I now turn to the Nash Equilibrium of this game, in Table 4.16.

Table 4.16: Nash Equilibrium of Game Where $p_t=1$ and $k=1$.

		Station *j*		
		$P_{j,t+1}=5$	$P_{j,t+1}=1$	$P_{j,t+1}=0$
Station *i*	$P_{i,t+1}=5$	A,A	B,D	C,G
	$P_{i,t+1}=1$	D,B	E,E	F,H
	$P_{i,t+1}=0$	G,C	H,F	I,I

[53] The firm in question could choose not to open, and earn a profit of zero, rather than negative profits.

There is still one pure-strategy Nash Equilibrium, but it is no longer at the lowest price. Thus, firms will not move down to marginal cost, but will retain some profits due to their spatial market power.

Before moving on to the case where k=2, it is worthwhile considering the equilibrium above. In each of the Nash equilibria in Tables 4.5, 4.8, 4.13 and 4.16, the equilibrium has relied on undercutting being preferred to the maximum price. This requires, successively, on tanα being less than 4/d, 3/d, 2/d and 1/d. The distances between the two firms do not change from game to game, and nor do the customers. Hence, there will be cases where tanα<4/d, but tanα>1/d (or 2/d or 3/d). Where relenting to the maximum price is preferred to undercutting, rather than a single equilibrium, one has two pure strategy Nash equilibria. Consider the situation outlined in Table 4.14, but assume that tanα>1/d, which leads to the preference ordering:

A>D>E>G= H=I=F=B=C

Now, Table 4.16 changes, and we have Table 4.17, thus:

Table 4.17: Nash Equilibria of Game Where p_t=*1*and k=*1*, but tanα>1/d.

		Station *j*		
		$P_{j,t+1}$=5	$P_{j,t+1}$=1	$P_{j,t+1}$=0
Station *i*	$P_{i,t+1}$=5	A,A	B,D	C,G
	$P_{i,t+1}$=1	D,B	E,E	F,H
	$P_{i,t+1}$=0	G,C	H,F	I,I

There are now two pure-strategy Nash equilibria in this game; one where the price equals one, and one where it equals five. A similar situation obtains in cases where tanα<4/d, but greater than 2/d or 3/d.

For illustrative purposes, I turn, therefore, to the mixed strategy equilibrium for the game shown in Table 4.17 (an analogous approach could be used for the cases where tanα<4/d, but greater than 2/d or 3/d). From Table 4.17, I take just the top left corner containing the two pure strategy equilibria, and I give the outcomes A and B their numerical values of one and zero. Further, I let:

γ = the probability expected by Station j that Station i will choose $p_{i,t+1}=5$

δ = the probability expected by Station i that Station j will choose $p_{j,t+1}=5$

Table 4.18: Mixed Strategy Nash Equilibrium of Game in Table 4.17.

		Station *j*		
		$P_{j,t+1}=5$	$P_{j,t+1}=1$	δ-mix
Station *i*	$P_{i,t+1}=5$	5q,5q	B,D	$5q\delta+(1-\delta)B$
	$P_{i,t+1}=1$	D,B	q, q	$Dq\delta+(1-\delta)$
	γ-mix	$5q\gamma+(1-\gamma)B$	$Dq\gamma+(1-\gamma)$	

To find the mixing probabilities, I set $5q\gamma+(1-\gamma)B= Dq\gamma+(1-\gamma)$ and $5q\delta+(1-\delta)B = Dq\delta+(1-\delta)$. Substituting in B and D from Table 4.14 and solving these functions gives:

$$\gamma=\delta=\frac{20-4d\tan\alpha}{16} \tag{4.28}$$

Thus, provided $4d\tan\alpha>4$ (which is true if $\tan\alpha>1/d$), one has a situation whereby the larger the distance between two firms or the larger the travel costs, the smaller the likelihood of raising price. This seems counter-intuitive, but is a result of the action of the principal of opponent indifference that underlies the calculation of the mixing probability in 4.28 above in this myopic, single-shot, simultaneous game. One way to think about this is to consider that, the further apart two firms are, the greater the temptation of one's rival to change the monopoly price, and hence the more frequently a firm must undercut in order to keep its rival from charging this price. In a more realistic setting, whereby firms considered profits over a longer time-frame, and Maskin & Tirole's (1988) "public good" comes into play, other forces may increase the likelihood of raising price, although each firm would still prefer the other to raise price first.

The important fact about the discussion around Table 4.17 and 4.18 is not the mixing probability itself, but the fact that a mixed strategy exists in the first instance. It is not necessary to assume some forward-looking multi-period framework, or to assume some form of strategic commitment to keeping prices fixed for two periods, or to assume a sequential game, in order to obtain an Edgeworth Cycle. Rather, one will emerge in a series of one-shot, myopic simultaneous-move games where the maximum price decrease is set exogenously, for a range of transport costs and distances. Moreover, as the discussion below suggests, the Edgeworth shape of the cycle is a product of the size of the exogenously-set maximum price decreases, but the cycle itself is not. To explore this further, I now turn to cases where k=2 and 3.

Game with *k=2*

In this instance, each firm has two undercutting choices, rather than one; they can choose to undercut by a cent, or by two cents.

Consider first the case where $p_t=5$. This gives rise to the following situations for prices and profits:

Table 4.19: Price and Profit Outcomes for $p_t=5$, $k=2$

	A	**B**	**C**	**D**	**E**
	$P_{i,t+1}=5$, $p_{j,t+1}=5$	$P_{i,t+1}=5$, $p_{j,t+1}=4$	$P_{i,t+1}=5$, $p_{j,t+1}=3$	$P_{i,t+1}=4$, $p_{j,t+1}=5$	$P_{i,t+1}=4$, $p_{j,t+1}=4$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha+1)$	$4q$
	F	**G**	**H**	**I**	
	$P_{i,t+1}=4$, $p_{j,t+1}=3$	$P_{i,t+1}=3$, $p_{j,t+1}=5$	$P_{i,t+1}=3$, $p_{j,t+1}=4$	$P_{i,t+1}=3$, $p_{j,t+1}=3$	
Profit$_{i,t+1}$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+1)$	$3q$	

Note that this is identical to Table 4.6 above, the case when $p_t=4$, $k=1$**,** it will thus have exactly the same outcome, and will result in a pure strategy equilibrium where $p_{i,t+1}=p_{j,t+1}=3$. In essence, the pattern is the same as was the case for higher prices in the game above with $k=1$; the pure strategy equilibrium is p_t-k.

The next logical step is $p=3$; the pure strategy equilibrium from the previous round of the game. However, for completeness, I show the results when $p=4$. A similar pattern emerges, which suggests that the relevant pure strategy equilibrium is not an artefact of the choice of starting point. In subsequent cases, for *k=2* and *k=3*, I take the same approach.

Consider, then case where $p_t=4$. This gives rise to the following situations for prices and profits:

Table 4.20: Price and Profit Outcomes for $p_t=4$, $k=2$

	A	**B**	**C**	**D**
	$P_{i,t+1}=5$, $p_{j,t+1}=5$	$P_{i,t+1}=5$, $p_{j,t+1}=4$	$P_{i,t+1}=5$, $p_{j,t+1}=3$	$P_{i,t+1}=5$ $p_{j,t+1}=2$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$
	E	**F**	**G**	**H**
	$P_{i,t+1}=4$, $p_{j,t+1}=5$	$P_{i,t+1}=4$, $p_{j,t+1}=4$	$P_{i,t+1}=4$, $p_{j,t+1}=3$	$P_{i,t+1}=4$, $p_{j,t+1}=2$
Profit$_{i,t+1}$	$\frac{4q}{d\tan\alpha}(d\tan\alpha+1)$	$4q$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-2)$
	I	**J**	**K**	**L**
	$P_{i,t+1}=3$, $p_{j,t+1}=5$	$P_{i,t+1}=3$, $p_{j,t+1}=4$	$P_{i,t+1}=3$, $p_{j,t+1}=3$	$P_{i,t+1}=3$, $p_{j,t+1}=2$
Profit$_{i,t+1}$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+1)$	$3q$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-1)$
	M	**N**	**O**	**P**
	$P_{i,t+1}=2$, $p_{j,t+1}=5$	$P_{i,t+1}=2$, $p_{j,t+1}=4$	$P_{i,t+1}=2$, $p_{j,t+1}=3$	$P_{i,t+1}=2$, $p_{j,t+1}=2$
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+1)$	$2q$

The matrix of preferred outcomes is shown in Table 4.21.

Table 4.21: Matrix of Preferred Outcomes, p_t=4, k=2

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
A		A	A	A	E	A	A	A	I	J	A	A	M	N	O	P
B	A		B	B	E	F	B	B	I	J	K	B	M	N	O	P
C	A	B		C	E	F	G	C	I	J	K	L	M	N	O	P
D	A	B	C		E	F	G	H	I	J	K	L	M	N	O	P
E	E	E	E	E		E	E	E	I	E	E	E	E	E	E	E
F	A	F	F	F	E		F	F	I	J	F	F	M	N	O	P
G	A	B	G	G	E	F		G	I	J	K	G	M	N	O	P
H	A	B	C	H	E	F	G		I	J	K	L	M	N	O	P
I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I
J	J	J	J	J	E	J	J	J	I		J	J	M	N	J	J
K	A	K	K	K	E	F	K	K	I	J		K	M	N	O	K
L	A	B	L	L	E	F	G	L	I	J	K		M	N	O	P
M	M	M	M	M	E	M	M	M	I	M	M	M		M	M	M
N	N	N	N	N	E	N	N	N	I	N	N	N	M		N	N
O	O	O	O	O	E	O	O	O	I	J	O	O	M	N		O
P	P	P	P	P	E	P	P	P	I	J	K	P	M	N	O	

This gives rise to the following preference relationship:

I>M>E>N>J>O>A>F>K>P>B>G>L>C>H>D

Note that a similar pattern emerges as for the games where *k=1*; all outcomes with lower prices dominate over those with the same price, which in turn dominate over all the outcomes where the firm has the higher price. Here, however, the best outcome is not the lowest price; it is better to charge a price of three when a rival charges a price of five that it is to charge a price of two. Thus, the additional gains from taking market share are outweighed by the losses from charging lower prices to “captive” (that is, closer) customers at a higher starting price than was the case when *k=1*. I now turn to the Nash Equilibrium of this game, shown in Table 4.22.

Table 4.22: Equilibrium of Game Where p_t=4and k=2.

		Station j			
		$P_{j,t+1}=5$	$P_{j,t+1}=4$	$P_{j,t+1}=3$	$P_{j,t+1}=2$
Station i	$P_{i,t+1}=5$	A,A	B,E	C,I	D,M
	$P_{i,t+1}=4$	E,B	F,F	G,J	H,N
	$P_{i,t+1}=3$	I,C	J,G	K,K	L,O
	$P_{i,t+1}=2$	M,D	N,H	O,L	P,P

Here, again, a single pure-strategy Nash Equilibrium exists, and results in both firms charging a price of two, or p_t-k, as previously.

Consider, then case where $p_t=3$. This gives rise to the following situation:

Table 4.23: Price and Profit Outcomes for p_t=3, k=2

	A	B	C	D
	$P_{i,t+1}=5, p_{j,t+1}=5$	$P_{i,t+1}=5, p_{j,t+1}=3$	$P_{i,t+1}=5, p_{j,t+1}=2$	$P_{i,t+1}=5\ p_{j,t+1}=1$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$
	E	F	G	H
	$P_{i,t+1}=3, p_{j,t+1}=5$	$P_{i,t+1}=3, p_{j,t+1}=3$	$P_{i,t+1}=3, p_{j,t+1}=2$	$P_{i,t+1}=3, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$3q$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-2)$
	I	J	K	L
	$P_{i,t+1}=2, p_{j,t+1}=5$	$P_{i,t+1}=2, p_{j,t+1}=3$	$P_{i,t+1}=2, p_{j,t+1}=2$	$P_{i,t+1}=2, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+1)$	$2q$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-1)$
	M	N	O	P
	$P_{i,t+1}=1, p_{j,t+1}=5$	$P_{i,t+1}=1, p_{j,t+1}=3$	$P_{i,t+1}=1, p_{j,t+1}=2$	$P_{i,t+1}=1, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+1)$	q

The matrix of preferred outcomes is shown in Table 4.24.

Table 4.24: Matrix of Preferred Outcomes, p_t=3, *k*=2

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
A		A	A	A	E	A	A	A	I	J	A	A	M	N	O	P
B	A		B	B	E	F	G	B	I	J	K	L	M	N	O	P
C	A	B		C	E	F	G	H	I	J	K	L	M	N	O	P
D	A	B	C		E	F	G	H	I	J	K	L	M	N	O	P
E	E	E	E	E		E	E	E	E	E	E	E	E	E	E	E
F	A	F	F	F	E		F	F	I	J	F	F	M	N	O	F
G	A	G	G	G	E	F		G	I	J	K	G	M	N	O	P
H	A	B	H	H	E	F	G		I	J	K	L	M	N	O	P
I	I	I	I	I	E	I	I	I		I	I	I	I	I	I	I
J	J	J	J	J	E	J	J	J	I		J	J	M	J	J	J
K	A	K	K	K	E	F	K	K	I	J		K	M	N	O	K
L	A	L	L	L	E	F	G	L	I	J	K		M	N	O	P
M	M	M	M	M	E	M	M	M	I	M	M	M		M	M	M
N	N	N	N	N	E	N	N	N	I	J	N	N	M		N	N
O	O	O	O	O	E	O	O	O	I	J	O	O	M	N		O
P	A	P	P	P	E	F	P	P	I	J	K	P	M	N	O	

This gives rise to the following preference relationship:

E>I>M>J>N>O>A>F>K>P>G>L>B>H>C>D

Note that a similar pattern emerges as for the previous game in terms of the best outcome; again it is when the price is two, rather than three below the monopoly outcome (which in turn is better than being four cpl below the monopoly outcome). Here, however, because the starting price has changed, the numbering also changes. I now turn to the Nash Equilibrium of this game, shown in Table 4.25.

Table 4.25: Equilibrium of Game Where p_t=3and k=2.

		Station *j*			
		$P_{j,t+1}=5$	$P_{j,t+1}=3$	$P_{j,t+1}=2$	$P_{j,t+1}=1$
Station *i*	$P_{i,t+1}=5$	A,A	B,E	C,I	D,M
	$P_{i,t+1}=3$	E,B	F,F	G,J	H,N
	$P_{i,t+1}=2$	I,C	J,G	K,K	L,O
	$P_{i,t+1}=1$	M,D	N,H	O,L	P,P

Here, again, a single pure-strategy Nash Equilibrium exists, and results in both firms charging a price of one, or p_t-k, as previously.

Consider, then case where $p_t=2$. This gives rise to the following situation:

Table 4.26: Price and Profit Outcomes for p_t=2, k=2

	A	**B**	**C**	**D**
	$P_{i,t+1}=5, p_{j,t+1}=5$	$P_{i,t+1}=5, p_{j,t+1}=2$	$P_{i,t+1}=5, p_{j,t+1}=1$	$P_{i,t+1}=5\ p_{j,t+1}=0$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$
	E	**F**	**G**	**H**
	$P_{i,t+1}=2, p_{j,t+1}=5$	$P_{i,t+1}=2, p_{j,t+1}=2$	$P_{i,t+1}=2, p_{j,t+1}=1$	$P_{i,t+1}=2, p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$2q$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-2)$
	I	**J**	**K**	**L**
	$P_{i,t+1}=1, p_{j,t+1}=5$	$P_{i,t+1}=1, p_{j,t+1}=2$	$P_{i,t+1}=1, p_{j,t+1}=1$	$P_{i,t+1}=1, p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+1)$	q	$\frac{q}{d\tan\alpha}(d\tan\alpha-1)$
	M	**N**	**O**	**P**
	$P_{i,t+1}=0, p_{j,t+1}=5$	$P_{i,t+1}=0, p_{j,t+1}=2$	$P_{i,t+1}=0, p_{j,t+1}=1$	$P_{i,t+1}=0, p_{j,t+1}=0$
Profit$_{i,t+1}$	0	0	0	0

The matrix of preferred outcomes is shown in Table 4.27, profits cannot be negative, which has the effect of bounding situations B, C, D, G, H and L at zero, meaning many more cells are shaded than in Table 4.24.

Table 4.27: Matrix of Preferred Outcomes, p_t=2, *k*=2

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
A		A	A	A	E	A	A	A	I	J	A	A	A	A	A	A
B	A				E	F			I	J	K					
C	A				E	F			I	J	K					
D	A				E	F			I	J	K					
E	E	E	E	E		E	E	E	E	E	E	E	E	E	E	E
F	A	F	F	F	E		F	F	I	J	F	F	F	F	F	F
G	A				E	F		G	I	J	K					
H	A				E	F	G		I	J	K					
I	I	I	I	I	E	I	I	I		I	I	I	I	I	I	I
J	J	J	J	J	E	J	J	J	I		J	J	J	J	J	J
K	A	K	K	K	E	F	K	K	I	J		K	K	K	K	K
L	A				E	F			I	J	K		M	N	O	P
M	A				E	F			I	J	K	M				
N	A				E	F			I	J	K	N				
O	A				E	F			I	J	K	O				
P	A				E	F			I	J	K	P				

This gives rise to the following preference relationship:

E>I>J>A>F>K>M=N=O=P=L=G=H=B=C=D

As with the situation where *k*=1 and *p*=1 (Table 4.15), all but the undercutting and matching moves are dominated. I now turn to the Nash Equilibrium of this game, shown in Table 4.28.

Table 4.28: Equilibrium of Game Where p_t=2and *k=2*.

		Station *j*			
		$P_{j,t+1}=5$	$P_{j,t+1}=2$	$P_{j,t+1}=1$	$P_{j,t+1}=0$
Station *i*	$P_{i,t+1}=5$	A,A	B,E	C,I	D,M
	$P_{i,t+1}=2$	E,B	F,F	G,J	H,N
	$P_{i,t+1}=1$	I,C	J,G	K,K	L,O
	$P_{i,t+1}=0$	M,D	N,H	O,L	P,P

Once again, as in the case where *p*=1, *k*=1, the equilibrium is one cpl, and this is a pure strategy equilibrium. However, the same phenomenon as discussed between Tables 4.17 and 4.18 applies here; the undercutting pure strategy Nash Equilibrium in each game above with *k*=2 depends upon tan*α* being less than 4/*d*, 3/*d*, 2/*d* and 1/*d*. Thus, one can make precisely the same conjecture as is made above; that tanα might be less that 4/d, but greater than one of 3/d/ 2/d or 1/d. If this occurs, there is once again two pure strategy Nash equilibria in the game concerned (one an undercut and one a return to the price of five cpl). The game then has an equilibrium in mixed strategies, and a cycle once again ensues. The key difference, in this instance, is that the steps are larger, because the exogenous restriction allows them to be. Thus when *k*=2, the cycles have less of an Edgeworth shape than when *k*=1. I now turn to the case where *k*=3, to ascertain whether a similar pattern emerges.

Game with *k=3*

At $p_t=5$, the same thing occurs as when we had *k=2;* that is, since the monopoly price is also the current price, there are one fewer choices than is the case where $p_t<m$, and hence the result is the same as was the case when k was one step smaller and p_t one cpl less. Thus, here, the case for $p_t=5$ and *k=3* (price choices available 5,4,3,2) is the same as for

$p_t=4$ and $k=2$. The net result will be, as above a pure strategy Nash Equilibrium where $p_{i,t+1}=p_{j,t+1}=2$.

I now turn to the case where $p_t=4$. The price and profit outcomes for this game are shown in Table 4.29.

Table 4.29: Price and Profit Outcomes for p_t=4, k=3

	A	**B**	**C**	**D**	**E**
	$P_{i,t+1}=5, p_{j,t+1}=5$	$P_{i,t+1}=5, p_{j,t+1}=4$	$P_{i,t+1}=5, p_{j,t+1}=3$	$P_{i,t+1}=5\ p_{j,t+1}=2$	$P_{i,t+1}=5\ p_{j,t+1}=1$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$
	F	**G**	**H**	**I**	**J**
	$P_{i,t+1}=4, p_{j,t+1}=5$	$P_{i,t+1}=4, p_{j,t+1}=4$	$P_{i,t+1}=4, p_{j,t+1}=3$	$P_{i,t+1}=4, p_{j,t+1}=2$	$P_{i,t+1}=4, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{4q}{d\tan\alpha}(d\tan\alpha+1)$	$4q$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{4q}{d\tan\alpha}(d\tan\alpha-3)$
	K	**L**	**M**	**N**	**O**
	$P_{i,t+1}=3, p_{j,t+1}=5$	$P_{i,t+1}=3, p_{j,t+1}=4$	$P_{i,t+1}=3, p_{j,t+1}=3$	$P_{i,t+1}=3, p_{j,t+1}=2$	$P_{i,t+1}=3, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+1)$	$3q$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-2)$
	P	**Q**	**R**	**S**	**T**
	$P_{i,t+1}=2, p_{j,t+1}=5$	$P_{i,t+1}=2, p_{j,t+1}=4$	$P_{i,t+1}=2, p_{j,t+1}=3$	$P_{i,t+1}=2, p_{j,t+1}=2$	$P_{i,t+1}=2, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+1)$	$2q$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-1)$
	U	**V**	**W**	**X**	**Y**
	$P_{i,t+1}=1, p_{j,t+1}=5$	$P_{i,t+1}=1, p_{j,t+1}=4$	$P_{i,t+1}=1, p_{j,t+1}=3$	$P_{i,t+1}=1, p_{j,t+1}=2$	$P_{i,t+1}=1, p_{j,t+1}=1$
Profit$_{i,t+1}$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+1)$	q

The matrix of preferred outcomes is too large to show, but the order of preferences from this matrix (following the same approach as in previous cases) is:

K>P>F>Q>L>R>U>V>W>X>A>G>M>S>Y>B>H>N>C>T>I>O>D>J>E

Note that the pattern is similar to the cases where $k<3$; all of the times when a firm has a lower price dominate over the times when prices are equal, which in turn dominate cases where a firm has the higher price. Again, the lowest price is not the optimal, for the same reasons as outlined previously. I now turn to the Nash Equilibrium, which is shown in Table 4.30.

Table 4.30: Equilibrium of Game Where $p_t=4$ and $k=3$.

		Station *j*				
		$P_{j,t+1}=5$	$P_{j,t+1}=4$	$P_{j,t+1}=3$	$P_{j,t+1}=2$	$P_{j,t+1}=1$
Station *i*	$P_{i,t+1}=5$	A,A	B,F	C,K	D,P	E,U
	$P_{i,t+1}=4$	F,B	G,G	H,L	I,Q	J,V
	$P_{i,t+1}=3$	K,C	L,H	M,M	N,R	O,W
	$P_{i,t+1}=2$	P,D	Q,I	R,N	S,S	T,X
	$P_{i,t+1}=1$	U,E	V,J	W,O	X,T	Y,Y

As was the case previously, there is one pure strategy equilibrium; at $p_t- k$.

I now turn to the case where $p_t=4$. The price and profit outcomes for this game are shown in Table 4.31.

Table 4.31: Price and Profit Outcomes for p_t=3, k=3

	A	B	C	D	E
	$P_{i,t+1}=5,\ p_{j,t+1}=5$	$P_{i,t+1}=5,\ p_{j,t+1}=3$	$P_{i,t+1}=5,\ p_{j,t+1}=2$	$P_{i,t+1}=5\ p_{j,t+1}=1$	$P_{i,t+1}=5\ p_{j,t+1}=0$
Profit$_{i,t+1}$	$5q$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-3)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-4)$	$\frac{5q}{d\tan\alpha}(d\tan\alpha-5)$
	F	**G**	**H**	**I**	**J**
	$P_{i,t+1}=3,\ p_{j,t+1}=5$	$P_{i,t+1}=3,\ p_{j,t+1}=3$	$P_{i,t+1}=3\ p_{j,t+1}=2$	$P_{i,t+1}=3,\ p_{j,t+1}=1$	$P_{i,t+1}=3,\ p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{3q}{d\tan\alpha}(d\tan\alpha+2)$	$3q$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-2)$	$\frac{3q}{d\tan\alpha}(d\tan\alpha-3)$
	K	**L**	**M**	**N**	**O**
	$P_{i,t+1}=2,\ p_{j,t+1}=5$	$P_{i,t+1}=2,\ p_{j,t+1}=3$	$P_{i,t+1}=2,\ p_{j,t+1}=2$	$P_{i,t+1}=2,\ p_{j,t+1}=1$	$P_{i,t+1}=2,\ p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+3)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha+1)$	$2q$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-1)$	$\frac{2q}{d\tan\alpha}(d\tan\alpha-2)$
	P	**Q**	**R**	**S**	**T**
	$P_{i,t+1}=1,\ p_{j,t+1}=5$	$P_{i,t+1}=1,\ p_{j,t+1}=3$	$P_{i,t+1}=1,\ p_{j,t+1}=2$	$P_{i,t+1}=1,\ p_{j,t+1}=1$	$P_{i,t+1}=1,\ p_{j,t+1}=0$
Profit$_{i,t+1}$	$\frac{q}{d\tan\alpha}(d\tan\alpha+4)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+2)$	$\frac{q}{d\tan\alpha}(d\tan\alpha+1)$	q	$\frac{q}{d\tan\alpha}(d\tan\alpha-1)$
	U	**V**	**W**	**X**	**Y**
	$P_{i,t+1}=0,\ p_{j,t+1}=5$	$P_{i,t+1}=0,\ p_{j,t+1}=3$	$P_{i,t+1}=0,\ p_{j,t+1}=2$	$P_{i,t+1}=0,\ p_{j,t+1}=1$	$P_{i,t+1}=0,\ p_{j,t+1}=0$
Profit$_{i,t+1}$	0	0	0	0	0

The matrix of preferred outcomes is again too large to show, but the order of preferences from this matrix (following the same approach as in previous cases and noting that one cannot have negative profits) is:

F>K>P>L>Q>R>A>G>M>S>U=V=W=X=Y=T=H=I=N=O=J=B=C=D=E

This gives rise to the following game:

Table 4.32: Equilibrium of Game Where p_t=3 and k=3.

		Station *j*				
		$P_{j,t+1}=5$	$P_{j,t+1}=3$	$P_{j,t+1}=2$	$P_{j,t+1}=1$	$P_{j,t+1}=0$
Station *i*	$P_{i,t+1}=5$	A,A	B,F	C,K	D,P	E,U
	$P_{i,t+1}=3$	F,B	G,G	H,L	I,Q	J,V
	$P_{i,t+1}=2$	K,C	L,H	M,M	N,R	O,W
	$P_{i,t+1}=1$	P,D	Q,I	R,N	S,S	T,X
	$P_{i,t+1}=0$	U,E	V,J	W,O	X,T	Y,Y

Once again, there is a single pure strategy Nash Equilibrium at a price of one cpl. However, the same set of requirements as for k=2 and k=1 in terms of undercutting being preferred to returning to a price of five cpl obtain here. That is, it requires tanα to be less (in turn) than 4/d, 3/d, 2/d and 1/d. Once again, it is feasible that there may be cases where the first of these inequalities is true, but that one or more of the rest are not. In this situation, there are again two pure strategy equilibria (the relevant undercut and a return to a price of five cpl), and the mixed strategy game that follows gives rise to a cycle. Here, the cycle has less of an Edgeworth shape than in the cases where k=1 and k=2, but it remains a cycle. It therefore does not seem unreasonable to conjecture that, where this myopic, simultaneous-move game is played repeatedly, situations where cycles occur will emerge. It remains to explore what might cause such cycles to have an Edgeworth shape; in other words, whether there are forces which impose an exogenous k on the game. I turn to this question below.

Which choice of *k*?

There is nothing in the structure of the games outlined above which points to a particular value of k being chosen; it is exogenously imposed in each case. The smaller is k, the more likely that, in cases where the costs of travel and distances between outlets favour cycles, the cycles will have an Edgeworth shape. Empirically, in Perth (as in many other cities) Edgeworth Cycles do emerge. Thus, if the myopic, simultaneous-move game described above is representative of how pricing decisions are made in the Perth retail petroleum market, then it is worthwhile asking what, if anything, might be imposing a small *k* on firms exogenously.

There is nothing in the regulatory system governing the market which imposes small price cuts. If anything, *FuelWatch* rewards larger price reductions by publicising the lowest-priced sites in the city. It may be the case, however, that petroleum retailers are themselves making credible commitments to each other that any price reductions they make will be small, in order to draw out the cycle.

There does seem to be some empirical evidence that firms seek to make such commitment. The ACCC (2007) suggests based on the evidence it received from Majors, independents and supermarkets which retail petroleum that most seek to match local competition in pricing, with Majors charging the "going market price" (ibid, p136) and supermarkets seeking to match the lowest price in a local market (ibid, p137). It also cites evidence from an independent operator that most independents try not to reduce prices too low, or wait too long before raising them, for fear of retaliation through very low prices (ibid, p137). Further, in the discussion on price cycles (ibid, p 170-80) Caltex suggests that it and the other majors engage in price matching (ibid p171), which Woolworths confirms in its submission (ibid p172). If firms are making these statements in public documents, and if they are common knowledge amongst retailers, then this may indicate a desire to make credible commitments not to reduce price by more than a small amount. Wang's (2005b, 2008) accounts of the cartel prosecution in Ballarat point to similar findings, with individual retailers repeatedly signalling their intent to only just undercut rivals and large undercuts precipitating a price war.

The evidence above is circumstantial at best, but it does not seem outside the realms of possibility that, to the extent that the myopic, simultaneous-move game outlined here applies, individual retailers do seek a reputation of not being a price gouger, in order to make cycles last longer, and thus increase their own profits. That is, even where strategic complementarity does not engender a sequential game, as Lau (2001) suggests, the firms may be able to make enough of a credible commitment around their undercutting strategy to draw out the cycle to the advantage of all firms.

Although speculative, the model in this section might also explain how price wars emerge more generally in retail petroleum markets. If there is some exogenous shock to the system, the tacit knowledge about the appropriate k might be lost, and thus one might expect to see price gouging, until the firms learn the "right" value of k again. This might explain some of the "false-starts" that Noel (2007a,b) observes in his data.[54] Moreover, it might explain why Wang (2009) sees price cycles taking some time to emerge in Perth after the introduction of the *FuelWatch* regime despite existing immediately prior to its introduction; firms are learning for the first time how to play a simultaneous rather than a sequential game in price choices.

[54] These also occur from time-to-time in the dataset used in this thesis; 56 times in around 98,000 price points; not enough for robust statistical analysis.

It is thus not guaranteed that a certain value of *k* will emerge. Nor is it guaranteed that the *k* chosen will be small enough to produce an Edgeworth Cycle. However, given the incentives of each of the players, it also would not seem to be particularly surprising if something akin to an Edgeworth Cycle did emerge. Since the pattern of pricing in the Perth market does seem to follow the Edgeworth pattern (see Figure 5.9 on p. 178), and prices are chosen simultaneously, the model presented in this section may represent a credible explanation as to why this has occurred.

Connecting Pairs and Constructing the Network

The link between the theoretical models in this chapter and the empirical work in Chapter Six flows, as mentioned, through the way in which the network summarising the structure of competition is constructed. I thus turn to a discussion about how the bilateral model outlined above is used to construct the network, and then to calculate the summary statistics used to summarise position in that network, for the purposes of the empirical analysis of Chapter Six.

Using the bilateral model to build the network requires a simplifying assumption; where a retail petroleum outlet interacts with many outlets at the same time, it treats each interaction as independent. Once this assumption is made, the duopoly model outlined above provides a simple means of determining whether two outlets are connected, and this provides a way in which to construct the network.

If Outlets A and B are indeed influencing each other's pricing decisions, then this should be apparent in the relationship between their minimum prices. Recall that, if the two firms have equal marginal costs, they will have the same price minimum, and it will be equal to:

$$p = d\tan\alpha \tag{4.10}$$

Where marginal costs are not equal to each other, one obtains:

$p = d\tan\alpha + \frac{2}{3}m + \frac{1}{3}n$ for Firm A,

and (4.18)

$p = d\tan\alpha + \frac{1}{3}m + \frac{2}{3}n$ for Firm B.

Finally, when marginal costs are not equal to each other, and the number of customers which pass each outlet first are also not equal to each other, one has:

$p = \frac{1}{3qr}\left(\left(2q^2 + r^2\right)d\tan\alpha + \left(2m + n\right)qr\right)$ for Firm A,

and (4.23)

$p = \frac{1}{3qr}\left(\left(q^2 + 2r^2\right)\tan\alpha + \left(m + 2n\right)qr\right)$ for Firm B.

In each case the $d\tan\alpha$ is common to both firms and thus, to find relative differences in minimum prices, it is unnecessary. Thus, to the extent that the duopoly model and simplifying assumption of independent interaction is correct, to find patterns of connection, one needs at most, empirical observations on actual price minima, marginal costs and traffic flows.

Summarising the Structure of the Network

Once the network is constructed by categorising all of the patterns of bilateral interaction, one needs to develop summary statistics for network structure if one is to follow the approach outlined above of regressing these against price to determine whether price is influenced by structure in the appropriate fashion. To obtain these summary statistics, I turn to the social networks literature summarised in Chapter Three. Two issues exist; whether density or structural holes are important, and whether local sub-markets should be considered in addition to the overall market.

The density vs. structural holes debate is summarised briefly in Chapter Three, and hinges around the nature of the industry being studied; if it is mature and stable, some authors suggest that denser networks are more appropriate and if it is young and dynamic, some authors suggest that a flexible network full of structural holes is more appropriate. Retail petroleum is a relatively mature market, but a given marketplace is in a constant state of flux as players enter and leave (particularly independents). Thus, it is not clear that one can characterise interaction as being similar to that amongst a small number of large firms which have each produced similar products for many years. Indeed, as Wang (2005b, 2008) suggests in his examination of the cartel in Ballarat (see Chapter Three), collusion is more likely to stick when the proprietors of individual sites have known each other for many years, or even decades. Thus, there may be scope for considering the network as being relatively young.

However, there is also the issue raised by Ingram & Roberts (2000) of whether networks of producers benefit from having structural holes, as producers tend to have similar interests. Whilst all petroleum retailers have an interest in higher prices, the nature of the competition they engage in, highlighted in the model above, suggests that their interests are not particularly well-aligned. Thus, they may not prefer dense networks, even though they are all producers.

Finally, as Figures 5.6 and 5.7 suggest, the pattern of interconnection between retail petroleum outlets in Perth is locally dense, but globally sparse, containing many gaps. Thus, it seems most appropriate to be agnostic in the density vs. structural holes debate, and incorporate structural measures from both camps. For structural holes, the suite of measures is rather limited, and I choose Burt's measures of efficiency and constraint (see Chapter Three), as well as considering redundancy of contacts between each outlet and the five most central outlets in its network.

For the network density side of the debate, the measure most often used is the direct, node-based consequence of density; centrality (see Borgatti & Everett, 2005).[55] There are a large number of centrality measure to choose from, although each has clear mathematical links (ibid.). The choice is generally made based upon the types of networks one is examining, or the types of questions one wishes to explore.

---

[55] Note that, in a zero-one matrix, Burt's (1992) measure of efficiency is strongly related to network density (Borgatti, 1997). Chapter Three provides further details of this relationship, which means that much of the information about density is likely to enter the regression through efficiency.

For retail petroleum markets, the nodes in the network are retail petroleum outlets, each of which is an economic agent and, as such, is likely to view link formation as a cost-benefit exercise. Link formation is likely to be costly (even though price information is free, proprietors still needs to ascertain other aspects, such as traffic flows), and thus one might expect each outlet to form links with those stations which are likely to provide it with the most information about pricing in the network; outlets which are themselves important. These outlets are then likely to respond in kind, as link formation is bilateral. Bonacich's (1972, 1987) measure summarises centrality based upon the centrality of the nodes to which one is directly connected, and thus seems to best reflect the kind of cost-benefit trade-offs and choices each station seems rationally likely to make. It is for this reason that I use it here.

Finally, as noted previously, in a market as geographically spread-out as Perth, it seems wise to consider sub-markets. Not only are the distances across the market so great that it seems highly unlikely that firms operating on opposite sides of it actually consider each other as competitors, but market demand and supply-side restrictions (like zoning laws, for examples) tend to aggregate retail petroleum outlets along major roads or at major shopping centres in the suburbs. Figures 5.6 and 5.7 show this small-world phenomenon at work in Perth's retail petroleum markets.

Conceptually, one could divide the market according to some exogenous geographical or socio-political grouping. For example Perth is split by a Freeway and a river, which could be used to divide it in four, or I could use even more detailed suburban divisions.

However, such arbitrariness has its costs; two outlets on the edge of arbitrarily defined suburban markets might logically be expected to interact more with each other if they are closer to each other than to their peers in the same defined market. It seems more appropriate to let the network structure itself determine where divisions should be made.

For this, I use Gould's (1967) approach. Its main attraction is its simplicity, and the relative uniqueness of results compared to more complex agglomerative or divisive methods (see Chapter Three). Moreover, as will be seen in Chapter Five, it is not clear that the choice of methodology is particularly crucial as many of the more complex graph-cutting techniques are based upon the work of Gould (1967) and thus give roughly similar results. Finally, it is also possible to undertake some ad-hoc investigations of the results and ascertain whether the sub-markets formed are reasonable, as I outline in Chapter Five.

Chapter Five: Data Characteristics and Network Construction

In Chapter Six, I undertake a series of regression analyses aimed at exploring the influence of network structure on pricing. The basic forms of the regressions are similar to previous literature in their included variables (see Chapter Three), but I add a number of new variables summarising network structure. In this chapter, I explore the characteristics of the data which form the inputs into the regression models used in Chapter Six.

Table 5.1 provides a summary of the data used, including the abbreviations for each variable used in the regression analysis in Chapter Six. It thus forms a reference point for that chapter. I have grouped the data into a number of families, for ease of presentation. The data on price, marginal cost and station characteristics come from *FuelWatch*,[56] whilst the data on demand characteristics are from the Australian Bureau of Statistics (ABS, 2006) *Census*. The remaining data are constructed for the thesis, and hence the process of construction is described in detail in this chapter.

[56] This is a proprietary dataset obtained from *FuelWatch*, containing a census of all prices for the time period being studied and selected characteristics of each station collected by *FuelWatch* as part of its own data collection exercise.

Table 5.1: Description of the Data

Group	Variable	Code
Price	Retail Price	RPRICE
	Marginal cost (tgp)	MC
	Median Price Change	MPC
Brand	Ampol	BR1
	BP	BR2
	Caltex	BR3
	Caltex-Woolworths	BR4
	Gull	BR5
	Independent	BR6
	Liberty	BR7
	Mobil	BR8
	Peak	BR9
	Shell	BR10
	Wesco	BR11
Type	Branded Independent	TP1
	Company Controlled	TP2
	Distributor Controlled	TP3
	Independent	TP4
	Larger Independent	TP5
	Price Supported	TP6
	Supermarket	TP7
Service	Conditional Service	SV1
	Full Service	SV2
	No Service	SV3
Convenience Store	BP Connect	CS1
	Caltex Starmart	CS2
	Caltex Starshop	CS3
	Mobil Quix	CS4
	Shell Select	CS5
Demand Side Characteristics	Median family Income	DCHAR1
	Average Household size	DCHAR2
	Number aboriginal	DCHAR3
	Number persons	DCHAR4
	Number born overseas	DCHAR5
	Number of families with dependent children	DCHAR6
	Number of families with Single Mother	DCHAR7
	Number of families	DCHAR8
	Av Number vehicles per hh	DCHAR9
	Dwelling density (houses per sq km)	DCHAR10
	Number of rented dwellings	DCHAR11
	Number of state housing dwellings	DCHAR12
	Number of dwellings	DCHAR13
	Number with post-school qualification	DCHAR14
	Number employed	DCHAR15
	Number using public transport for work travel	DCHAR16
	On a main Rd	DCHAR17
	Number of competitors within 5km	DCHAR18
	Distance to nearest competitor	DCHAR19
Spectra	Variation at 7 days	SPM1
	Variation at all harmonics of 7 days	SPM2
	Variation at 9&10 days	SPM3
Influence of Most Important Alters on Ego	Burt Redundancy of most central	EGOR1
	Burt Redundancy of 2nd most central	EGOR2
	Burt Redundancy of 3rd most central	EGOR3
	Burt Redundancy of 4th most central	EGOR4
	Burt Redundancy of 5th most central	EGOR5
Network characteristics	Global Burt Efficiency	NCHAR1
	Global Burt Constraint	NCHAR2
	Global Evec centrality	NCHAR3
	Global NEvec Centrality	NCHAR4
	Local Burt Efficiency	NCHAR5
	Local Burt Constraint	NCHAR6
	Local Evec centrality	NCHAR7
	Local NEvec Centrality	NCHAR8
Sub-markets	Fremantle	SUBM1
	Curtin	SUBM2
	Midland	SUBM3
	North East	SUBM4
	Fwy North	SUBM5
	City Central	SUBM6
	Western Suburbs	SUBM7
	Melville	SUBM8
Day of Week Dummies	Monday	DWD1
	Tuesday	DWD2
	Wednesday	DWD3
	Thursday	DWD4
	Friday	DWD5
	Saturday	DWD6
	Sunday	DWD7
Monthly Dummies	January	MD1
	February	MD2
	March	MD3
	April	MD4
	May	MD5
	June	MD6
	July	MD7
	August	MD8
	September	MD9
	October	MD10
	November	MD11
	December	MD12
Occurrences where outlet is… out of all outlets in sample	Max	OCO1
	Min	OCO2
	Median	OCO3
	Lower Quartile	OCO4
	Upper Quartile	OCO5
	Below Average	OCO6
	Above Average	OCO7
	Leader	OCO8
	Follower	OCO9
Occurrences where outlet is… out of all outlets in sub-market	Max	OCS1
	Min	OCS2
	Median	OCS3
	Lower Quartile	OCS4
	Upper Quartile	OCS5
	Below Average	OCS6
	Above Average	OCS7
	Leader	OCS8
	Follower	OCS9

Station Characteristics: Brand, Type, Service and Convenience Stores.

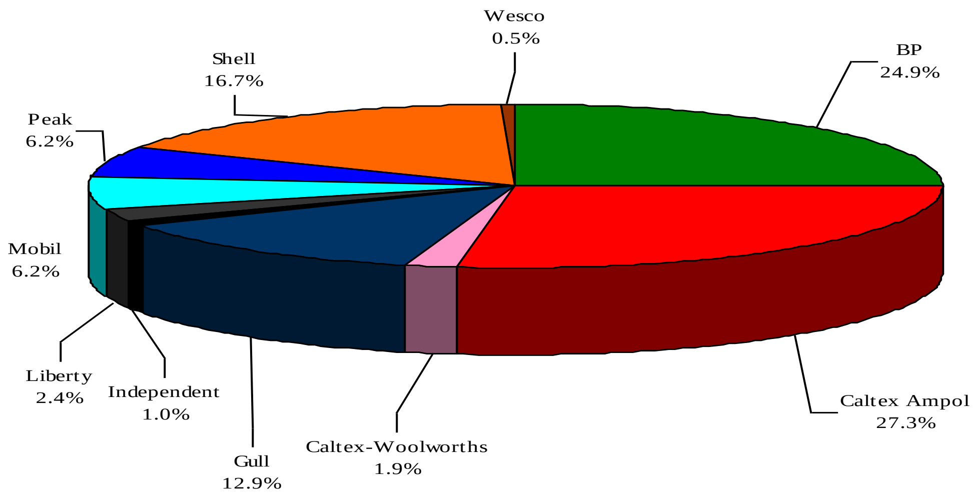
The regression analysis in Chapter Six uses 208 of the 357 retail petroleum outlets which operated during the period under analysis; the 1st of January 2003 to the 14th of March 2004. There were a number of reasons for not using the full set:

- 77 outlets were located on the fringes of the city, more than five kilometres from the main network, and were thus not considered to be connected to it.
- 46 outlets either closed or opened during the period under analysis, and a small number of Caltex-Woolworths outlets operating from shopping centre car-parks did not open on Sundays. Both had incomplete datasets. [57]
- 21 outlets had fewer than ten cycles during the period (against more than 50 for the remainder). *FuelWatch* requires all sellers of petroleum to provide daily prices, and this includes marinas, taxi depots, mechanical repair shops and others for whom the sale of petroleum is a secondary business. These outlets do not exhibit cycles and are excluded because the sale of retail petroleum is not a primary business.

Figures 5.1 and 5.2 provide an overview of the outlets characterised by brand and by ownership type.

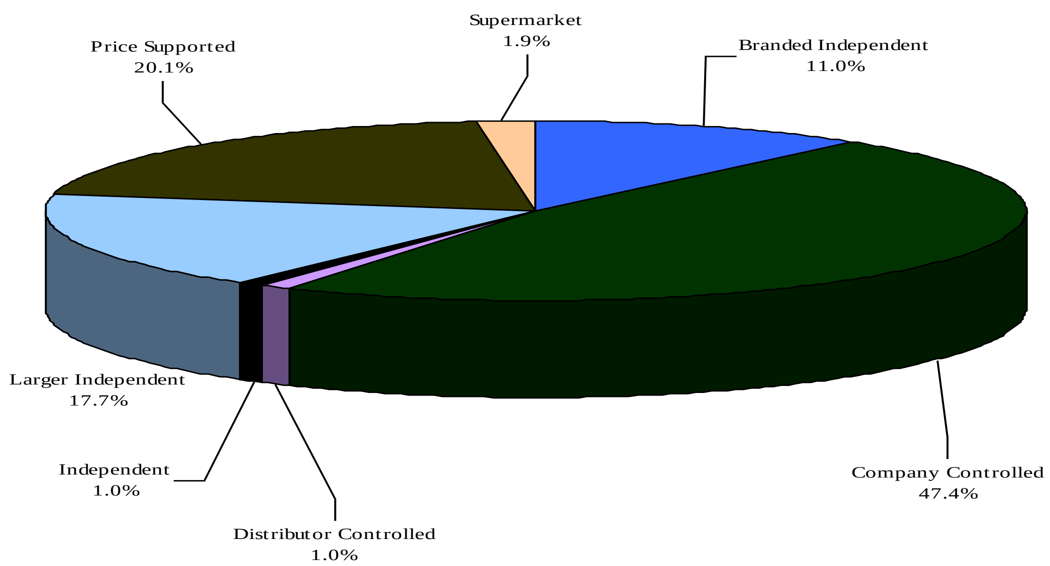
[57] Caltex-Woolworths outlets are under-represented in the sample; 20 were open for part of the period, 11 were open for the whole period (except on Sundays), but only four are in the sample. The result is that the regression models do not reflect the behaviour of supermarkets particularly well.

Figure 5.1: Retail Petroleum Outlets by Brand



Source: FuelWatch Data

Figure 5.2: Ownership Patterns



Source: FuelWatch Data

Caltex has the largest market share, followed by BP and Shell. Independent chains (Gull, Liberty and Peak) make up roughly a quarter of the sample, making them collectively more important than either Shell or Mobil and slightly smaller than BP.

Company controlled outlets comprise roughly half of those in Figure 5.2. However, *FuelWatch* defines both those outlets owned directly by the Majors and those owned by their multi-site franchisees as being company controlled. In WA as a whole, Shell owns eight sites, BP owns five and Mobil none.[58] Thus, most of the outlets listed as company controlled in Figure 5.2 are owned by one of the multi-site franchisees of these brands.

Shepard (1991) explores the influence of retail petroleum outlets offering different types of service on pricing, finding that those offering both self service and full service do so in order to better sort their customers and practice price discrimination. In Perth, however, the role of service in price discrimination would appear to be less important, as only five percent of outlets in the sample offer full service, with a further 20 percent offering conditional service.[59] Most of these are independents or branded independents.

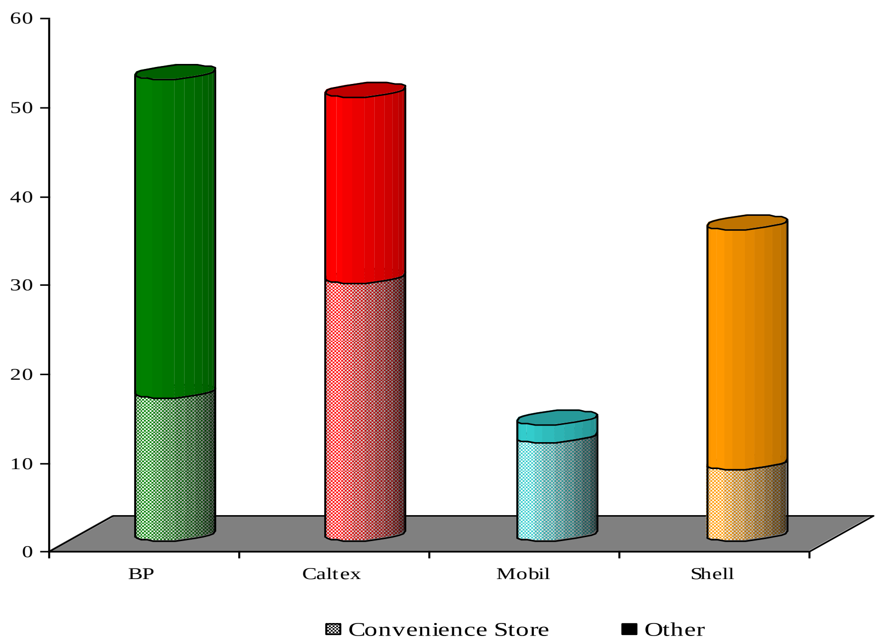
Each of the Majors has one convenience store brand, and Caltex has two. These are: Shell Select, BP Connect, Caltex Starshop, Caltex Starmart and Mobil Quix. Whilst Mobil, Shell and BP (or their multi-site franchisees) own all of their convenience stores,

[58] These data come from a personal communication from the Department of Industry, Tourism and Resources, which collects such data on a state-wide, but not a city basis. Note that Caltex has no multi-site franchisees, and thus owns 15 outlets in Perth. Since Mobil has 13 sites listed by *FuelWatch* as company controlled and all of these are under a single multi-site franchisee, this leaves 71 sites, more than 50 of which would be operated by the multi-site franchisees of BP or Shell.

[59] That is, pumping services are offered at some times, but not at others.

Caltex convenience stores are as likely to be operated by price-supported, single-site franchisees as they are to be operated by Caltex itself. Convenience stores offer other potential profit streams, which mean that fuel itself might be a loss-leader.[60] Figure 5.3 shows how many outlets have convenience stores by brand.

Figure 5.3: Convenience Stores

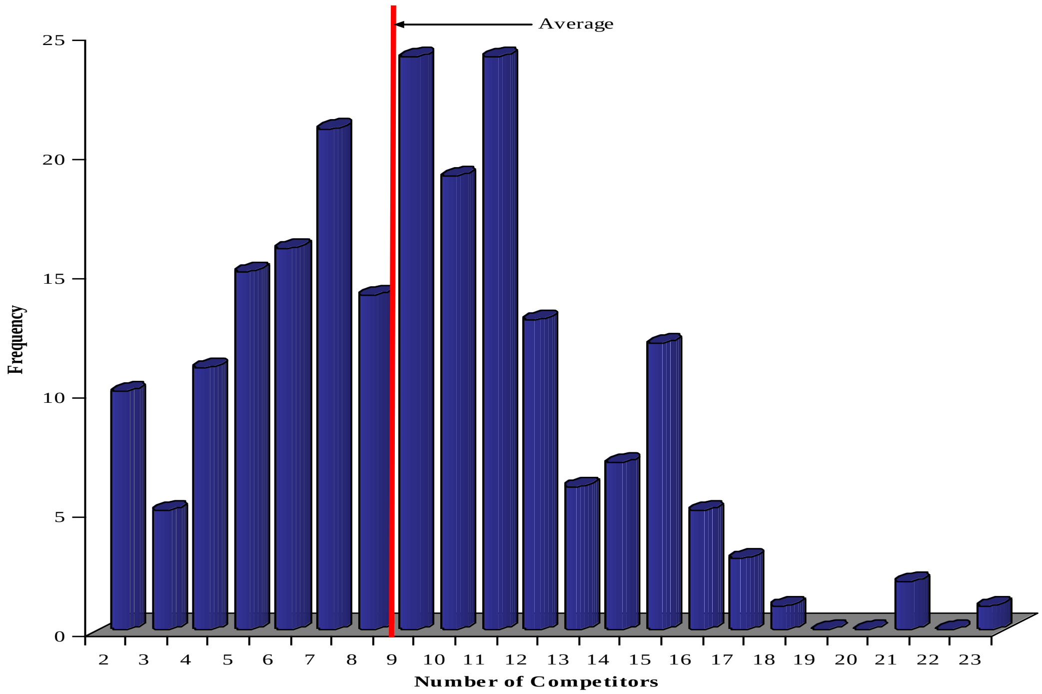


Source: FuelWatch Data

Although this thesis focuses on competition through a network structure, one can also characterise local competition through examining the number of competitors within a certain radius (here 5km) or the distance to the nearest competitor. Figures 5.4 and 5.5 below provide details on both measures. Whilst Perth itself is a fairly low-density city, the retail petroleum market is quite concentrated, as retail petroleum outlets tend to congregate at major shopping centres or along major roads. This is partly in response to demand and partly due to local town-planning restrictions.

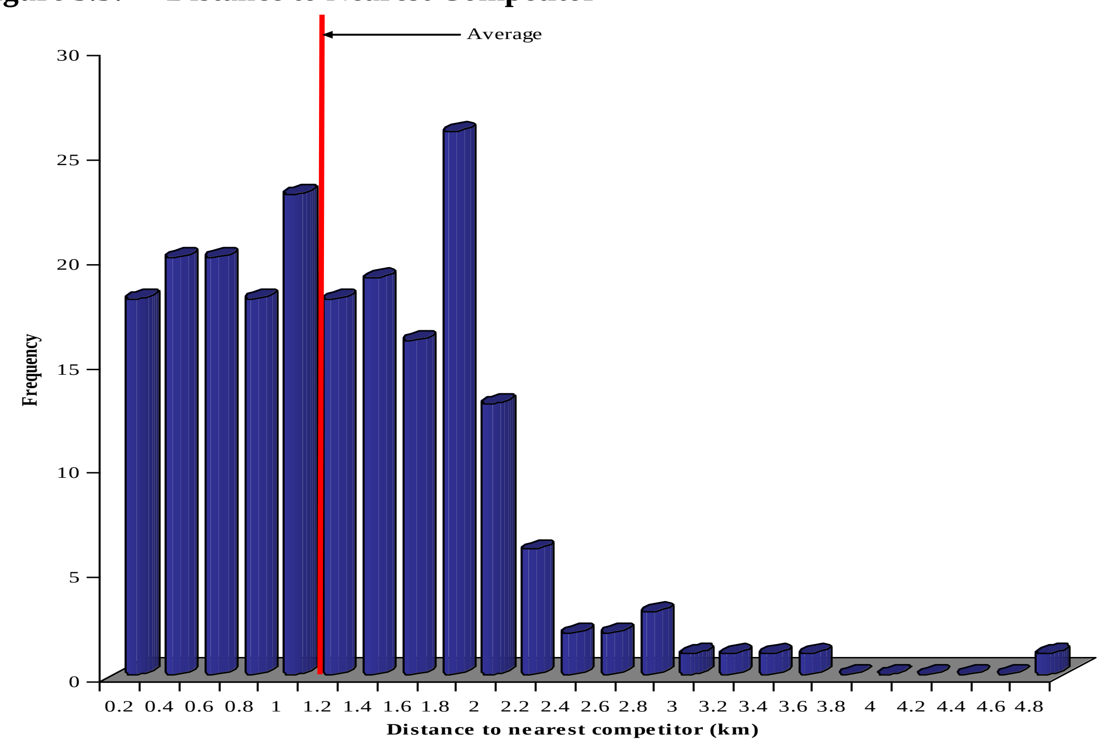
[60] Although Adams (1997) suggests otherwise; see Chapter Three for details.

Figure 5.4: Number of Competitors within 5 km



Source: Author calculations based on Universal Business Directories (2002)

Figure 5.5: Distance to Nearest Competitor



Source: Author calculations based on Business Directories (2002)

Demand Characteristics

The choice of demand characteristics is based on the findings of the elasticity literature summarised in Chapter Three, and the availability of data from the ABS (2006). ABS data at the postcode level is matched to the postcode of each retail petroleum outlet. This implicitly assumes that all demand is local, ignoring the commuter traffic that Marvel (1976) finds to be of importance for demand in the US. The assumption is made because there are no data available on demand for each retail petroleum outlet. However, its consequences might not be too egregious; most of Perth's commuter traffic flows down its freeways, which have no retail petroleum outlets on them.

Table 5.2 summarises the demand data, showing city-wide averages and the upper and lower bounds of 95 percent confidence intervals around these averages. Table 5.7 provides more detail at the sub-market level.

Table 5.2: Demand-Side Characteristics

	Lower Bound	Average	Upper Bound
Median family Income	1321.5133	1362.7889	1404.0645
Average Household size	2.4503018	2.4922705	2.5342392
Number aboriginal	312.46014	362.88406	413.30798
Number persons	19931.575	21479.348	23027.121
Number born overseas	7627.2796	8243.0386	8858.7977
Number of families with dependent children	2360.4874	2569.7826	2779.0778
Number of families with Single Mother	817.59251	896.27536	974.95822
Number of families	5295.9837	5731.7971	6167.6105
Av Number vehicles per household	1.4479305	1.4681488	1.4883671
Dwelling density (houses per sq km)	431.34798	468.12804	504.90811
Number of rented dwellings	1830.5952	1969.9517	2109.3081
Number of state housing dwellings	265.2835	308.80676	352.33003
Number of dwellings	7355.8529	7889.7585	8423.664
number with post-school qualification	6566.6349	7041.1932	7515.7516
Number employed	9735.9579	10502.449	11268.941
Number using public transport for work travel	861.12314	915.24638	969.36962

Source: ABS (2006)

Occurrences Families

The two occurrence families are groups of dummy variables which indicate whether the price of a given outlet displays a certain characteristic on a given day. One pertains to the whole market, and the other to the sub-market within which the relevant outlet sits. Tables 5.3 and 5.4 summarise the frequencies of the cumulative total of each of these occurrences in the 441 days of the sample period.

Table 5.3: Occurrences in the Whole Market

Frequency Bands	In Whole Market								
	Max Price Occurrences	Min Price Occurrences	Median Price Occurrences	Lower Quartile Price Occurrences	Upper Quartile Price Occurrences	Below Average Price Occurrences	Above Average Price Occurrences	Leadership Occurrences	Follower Occurrences
0	19	4	0	0	0	0	0	43	0
25	85	147	12	19	44	0	3	86	0
50	85	48	27	28	59	0	8	77	0
75	17	7	47	42	38	0	4	2	0
100	2	2	36	25	20	5	6	0	0
125	0	1	29	27	26	2	10	1	1
150	0	0	36	25	10	12	19	0	2
175	0	0	20	13	0	10	17	0	13
200	1	0	2	7	1	14	32	0	124
225	0	0	0	7	6	44	41	0	69
250	0	0	0	10	2	34	34	0	0
275	0	0	0	1	2	27	13	0	0
300	0	0	0	3	1	22	8	0	0
325	0	0	0	1	0	12	9	0	0
350	0	0	0	1	0	6	2	0	0
375	0	0	0	0	0	9	3	0	0
400	0	0	0	0	0	5	0	0	0
425	0	0	0	0	0	7	0	0	0
450	0	0	0	0	0	0	0	0	0

Source: FuelWatch data

The major point of Tables 5.3 and 5.4 is the concentration of frequencies in the lower bands; there are no consistent price leaders at the local or global level, and few outlets that are consistently above or below the average. This lack of consistent behaviour should not be particularly surprising as the nature of the mixed strategy equilibrium in Chapter Four precludes such consistency.

Table 5.4: Occurrences in the Relevant Sub-market

Frequency Bands	In Sub-market								
	Max Price Occurrences	Min Price Occurrences	Median Price Occurrences	Lower Quartile Price Occurrences	Upper Quartile Price Occurrences	Below Average Price Occurrences	Above Average Price Occurrences	Leadership Occurrences	Follower Occurrences
0	16	2	0	0	0	0	0	43	0
25	50	112	9	22	34	0	0	76	2
50	75	52	21	49	46	0	7	85	9
75	34	17	34	37	44	3	5	4	14
100	16	12	45	34	34	4	5	1	70
125	4	5	26	18	21	2	3	0	53
150	8	4	36	22	12	19	15	0	47
175	3	2	21	10	5	15	15	0	14
200	0	3	11	2	0	32	38	0	0
225	1	0	6	6	4	29	32	0	0
250	2	0	0	6	3	38	26	0	0
275	0	0	0	0	5	28	29	0	0
300	0	0	0	2	1	12	20	0	0
325	0	0	0	1	0	7	6	0	0
350	0	0	0	0	0	5	5	0	0
375	0	0	0	0	0	4	2	0	0
400	0	0	0	0	0	6	1	0	0
425	0	0	0	0	0	5	0	0	0
450	0	0	0	0	0	0	0	0	0

Source: FuelWatch data

Network Structure: Network Characteristics, Sub-markets and Redundancy

In order to develop summary statistics on network structure and identify sub-networks, I need first to identify the network. The process is of building the network based upon the relationship between price-cycle minima is outlined in Chapter Four, and here I explain how this is done empirically in the case study. I also examine the network results in some detail, particularly the sub-networks. This is not a formal test, either of network structure or of the model in Chapter Four, but is rather a more modest examination of reasonableness, which seeks to ascertain whether the prices of outlets grouped in a given submarket are more similar than the prices of outlets grouped in some other logical way, such as by the same brand. If the network approach is even remotely valid, one would expect outlets in the same sub-market to have reasonably cohesive pricing with their neighbours, and thus the examination in this section performs the role of assessing reasonableness, before the network summary data is used as an input into the regression models of Chapter Six.

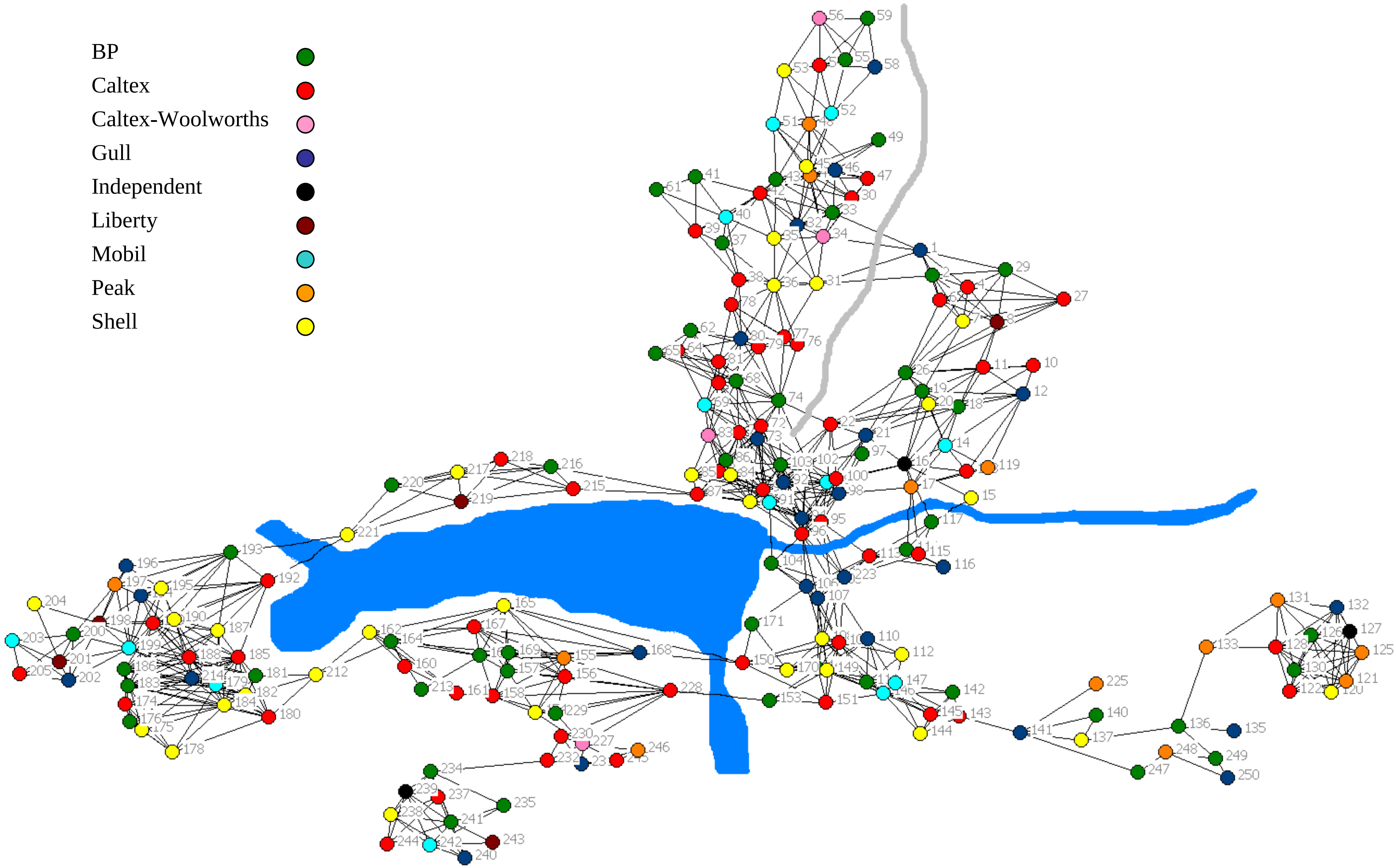
Recall from Chapter Four that the spatial duopoly model presented therein makes a number of predictions pertaining to the relationship between the minimum prices charged by pairs of outlets which are interacting with each other on price. This, as mentioned, is the link between the theoretical model of Chapter Four and the empirical models of Chapter Six, and this section explains how that link was made in practice. In the simplest case of equal marginal costs, minimum prices will be equal. In the study period in Perth, the correlation between daily tgps at the different wholesalers is more than 99 percent in every case (see Table 5.12 below) and thus I assume that marginal costs are equal for each pair of outlets examined. To test for equality in cycle minima, I take the average of the cycle minima for each station over the whole sample period and then, for each pair analysed, I conduct a test of the difference between these means. Where I find no statistical difference between the means, I declare that pair to be connected.[61] The cycle minima are determined by searching for the lowest price in the three days prior to each price increase of greater than five percent.[62] There are 208 stations overall in the sample, and, rather than testing every pair, I restrict attention only to outlets that are within five kilometres of one another. There is only a limited range of prices across the whole market on a given day, and thus distant outlets might show related pricing purely by chance. Focussing only on nearby outlets obviates this issue.

[61] An obvious extension to the model is to consider the proportion of times two stations share the same minima as an indication of the strength of their connection.
[62] I also looked for minima four days from the price hike, and tested a number of smaller and larger price hikes. This made little difference to the results.

The results are summarised in Figure 5.6 (overleaf). The blue area represents the Swan River, which divides the city North from South, and the grey line represents the main north-south freeway, which divides East from West. Placement of each station is approximate, but roughly correlates to the physical shape of the Perth market.[63] The different coloured dots represent different brands. Brands tend to be spread throughout the Perth market, rather than focussing on any particular area.

[63] The software used to construct the networks and calculate their structural characteristics (Borgatti, Everett, & Freeman, 2002) has only limited capabilities in terms of spatial mapping.

Figure 5.6: Retail Petroleum Market Network



I now turn to the process of dividing the network into sub-networks. I follow Gould's (1967) methodology of examining patterns of positive and negative entries in the eigenvectors associated with the second to n^{th}-largest eigenvalues of the adjacency matrix which summarises the network. Here, I stop at the sixth largest eigenvalue, as smaller eigenvectors contain too much noise for any useful signals to be extracted.

This method of defining sub-markets by visual inspection is vulnerable to the numbering system used. To endeavour to ensure that outlets which are close to each other geographically (and hence more likely to be connected) are also close to each other on the number line, I start by taking two stations which are connected and close to each other, numbering them one and two and then establishing the geographical midpoint between them. The third outlet is the nearest to the midpoint, and subsequent outlets are numbered by the same process. In most cases, this results in outlets located close to each other geographically also being near each other on the number line. However, the process is not perfect, and thus a degree of judgement must be exercised.

Table 5.5 (overleaf) provides an overview of the results, with the positive and negative elements of the eigenvectors coloured green and red to aid visual inspection. The numbers in bold across the top of Table 5.5 are the eigenvectors. All are relatively close together, which Gould (1967), examining terrain, suggests means the terrain is rather smooth. In terms of prices, this suggests that no region dominates another.

Table 5.5: Eigenvector Results

	11.42	9.31	8.98	8.61	8.19												
Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*	Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*	Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*
1	-0.0000007	-0.0079032	-0.0805149	-0.0389494	0.0000007	**47**	-0.0000003	-0.0159671	-0.1723933	-0.0598749	0.0000002	**94**	-0.0000402	0.0517979	0.0308661	-0.1200665	0.0000006
2	-0.0000010	-0.0022027	-0.0327434	-0.0355714	0.0000011	**48**	-0.0000002	-0.0170015	-0.1909190	-0.0693686	0.0000003	**95**	-0.0000395	0.0803048	0.0278101	-0.1219587	-0.0000001
4	-0.0000017	0.0010320	-0.0210339	-0.0512642	0.0000016	**49**	-0.0000001	-0.0086466	-0.0960972	-0.0344564	0.0000001	**96**	-0.0000374	0.1147139	0.0228217	-0.1180553	-0.0000010
6	-0.0000017	0.0010320	-0.0210339	-0.0512642	0.0000016	**51**	-0.0000002	-0.0150901	-0.1692028	-0.0613403	0.0000002	**97**	-0.0000080	0.0060654	0.0063730	-0.0274023	0.0000003
7	-0.0000021	0.0027023	-0.0112132	-0.0529829	0.0000016	**52**	-0.0000001	-0.0109796	-0.1251859	-0.0463788	0.0000002	**98**	-0.0000370	0.0412854	0.0316770	-0.1354419	0.0000014
8	-0.0000026	0.0037503	-0.0109473	-0.0634571	0.0000020	**53**	-0.0000001	-0.0050470	-0.0593300	-0.0227847	0.0000001	**99**	-0.0000429	0.0409163	0.0348935	-0.1542006	0.0000019
10	-0.0000023	0.0044270	0.0012279	-0.0465131	0.0000014	**54**	0.0000000	-0.0037343	-0.0444036	-0.0173073	0.0000001	**100**	-0.0000402	0.0394359	0.0322365	-0.1470455	0.0000018
11	-0.0000040	0.0073002	0.0015620	-0.0772819	0.0000023	**55**	0.0000000	-0.0023948	-0.0289811	-0.0115368	0.0000000	**102**	-0.0000549	0.0151690	0.0255726	-0.1005959	0.0000014
12	-0.0000038	0.0082180	0.0040348	-0.0747840	0.0000022	**56**	0.0000000	-0.0015094	-0.0186828	-0.0076375	0.0000000	**103**	-0.0000460	-0.0081161	0.0185109	-0.0442979	0.0000008
14	-0.0000049	0.0112029	0.0058390	-0.0815050	0.0000022	**58**	0.0000000	-0.0018526	-0.0223765	-0.0088917	0.0000000	**104**	-0.0000029	0.0755256	-0.0031013	-0.0174237	-0.0000017
15	-0.0000013	0.0048768	0.0016100	-0.0166594	0.0000003	**59**	0.0000000	-0.0010197	-0.0127398	-0.0052675	0.0000000	**105**	0.0000083	0.1915644	-0.0228038	0.0017908	-0.0000042
16	-0.0000131	0.0226724	0.0140411	-0.1209906	0.0000026	**61**	-0.0000001	-0.0029725	-0.0249798	-0.0051885	0.0000000	**106**	0.0000111	0.1662037	-0.0215686	0.0071249	-0.0000039
17	-0.0000061	0.0198213	0.0067604	-0.0674184	0.0000012	**62**	-0.0000101	-0.0570344	-0.0545423	0.1648209	-0.0000017	**107**	0.0000187	0.2152171	-0.0328347	0.0278431	-0.0000050
18	-0.0000100	0.0155179	0.0074068	-0.1318701	0.0000036	**64**	-0.0000111	-0.0584830	-0.0506205	0.1659137	-0.0000017	**108**	0.0000524	0.2870851	-0.0570536	0.0863556	-0.0000062
19	-0.0000093	0.0130637	0.0065800	-0.1189298	0.0000032	**65**	-0.0000079	-0.0429480	-0.0363892	0.1242411	-0.0000013	**109**	0.0000592	0.3334857	-0.0679676	0.1070083	-0.0000067
20	-0.0000091	0.0128015	0.0077032	-0.1134186	0.0000031	**67**	-0.0000269	-0.1033889	-0.0745875	0.2617518	-0.0000024	**110**	0.0000303	0.2336763	-0.0504910	0.0861307	-0.0000039
21	-0.0000222	0.0234816	0.0190166	-0.1450100	0.0000031	**68**	-0.0000269	-0.1033889	-0.0745875	0.2617518	-0.0000024	**111**	0.0000305	0.2248086	-0.0506090	0.0907709	-0.0000031
22	-0.0000286	0.0075257	0.0126925	-0.1098748	0.0000027	**69**	-0.0000253	-0.0850355	-0.0475474	0.1988394	-0.0000016	**112**	0.0000130	0.1087090	-0.0244532	0.0437997	-0.0000016
26	-0.0000083	0.0101688	-0.0019735	-0.1167175	0.0000033	**71**	-0.0000415	-0.0890438	-0.0253464	0.1587635	-0.0000009	**113**	-0.0000001	0.1022730	-0.0077051	-0.0199822	-0.0000023
27	-0.0000015	0.0020124	-0.0096890	-0.0435127	0.0000014	**72**	-0.0000408	-0.0768271	-0.0228241	0.1328112	-0.0000007	**114**	-0.0000005	0.0408162	-0.0020799	-0.0181326	-0.0000007
29	-0.0000010	0.0000455	-0.0208362	-0.0391235	0.0000012	**73**	-0.0000462	-0.0761878	-0.0181332	0.1229412	-0.0000006	**115**	-0.0000005	0.0408162	-0.0020799	-0.0181326	-0.0000007
30	-0.0000004	-0.0222555	-0.2342687	-0.0787222	0.0000003	**74**	-0.0000343	-0.0871007	-0.0647308	0.1921043	-0.0000015	**116**	-0.0000001	0.0197587	-0.0013208	-0.0065299	-0.0000005
31	-0.0000016	-0.0211608	-0.1285606	-0.0093633	0.0000000	**76**	-0.0000056	-0.0297108	-0.0495572	0.0732830	-0.0000008	**117**	-0.0000014	0.0227186	0.0004215	-0.0225101	-0.0000001
32	-0.0000010	-0.0314480	-0.2884690	-0.0794662	0.0000002	**77**	-0.0000069	-0.0390489	-0.0719034	0.0932990	-0.0000010	**118**	-0.0000026	0.0071880	0.0036663	-0.0436199	0.0000011
33	-0.0000005	-0.0234264	-0.2388779	-0.0780559	0.0000003	**78**	-0.0000054	-0.0382569	-0.0675289	0.1005777	-0.0000012	**119**	-0.0000015	0.0049884	0.0022598	-0.0310348	0.0000008
34	-0.0000010	-0.0288789	-0.2601933	-0.0708590	0.0000002	**79**	-0.0000131	-0.0701036	-0.0866992	0.1883329	-0.0000020	**120**	0.0000000	0.0000018	-0.0000007	0.0000034	0.3176010
35	-0.0000009	-0.0227966	-0.1896731	-0.0428065	0.0000000	**80**	-0.0000138	-0.0750925	-0.0945255	0.2017927	-0.0000021	**121**	0.0000000	0.0000018	-0.0000007	0.0000034	0.3176010
36	-0.0000046	-0.0420250	-0.1543183	0.0569302	-0.0000009	**81**	-0.0000153	-0.0774459	-0.0725533	0.2159476	-0.0000022	**122**	0.0000000	0.0000016	-0.0000007	0.0000031	0.2838592
37	-0.0000007	-0.0120018	-0.0720906	-0.0011754	-0.0000002	**82**	-0.0000225	-0.0523567	0.0030607	0.0611246	-0.0000001	**125**	0.0000000	0.0000018	-0.0000007	0.0000034	0.3176010
38	-0.0000024	-0.0226516	-0.0770672	0.0367695	-0.0000006	**83**	-0.0000213	-0.0636067	-0.0215330	0.1264139	-0.0000009	**126**	0.0000000	0.0000020	-0.0000008	0.0000038	0.3408803
39	-0.0000004	-0.0087343	-0.0640546	-0.0089533	-0.0000001	**84**	-0.0000206	-0.0469237	0.0032821	0.0533898	0.0000000	**127**	0.0000000	0.0000020	-0.0000008	0.0000038	0.3408803
40	-0.0000005	-0.0135600	-0.1112298	-0.0230837	0.0000000	**85**	-0.0000088	-0.0384787	0.0016212	0.0485897	-0.0000001	**128**	0.0000000	0.0000034	-0.0000012	0.0000048	0.3484758
41	-0.0000001	-0.0053723	-0.0491137	-0.0126557	0.0000000	**86**	-0.0000240	-0.0560004	-0.0022105	0.0743610	-0.0000002	**130**	0.0000000	0.0000020	-0.0000008	0.0000038	0.3408803
42	-0.0000006	-0.0247365	-0.2409327	-0.0717877	0.0000002	**87**	0.0001096	-0.0241351	0.0141251	0.0002582	0.0000004	**131**	0.0000000	0.0000027	-0.0000009	0.0000034	0.2138640
43	-0.0000005	-0.0269452	-0.2812849	-0.0930405	0.0000003	**89**	-0.0000332	-0.0086699	0.0203046	-0.0261002	0.0000003	**132**	0.0000000	0.0000019	-0.0000008	0.0000035	0.3099819
44	-0.0000005	-0.0296729	-0.3166410	-0.1081936	0.0000004	**90**	-0.0000470	-0.0174068	0.0228804	-0.0296695	0.0000006	**133**	0.0000000	0.0000139	-0.0000040	0.0000097	0.0697791
45	-0.0000005	-0.0274001	-0.2927130	-0.1000745	0.0000003	**91**	-0.0000339	0.0152597	0.0265255	-0.0687877	0.0000005	**135**	0.0000000	0.0000132	-0.0000037	0.0000088	0.0010911
46	-0.0000004	-0.0234061	-0.2539043	-0.0885317	0.0000003	**92**	-0.0000496	-0.0052923	0.0288033	-0.0664569	0.0000011	**136**	0.0000000	0.0001230	-0.0000335	0.0000756	0.0089328

Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*
137	0.0000001	0.0010910	-0.0002856	0.0006148	0.0011310
140	0.0000001	0.0010790	-0.0002822	0.0006070	0.0001586
141	0.0000007	0.0089523	-0.0022497	0.0046134	0.0001676
142	0.0000078	0.0783503	-0.0189124	0.0369581	0.0000036
143	0.0000078	0.0792188	-0.0191377	0.0374380	0.0000218
144	0.0000078	0.0783503	-0.0189124	0.0369581	0.0000036
145	0.0000102	0.1001604	-0.0239818	0.0463999	0.0000032
146	0.0000348	0.2516757	-0.0572615	0.1041823	-0.0000001
147	0.0000281	0.2198447	-0.0505998	0.0933712	0.0000007
148	0.0000598	0.2788911	-0.0614104	0.1073166	-0.0000054
149	0.0000598	0.2788911	-0.0614104	0.1073166	-0.0000054
150	0.0002397	0.1723664	-0.0383897	0.0688310	-0.0000056
151	0.0000434	0.1497237	-0.0339038	0.0613803	-0.0000031
153	0.0000426	0.0782518	-0.0181242	0.0340618	-0.0000024
154	0.0003167	0.0129407	-0.0041778	0.0135391	-0.0000050
155	0.0008720	0.0254825	-0.0078826	0.0242755	-0.0000084
156	0.0006913	0.0208325	-0.0065547	0.0206123	-0.0000073
157	0.0008184	0.0222759	-0.0070033	0.0219981	-0.0000078
158	0.0006512	0.0174720	-0.0056278	0.0181897	-0.0000067
160	0.0011247	0.0034360	-0.0011168	0.0036516	-0.0000014
161	0.0011772	0.0051310	-0.0016805	0.0055437	-0.0000021
162	0.0057522	0.0120801	-0.0037440	0.0115627	-0.0000040
163	0.0017582	0.0231858	-0.0071656	0.0220492	-0.0000077
164	0.0059107	0.0147692	-0.0046081	0.0143480	-0.0000051
165	0.0017267	0.0398385	-0.0109726	0.0290213	-0.0000082
167	0.0017074	0.0231162	-0.0071272	0.0218617	-0.0000076
168	0.0006658	0.0330515	-0.0087779	0.0218940	-0.0000055
169	0.0012965	0.0236393	-0.0073159	0.0225510	-0.0000079
170	0.0000435	0.1507693	-0.0330152	0.0571503	-0.0000038
171	0.0000258	0.0525744	-0.0103497	0.0154527	-0.0000016
174	0.0975671	-0.0000878	0.0000203	-0.0000671	0.0000000
175	0.0975671	-0.0000878	0.0000203	-0.0000671	0.0000000
176	0.0975671	-0.0000878	0.0000203	-0.0000671	0.0000000
178	0.1091174	-0.0000474	0.0000042	-0.0000109	0.0000000
179	0.2679232	-0.0001647	0.0000339	-0.0001073	0.0000000
180	0.1678147	0.0002713	-0.0001082	0.0003726	-0.0000002
181	0.1979027	0.0002278	-0.0000942	0.0003223	-0.0000001
182	0.2192776	0.0002024	-0.0000871	0.0002986	-0.0000001
183	0.2679232	-0.0001647	0.0000339	-0.0001073	0.0000000

Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*
184	0.2493559	-0.0001197	0.0000171	-0.0000503	0.0000000
185	0.2948518	-0.0002130	0.0000501	-0.0001551	0.0000000
186	0.2653972	-0.0002614	0.0000704	-0.0002273	0.0000001
187	0.2128723	-0.0002662	0.0000803	-0.0002545	0.0000001
188	0.2937338	-0.0002800	0.0000769	-0.0002592	0.0000001
189	0.2616193	-0.0003633	0.0001144	-0.0003744	0.0000001
190	0.2616193	-0.0003633	0.0001144	-0.0003744	0.0000001
192	0.1507700	-0.0002820	0.0001055	-0.0002689	0.0000001
193	0.1170226	-0.0002657	0.0001046	-0.0002680	0.0000001
194	0.1468553	-0.0002742	0.0000954	-0.0003139	0.0000001
195	0.1368058	-0.0002526	0.0000880	-0.0002865	0.0000001
196	0.0689141	-0.0001491	0.0000542	-0.0001811	0.0000001
197	0.0723172	-0.0001574	0.0000572	-0.0001926	0.0000001
198	0.1247781	-0.0002217	0.0000746	-0.0002635	0.0000001
199	0.1889658	-0.0002165	0.0000674	-0.0002352	0.0000001
200	0.0422544	-0.0000853	0.0000299	-0.0001109	0.0000001
201	0.0375754	-0.0000731	0.0000253	-0.0000952	0.0000000
202	0.0364300	-0.0000700	0.0000242	-0.0000909	0.0000000
203	0.0111613	-0.0000275	0.0000099	-0.0000390	0.0000000
204	0.0142212	-0.0000317	0.0000111	-0.0000416	0.0000000
205	0.0111613	-0.0000275	0.0000099	-0.0000390	0.0000000
212	0.0522636	0.0029601	-0.0009620	0.0031234	-0.0000012
213	0.0006718	0.0040779	-0.0013106	0.0042255	-0.0000016
214	0.2572096	-0.0001552	0.0000322	-0.0001042	0.0000000
215	0.0006568	-0.0032911	0.0020310	0.0000356	0.0000001
216	0.0008796	-0.0033626	0.0020795	0.0000354	0.0000001
217	0.0028193	-0.0010565	0.0006876	0.0000021	0.0000000
218	0.0008708	-0.0010211	0.0006646	0.0000085	0.0000000
219	0.0028193	-0.0010565	0.0006876	0.0000021	0.0000000
220	0.0027664	-0.0007372	0.0004842	-0.0000016	0.0000000
221	0.0241932	-0.0003651	0.0002304	-0.0000620	0.0000000
223	0.0000028	0.1745117	-0.0147604	-0.0216171	-0.0000037
225	0.0000001	0.0009618	-0.0002504	0.0005356	0.0000205
227	0.0000788	0.0052488	-0.0016864	0.0054343	-0.0000020
228	0.0003231	0.0208270	-0.0060881	0.0173873	-0.0000054
229	0.0001805	0.0083073	-0.0026867	0.0087259	-0.0000032
230	0.0000373	0.0030375	-0.0009468	0.0029341	-0.0000010
231	0.0000127	0.0011668	-0.0003890	0.0013097	-0.0000005
232	0.0000114	0.0010293	-0.0003414	0.0011420	-0.0000004

Station Number	*Evec2*	*Evec3*	*Evec4*	*Evec5*	*Evec6*
234	0.0000011	0.0001269	-0.0000444	0.0001586	-0.0000001
235	0.0000001	0.0000181	-0.0000067	0.0000259	0.0000000
237	0.0000001	0.0000237	-0.0000089	0.0000348	0.0000000
238	0.0000002	0.0000278	-0.0000105	0.0000414	0.0000000
239	0.0000002	0.0000278	-0.0000105	0.0000414	0.0000000
240	0.0000002	0.0000266	-0.0000101	0.0000395	0.0000000
241	0.0000002	0.0000277	-0.0000105	0.0000413	0.0000000
242	0.0000001	0.0000142	-0.0000056	0.0000229	0.0000000
243	0.0000000	0.0000045	-0.0000018	0.0000074	0.0000000
244	0.0000001	0.0000115	-0.0000045	0.0000185	0.0000000
245	0.0000088	0.0007723	-0.0002600	0.0008858	-0.0000003
246	0.0000088	0.0007723	-0.0002600	0.0008858	-0.0000003
247	0.0000001	0.0009735	-0.0002537	0.0005433	0.0000403
248	0.0000000	0.0001090	-0.0000295	0.0000662	0.0001623
249	0.0000000	0.0000265	-0.0000075	0.0000176	0.0011302
250	0.0000000	0.0000146	-0.0000041	0.0000097	0.0001579

The third eigenvector appears to be dividing outlets north of the Swan River into those near the Freeway, and those further to the north-east. It also appears to be pulling out those in the city centre, whilst the sixth eigenvector distinguishes between those outlets near the centre of the city and those in Midland. The third and fourth eigenvectors appear to be separating stations near Fremantle from those around Melville, and those in turn from the stations in the Victoria Park-Bentley area further to the east (a split which the sixth eigenvector makes clearer).

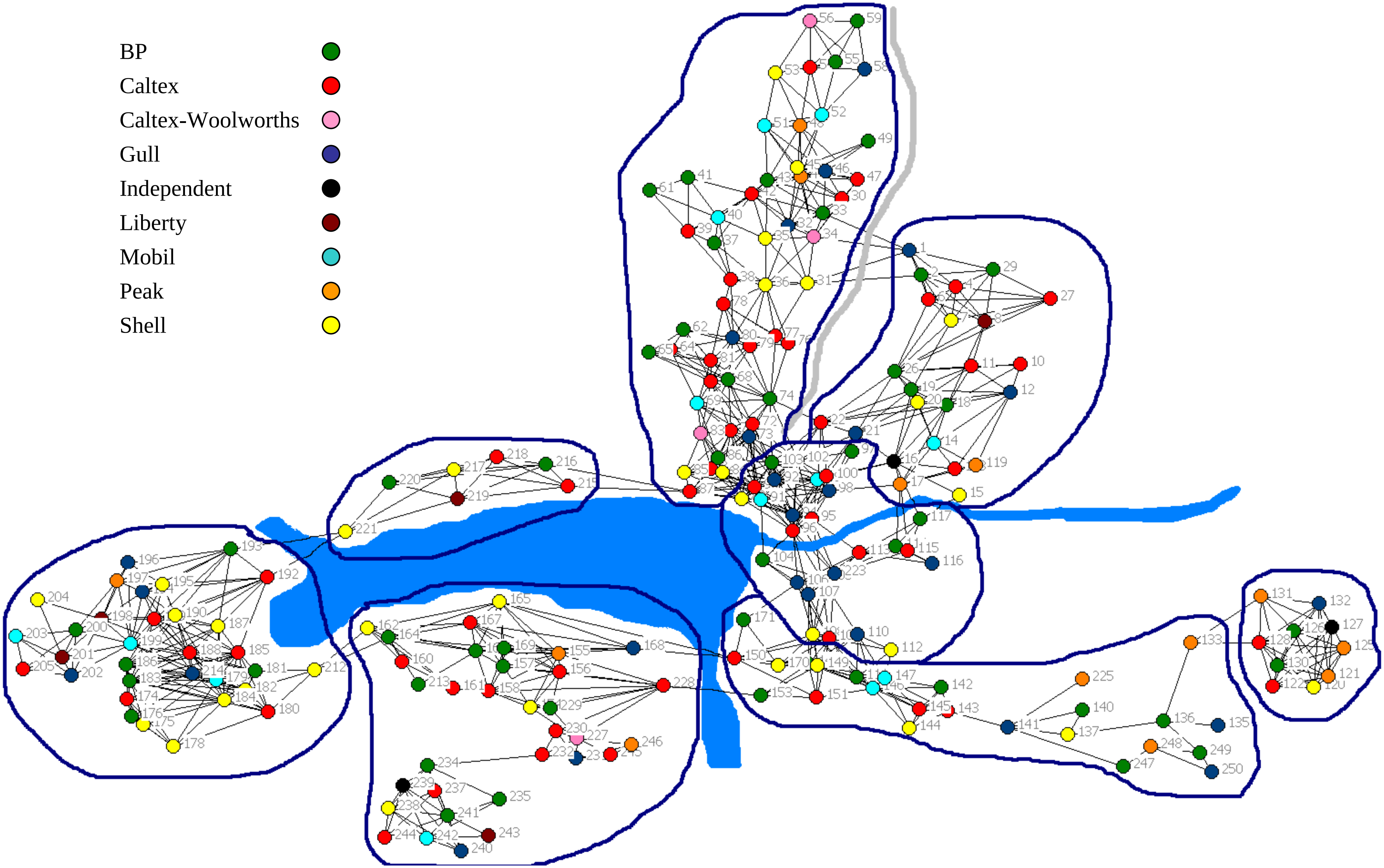
The process is somewhat judgemental, but it seems reasonable to divide the market, based on Table 5.5 above into the eight markets shown in Table 5.6.

Table 5.6: Sub-markets

Sub-market	Station Numbers
Fremantle	174-212, 214
Curtin	133-153, 170, 171, 225, 247-50
Midland	120-132
North East	1-29, 118,119
Freeway North	30-90
City Central	91-117, 223
Western Suburbs	215-221
Melville	154-169, 213, 227-246

Translating this onto Figure 5.6, we obtain Figure 5.7 (overleaf).

Figure 5.7: Sub-markets in Market Network



Examining the Reasonableness of the Sub-networks

Having constructed the network and divided it into sub-networks, I now conduct a series of somewhat ad-hoc investigations to ascertain whether the sub-market division is reasonable. I examine only the sub-networks as establishing a useful counterfactual for the network as a whole is difficult. For the sub-networks, I employ three approaches:

- A modularity approach based on the work of Girvan & Newman (2003a,b) which is a direct structural approach.
- An examination of demand-side characteristics in each sub-market, to ascertain whether these are different.
- An examination of supply-side characteristics; specifically an examination of whether pricing within each sub-market is more cohesive than in other types of groupings.

None of these approaches are statistically definitive tests, but each sheds some light on the question of whether the sub-market divisions are reasonable, and thus perform the role of being a first pass assessment of whether one would expect useful results from the network structure variables in the regressions in Chapter Six.

I do not replicate Girvan & Newman's (2003a,b) approach in its entirety, as this would require calculating edge centrality, and recalculating it every time an edge was removed. However, examining the edges which need to be removed in order to divide the network into the sub-markets shown in Figure 5.7, these comprise half of the edges with the highest edge centrality (calculated according to Girvan & Newman's, 2003a,b, methodology). This suggests that they would be amongst the first removed and that, if one were to follow Girvan & Newman (2003a,b) rather than Gould (1967), the results would not be particularly different.

I also calculate Girvan & Newman's (2003a,b) modularity score for the network as divided into the sub-markets shown in Figure 5.7. The calculation involves comparing the number of within sub-group connections with the number of within sub-group connections that would result in a random network with the same number of sub-groups and same number of connections overall. The measure is proportional, ranging from zero to one, with scores of over one-half indicating a performance better than random. The division in Figure 5.7 scores a little more than two-thirds, indicating that it is a reasonable division of the network.[64]

I now turn to the demand-side analysis, comparing the demand characteristics of each sub-market in Table 5.7. The characteristic values shown are a weighted average of the characteristics for each postcode within the relevant sub-market, with the weights coming from the number of outlets in the sub-market having that postcode.

[64] Girvan & Newman (2003a,b) provide no means of testing the statistical significance of their modularity score.

Table 5.7: Sub-markets – Demand Side Analysis

	Curtin		City Central		Fremantle		Freeway North	
	Av	*St. Dev*	*Av*	*St. Dev*	*Av*	*St. Dev*	*Av*	*St. Dev*
Median family Income	1173.825	174.071	1491.142	297.241	1398.959	228.816	1475.479	254.531
Average Household size	2.446	0.228	2.115	0.135	2.406	0.263	2.555	0.369
Number aboriginal	431.042	309.451	161.154	121.526	322.531	365.401	188.377	180.761
Number persons	18537.875	7737.795	11292.615	3582.010	22190.719	15742.706	24002.868	11785.194
Number born overseas	7105.875	2976.731	4708.231	1201.322	8184.438	5809.194	9455.736	5272.188
Number of families with dependent children	1980.792	973.447	1059.346	448.082	2589.750	1846.560	3038.189	1636.161
Number of families with Single Mother	811.667	385.912	401.577	174.917	1019.031	869.612	834.943	505.621
Number of families	4836.042	2123.360	2676.846	925.802	5988.688	4354.068	6531.113	3364.280
Av Number vehicles per hh	1.446	0.148	1.296	0.122	1.447	0.116	1.521	0.170
Dwelling density (houses per sq km)	290.423	229.852	763.026	236.916	526.897	213.544	494.664	249.280
Number of rented dwellings	1951.833	1043.760	1764.500	614.910	2188.531	1553.067	1914.717	945.549
Number of state housing dwellings	320.250	240.612	269.423	304.099	446.188	422.651	210.094	256.237
Number of dwellings	6951.583	2801.148	4634.654	1463.972	8574.875	5970.479	8620.075	3856.931
number with post-school qualification	5912.000	2686.207	4341.500	1616.796	7591.844	4484.205	8434.660	3815.702
Number employed	8799.917	3883.595	5703.231	1895.337	10598.625	7397.693	12448.906	6114.711
Number using public transport for work travel	779.125	403.232	910.077	320.565	874.531	462.901	1024.623	450.696
	Melville		**Midland**		**North East**		**Western Suburbs**	
	Av	*St. Dev*	*Av*	*St. Dev*	*Av*	*St. Dev*	*Av*	*St. Dev*
Median family Income	1231.824	198.290	1127.090	0.145	1130.770	141.711	2186.843	253.179
Average Household size	2.730	0.198	2.600	0.000	2.578	0.232	2.457	0.113
Number aboriginal	466.061	267.359	1437.000	0.000	477.870	308.467	51.571	15.946
Number persons	24003.061	10280.143	35000.000	0.000	22462.609	6899.537	13792.857	3770.151
Number born overseas	9320.758	4289.151	10449.000	0.000	9374.478	3633.875	5089.143	1787.387
Number of families with dependent children	3104.576	1612.959	4150.000	0.000	2676.174	805.718	1607.286	462.465
Number of families with Single Mother	1029.697	341.957	1818.000	0.000	1131.087	466.204	316.714	62.270
Number of families	6568.485	2797.167	9284.000	0.000	6018.391	1914.354	3266.143	899.533
Av Number vehicles per hh	1.556	0.100	1.475	0.000	1.465	0.104	1.471	0.070
Dwelling density (houses per sq km)	298.241	213.028	94.805	0.000	594.089	140.125	457.279	150.652
Number of rented dwellings	1590.121	558.516	3264.000	0.000	2190.913	1044.158	1464.000	343.482
Number of state housing dwellings	193.424	132.683	655.000	0.000	466.217	445.773	113.714	102.970
Number of dwellings	8258.939	3048.020	12667.000	0.000	8280.391	2519.594	4984.143	1301.390
number with post-school qualification	7258.212	3602.530	9311.000	0.000	6288.783	1816.824	6041.714	1764.179
Number employed	11719.636	5417.499	16096.000	0.000	10284.304	2984.206	6316.000	1700.449
Number using public transport for work travel	902.000	446.333	1087.000	0.000	823.174	201.722	852.857	256.007

Source: ABS (2006)

There are some clear differences between each of the sub-markets. The Western Suburbs market, for example, is richer than the remainder, as well as being better educated and more likely to contain people who people own their own homes. It has comparatively little public housing, or Aboriginal inhabitants. At the other extreme, the North-East has much lower incomes, lower employment and higher levels of public housing and Aboriginal inhabitants. The Freeway North and Melville markets seem most indicative of white, middle-class suburbia on their respective side of the Swan River, with middling incomes, many families with dependent children and a greater likelihood that an inhabitant was born in Australia. The City Central market has denser housing than the rest (followed by Fremantle, another important city centre within Perth), along with higher numbers of renters and fewer families with dependent children. It also has the highest number of people using public transport for travel to work, indicative of good public transport links within the area.

The demand-side analysis provides some support for the sub-market divisions, but the results are statistically weak; a one-tailed ANOVA analysis of the sub-groups for each of the characteristics above suggests that only the numbers of people using public transport for travel to work is different across the sub-groups.

I thus turn finally to the supply-side analysis, comparing the cohesion of prices within each sub-market with two counterfactuals; grouping by like brands and a set of random groupings where members of the group share neither the same brand nor the same sub-market.[65] The simplest way to compare these three different sets of groups is to conduct a one-tailed ANOVA test, and the results of such a test are shown in Table 5.8.

[65] The random groups are quite small; with eight sub-markets, each can have but eight elements. Moreover, because there are only four distinct brands in the Western Suburbs sub-market, the smallest of the eight, one can construct only four groups that have members that have neither the same sub-market nor the same branding

Table 5.8: Similarity of Prices – ANOVA Analysis

Branding			*Sub-Market*			*Random*		
	F-Test	*P-Value*		*F-Test*	*P-Value*		*F-Test*	*P-Value*
BP	9.1801	0	Fremantle	12.186	0	One	10.885	0
Caltex	1.7816	0.0003	Curtin	12.640	0	Two	6.6960	0
Caltex-Woolworths	5.3605	0.0011	Midland	11.935	0	Three	12.145	0
Gull	8.8459	0	North East	13.398	0	Four	22.141	0
Independent	1.802	0.1654	Fwy North	7.1813	0			
Liberty	10.981	0	City Central	13.696	0			
Mobil	1.0275	0.4198	Western Suburbs	0.79921	0.5704			
Peak	5.9313	0	Melville	8.3543	0			
Shell	2.3706	0						

Unfortunately, the results of the ANOVA test are inconclusive; all groupings are valid, although the sub-market and random groupings perform a little better than brands. The problem is that ANOVA tests rely upon averages, and on average there are few differences between outlets. Indeed, an ANOVA test on the whole sample gives a test statistic of 11.347 (and a P-value of zero), which suggests that all of the outlets come from the same group.

To examine cohesiveness of pricing in a more robust manner, I thus turn to an approach based on that suggested by Brillinger (1975) and used by Bartels (1977) to explore regional unemployment in Holland. The approach relies upon examining the eigenvalues of the cross-coherency matrix for each group in Table 5.8. The coherency between any two outlets shows the degree of linear relationship between the magnitudes of their power spectra at the relevant frequency band of the spectrogram (or alternatively, the degree to which each element in the pair has the same amount of its total variance explained by cycles of a particular length).[66]

As Brillinger (1975) points out, the eigenvectors of the cross-spectral matrix (using the cross-coherency matrix normalises the results) gives the closest result of any mapping from the smaller space described by the frequency data to the larger space described by the original data. It is thus the best way to reduce the dimensionality of a problem involving a comparison of a large number of pairs of outlets (as one has with coherency scores) to one where comparisons are between groups of outlets. The spectral density matrix of this mapping mechanism has the eigenvalues of the cross-coherency matrix down the main diagonal and zeroes on the off-diagonal elements.[67] Thus, the key to the analysis is to examine the relevant eigenvalues; the closer these are to zero, the better is the mapping and thus the more cohesive is the relevant subgroup.

In order to undertake the analysis of the cross-coherency matrix eigenvalues, I follow a number of steps:

- Firstly, I undertake an auto-spectral analysis, using 42 frequency bands (see discussion on prices below) and ascertain the cycles with the most power and hence the most important lags for each of the 208 stations.
- Secondly, I regress these lags (which differ for each outlet, but usually contain the seventh and tenth lags) against price for each outlet, and collect the residual vector.

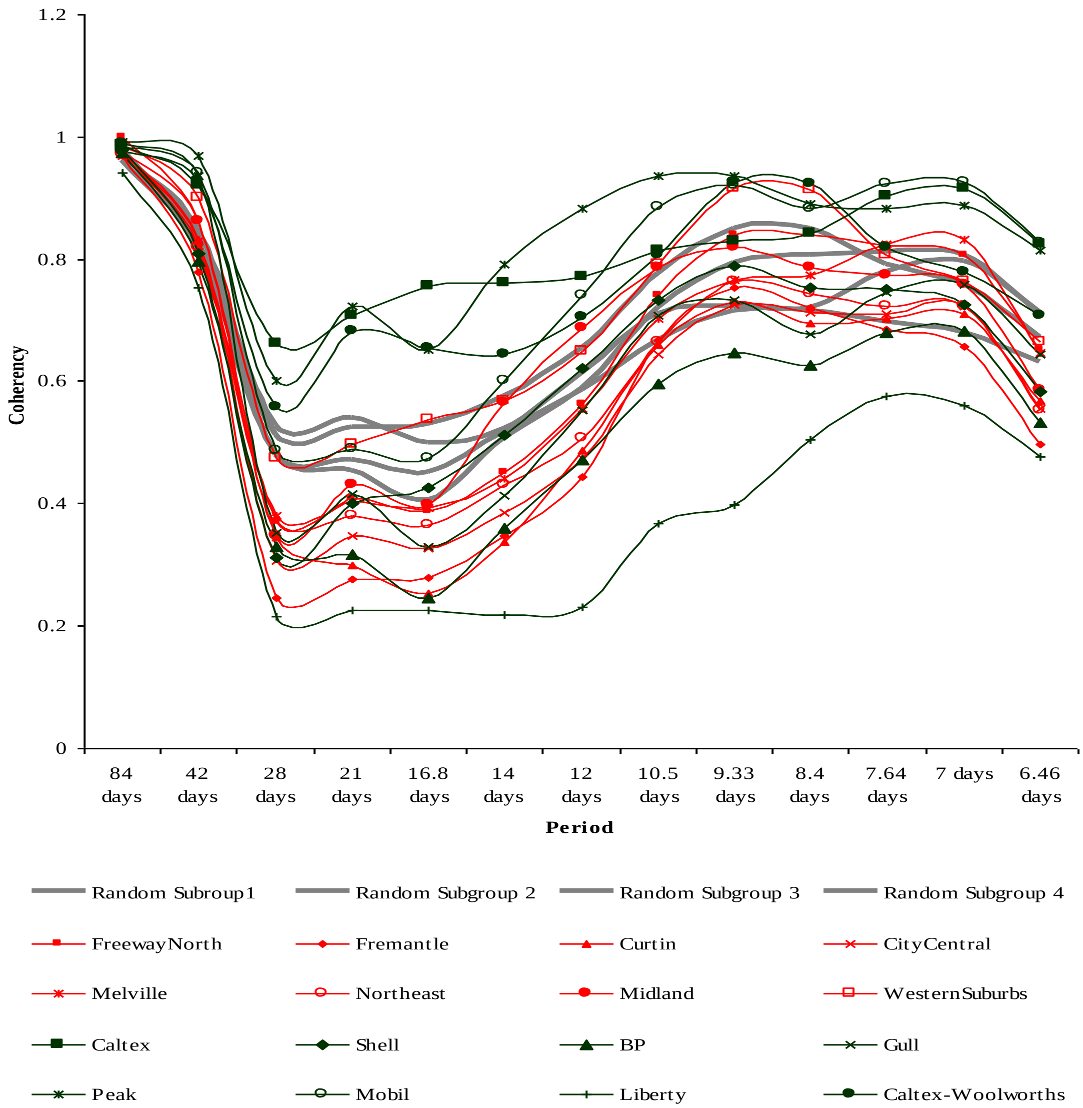
[66] The auto-spectra are examined under pricing below, where I create spectrograms with 42 frequency bands. Chatfield (2006), Brillinger (1975) or Granger & Hatanaka (1964) provide further details on coherency, phase and gain, the three elements of cross-spectral analysis, and the formulae used to calculate coherency in this analysis are taken from Granger & Hatanaka (1964, Chapters Five and Six).
[67] Under certain assumptions that seem reasonable to assume hold here, see Brillinger, 1975, pp. 344-5.

Coherency analysis is undertaken using this residual vector to avoid auto-correlation from introducing bias to results (Chatfield, 2006).

- Thirdly, having found the coherency between each pair in each of the nine brand groups, seven sub-market groups and four random groups, I arrange these into symmetric matrices (with ones down the main diagonal, indicating perfect coherency between each outlet and itself). Each of the 20 groups has 42 such matrices; one for each frequency band.
- Fourthly, I reduce the amount of data to be analysed. There are 42 frequency bands for each of the 20 groups, but the first 12 comprise more than 80 percent of the variance in the average outlet, so I consider only these. Moreover, each coherency matrix has *n* eigenvalues, where *n* is the number of outlets in that group. I take only sufficient of the eigenvalues to explain 90 percent of the variation in each of the coherency matrices.
- Finally, I take a weighted average for each of the eigenvalues (weights being the proportion of the 90 percent of variance each comprises) to give me a single score for each group at each frequency band.

The results of this rather complex procedure are shown in Figure 5.8. There is a wide dispersion of scores, with the branding grouping exhibiting much more diversity than the sub-markets grouping. There are also not many differences between the various groupings for longer-term cycles but, over the shorter cycles of roughly a week, there is much greater variation. Importantly, the branding groupings appear to be above the sub-market groupings in most cases at these frequencies, suggesting, albeit weakly, that sub-markets describe these cycles better than brands.

Figure 5.8: Brillinger Analysis Results



Source: Author calculation based on FuelWatch price data

As a straight average across all frequency bands, the four randomised groups scored 0.684, whilst the sub-market groupings scored 0.636 and the branding groupings scored 0.687. If this is weighted by the power of the relative frequency band in explaining total variance for the average outlet across the whole sample, then the averages are 0.717, 0.685 and 0.724 respectively. There are differing numbers of outlets in each of the groupings, and if the (unweighted) average frequency scores for each grouping are themselves weighted by the number of elements in that grouping, then the weighted average scores for sub-markets and branding groups are 0.628 and 0.690 respectively. The greater distance between the two scores is due to the fact that Liberty, which has very cohesive pricing amongst its stations, has only a small number of outlets, whilst Caltex, with much less cohesive pricing, has more outlets.

It is difficult to assess the statistical significance of the differences between each of the average values above, or between each of the coherency curves shown in Figure 5.8, unless one makes some rather heroic assumptions concerning the distribution of each after being subjected to the various procedures outlined above. However, it does not seem completely unreasonable to suggest that, based upon the procedure above, the sub-market grouping of outlets does perform better, albeit marginally so, in explaining the degree to which prices are cohesive within a group than does the branding grouping which, in general, does no better than a random collection of stations. That is not to say, however, that all brands are equal; BP and (more particularly) Liberty, have pricing which is as good as or better than the best of the sub-market groupings. Nor is it to say that each sub-market is equal; the Western Suburbs and (to a lesser extent) the Freeway North sub-markets do not have particularly cohesive pricing compared to the other sub-markets.

Summary of Network Data

Having constructed the network, divided it into sub-markets and investigated the reasonableness of this division, I then calculate the Bonacich (1972, 1987) centrality and Burt (1992) efficiency and constraint of each outlet relative to the network as a whole and within each sub-market using the *Ucinet* software developed by Borgatti, Everett & Freeman (2002).[68] The data thus generated are summarised briefly below.

The distribution of scores for each of the network characteristics is presented in Table 5.9. Note that I have normalised the centrality scores such that they range from zero to one, like the constraint and efficiency scores. This then means that the normalised eigenvector centrality and eigenvector centrality scores are the same.

Table 5.9: Summary of Network Characteristics

Frequency Bands	***Global Burt Efficiency***	***Global Burt Constraint***	***Global NEvec Centrality***	***Local Burt Efficiency***	***Local Burt Constraint***	***Local NEvec Centrality***
0.1	0	206	168	0	204	64
0.2	7	0	12	15	0	18
0.3	15	0	2	22	0	16
0.4	52	0	6	54	0	18
0.5	55	0	1	58	0	20
0.6	44	0	3	36	0	18
0.7	23	0	7	13	0	24
0.8	7	0	5	3	0	21
0.9	0	0	1	0	0	4
1	5	2	3	7	4	5

The Global and Local Burt Efficiency scores follow, very roughly, a normal distribution, with most retail petroleum outlets, suggesting that most outlets have roughly the average amount of redundant contacts in the network. A smaller number of outlets either have mostly redundant contacts, suggesting they sit on the periphery of the network, or have

[68] I also calculate the redundancy of the connections of each outlet to each of the five most central in each sub-market.

very few redundant contacts, suggesting they sit at the most strategic points in between sub-networks. These outlets can be identified more clearly in Figure 5.7 above.

The centrality results appear to be following, very roughly, a power curve relationship. That is, a few outlets are very central, whilst most are not. This is a common result in studies of networks (see for example Barabassi, 2002). Moreover, the result appears to be, very roughly, scale-free. The sub-networks also seem to evince a power-curve relationship, albeit one with a fatter tail, reflective of the smaller numbers of outlets in each sub-market.

The results for constraint are difficult to interpret in Table 5.9 above, except to say that there are a very small number of highly constrained outlets with no freedom to move, whilst most outlets enjoy considerable freedom in this regard. The problem is the rather coarse grain of the frequency bins in Table 5.9 above. Table 5.10, below, examines the frequency scores for these two measures, taking out the outlets scoring one in each case, with more fine grained frequency bins.

Table 5.10: Burt Constraint Scores – Zero to 0.1

Frequency Bands	***Global Burt Constraint***	***Local Burt Constraint***		***Frequency Bands***	***Global Burt Constraint***	***Local Burt Constraint***
0.005	35	49		0.055	0	0
0.01	62	47		0.06	0	0
0.015	47	36		0.065	0	0
0.02	30	28		0.07	0	0
0.025	8	16		0.075	0	0
0.03	6	7		0.08	1	1
0.035	5	6		0.085	0	0
0.04	2	4		0.09	0	0
0.045	6	6		0.095	0	0
0.05	4	4		0.1	0	0

The results now are more akin to power curves. That is, most outlets are not constrained much, with smaller numbers of them facing increasing amounts of constraint. Interestingly, four outlets are unconstrained (constraint equals zero) at the global level, and a further two at the local level. These, and the most constrained outlets, all sit at the Eastern extremity of the Perth market. It is not clear why these peripheral outlets represent both the most and least constrained, as it is not a general relationship, but it appears to be related to the distance from all stations in this sub-market to the centre of the overall market in the CBD.

Delving further into the network structure scores and examining, for example, whether the majors are more likely to have central outlets, reveals little of value. There are no statistically significant differences in any of the above network scores between Major and non-Major outlets. There are also few differences when comparisons are done between brands, or between outlet types (branded independent, franchisee etc), and where such differences do arise, there does not appear to be any kind of consistent pattern, except that the single Wesco outlet in the sample is consistently different from other outlets.

I now turn to the redundancy information and, more specifically, to some detail on whether there is a consistent link between redundancy and centrality. This is summarised in the EGOR values in Table 5.1, which summarise the Burt Redundancy of the five most central retail petroleum outlets in each sub-market vis-à-vis each retail petroleum outlet. Note that, in each case, the scores have been normalised, with the highest redundancy scores receiving a value of one. This allows one to compare across the five EGOR values, which have differing maximum scores.

Table 5.11: Burt Redundancy of Five Most Central Outlets

Frequency Band	*EGOR1*	*EGOR2*	*EGOR3*	*EGOR4*	*EGOR5*
0	120	125	132	134	141
0.1	0	0	0	0	0
0.2	0	0	2	0	0
0.3	1	1	0	0	1
0.4	0	6	2	2	0
0.5	8	3	6	6	7
0.6	5	9	10	9	9
0.7	8	12	6	14	12
0.8	14	12	14	11	12
0.9	27	22	16	14	17
1	25	18	20	18	9

In the vast majority of cases, the redundancy is zero; the outlet in question does not share any redundant contacts with the most central outlets in each sub-group. However, where there is redundancy, the distribution is skewed towards a high proportion of redundancy. This is perhaps a corollary of the distribution of centrality scores. Some outlets have very high scores, but most have quite low scores. Where the low scoring outlets are more than a few steps away from the centre of the give sub-network, they have few common links with the centre. However, where an outlet is slightly closer to the centre, it has many common contacts and, indeed, almost all of its contacts are also shared with the centre.

Pricing Characteristics: Price and Spectra

In this section I explore prices, marginal costs and margins (prices minus marginal costs, or tgps). The most salient characteristic of prices and margins is that they cycle. Thus, I take some time examining these cycles, using spectral analysis to draw out useful information. This is then used in Chapter Six, when I explore what drives cycles of a particular length.

Marginal costs are the simplest of the three data series, and I examine them first. They are proxied by the tgp for each wholesaler.[69] Although this might not be precisely the price each retailer pays for fuel and might not represent precisely the costs that are marginal to a retailer, it is the best publically-available data associated with marginal costs for retail petroleum outlets, and is thus used widely in the literature. TGPs do not cycle, but rather follow Singapore benchmarks with a certain lag (see ACCC, 2007, for a detailed analysis of this relationship). Moreover, they are surprisingly uniform in Perth; almost every brand, on almost every day has exactly the same tgp. This is shown in Table 5.12.

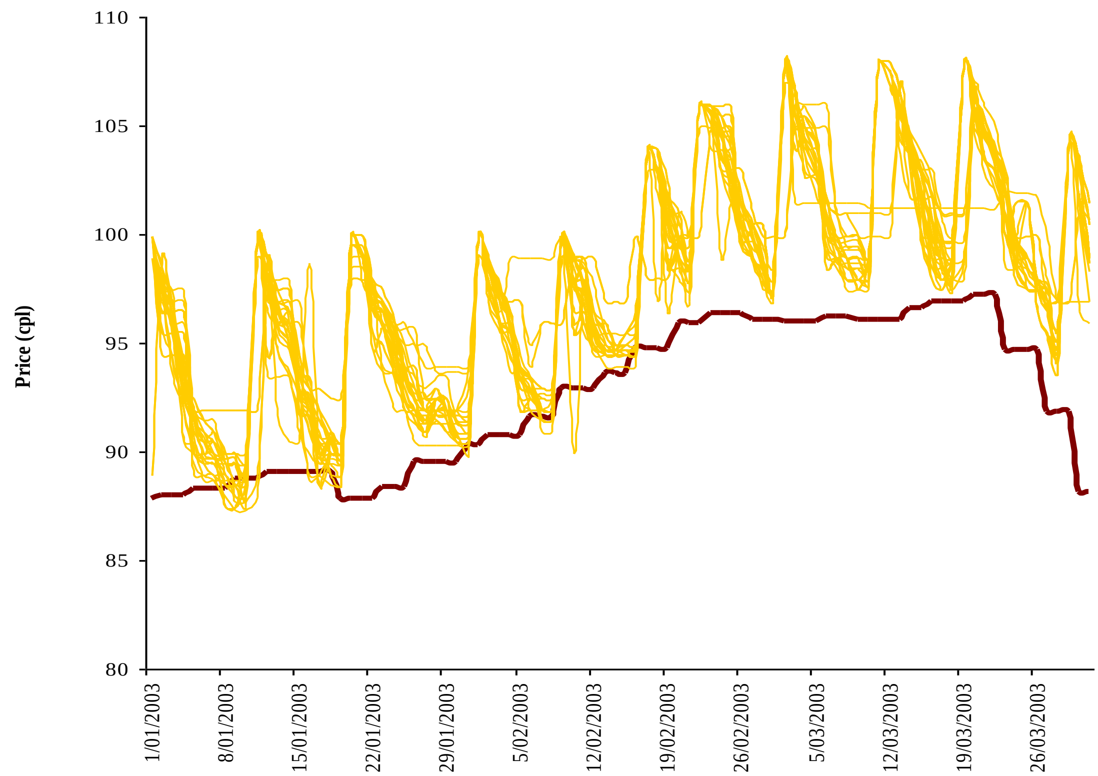
Table 5.12: Terminal Gate Price Correlation Coefficients

	BP	***Caltex***	***Gull***	***Mobil***	***Shell***
BP	1.0000	0.9986	0.9963	0.9958	0.9994
Caltex		1.0000	0.9966	0.9961	0.9989
Gull			1.0000	0.992976564	0.9961
Mobil				1.0000	0.9956
Shell					1.0000

Prices, and by extension, margins, are more variable and more interesting. Figure 5.9 provides an overview of prices charged at all Shell outlets for a three-month period within the timeframe being analysed. The yellow lines represent the price path of each retail petroleum outlet and the thicker brown line the Shell tgp. The patterns of both are typical of other brands, and of other subsets of the time period being analysed.

[69] Under the *FuelWatch* regulations, wholesalers are required to use the same components when calculating their TGP (the spot price of petrol in Singapore, freight, insurance and loss, excise, GST, quality premiums and other costs such as terminal operating margin and temperature compensation), but they are not required to ascribe the same value to each. In practice, they often do, but this is not because the regulatory system requires it thus.

Figure 5.9: Shell 2003, an Example of Perth's Price Cycles



There are three points to note about these prices. Firstly, they cycle. Secondly, the cycles have the characteristic, saw-toothed shape of an Edgeworth Cycle. The ACCC (2007) suggests that cycles in Perth last for roughly a week, and one obtains a similar result following Noel's (2007a) approach of calculating cycle length based upon switching probabilities.

To examine price cycles in more detail, I use spectral analysis. I follow the approach outlined in Granger & Hatanaka (1964) and construct a spectrogram for prices and margins,[70] dividing the spectra into 42 different frequency bands.[71] Spectral analysis

[70] In most cases, particularly in the physical sciences where spectral analysis is widely used, this approach has been superseded by the use of fast Fourier transformation or, more recently, by maximum entropy approaches (see Press, Teukolsky, Vetterling and Flannery, 2007 for a textbook treatment). These

becomes complicated with non-stationary data, so prior to constructing the spectrograms, I conduct a Phillips-Perron unit root test on the data in their natural order (from t_0 to t_{441}) and in their reversed order (t_{441} to t_0) to improve robustness. Aside from one outlet for which the null hypothesis is accepted in some versions of the test, all outlets reject the null in all formulations of the test and in both orderings of the data. It seems unlikely that the data are non-stationary, and therefore it is reasonable to use spectral analysis.

The resulting spectrograms are shown in Figures 5.10 (prices) and 5.11 (margins). In each, the red lines indicate Caltex or Ampol-branded stations, green indicates BP, orange indicates Shell, light blue indicates Mobil, and dark blue indicates all of the non-Major branded and independent outlets. The thick black line shows the average power for each frequency band.

---

approaches give more precise results, but require specialist software, whilst the approach of Granger and Hatanaka (1964) can be relatively easily implemented using a spreadsheet. Moreover, experimentation with more sophisticated techniques for some retail petroleum outlets produced spectrograms very similar to those in Figures 5.10 and 5.11.

[71] Chatfield (2006) suggests the use of, $M=2\sqrt{N}$ is common in the literature, where M is the number of frequency bands and N the number of observations. Here, N=441, thus M=42.

Figure 5.10: Spectra for Price Levels

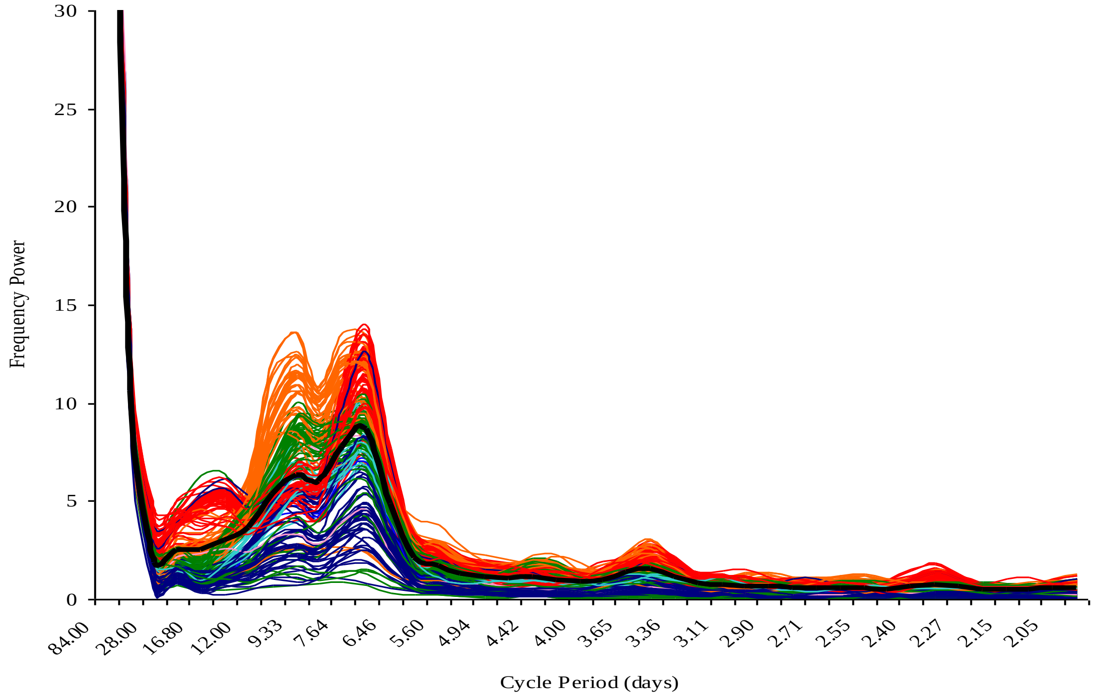
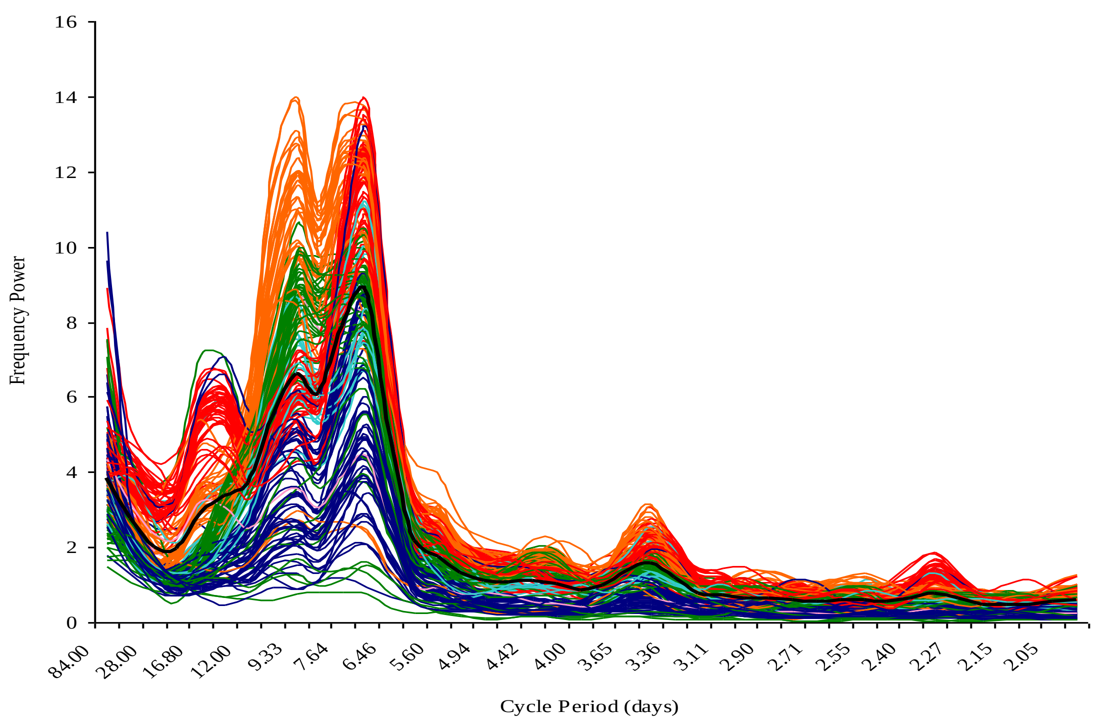


Figure 5.11: Spectra for Price Margins



The most obvious aspect of Figures 5.10 and 5.11 is the dual peak at seven and ten days.[72] This is most pronounced for BP and Shell. Moreover, it is not the case that some outlets follow cycles of seven days and some follow cycles of ten days; most in fact exhibit peaks at both frequency bands.

The dual peak should not be surprising. Indeed, it is more logical than a single peak. If a retail petroleum outlet consistently followed a seven day cycle, this would become immediately obvious to all of its rivals, each of whom could then underbid it on the eighth day and capture market share. The same is true of groups of outlets following a seven-day cycle. Indeed, if retail petroleum outlets were colluding successfully, it seems unlikely they would collude around a cycle, when colluding at its peaks would be more profitable. A far more logical explanation for the patterns observed is that each outlet uses cycles of different lengths, randomising (mostly) between seven and ten-day cycles so that rivals will not know when it will raise its price.[73]

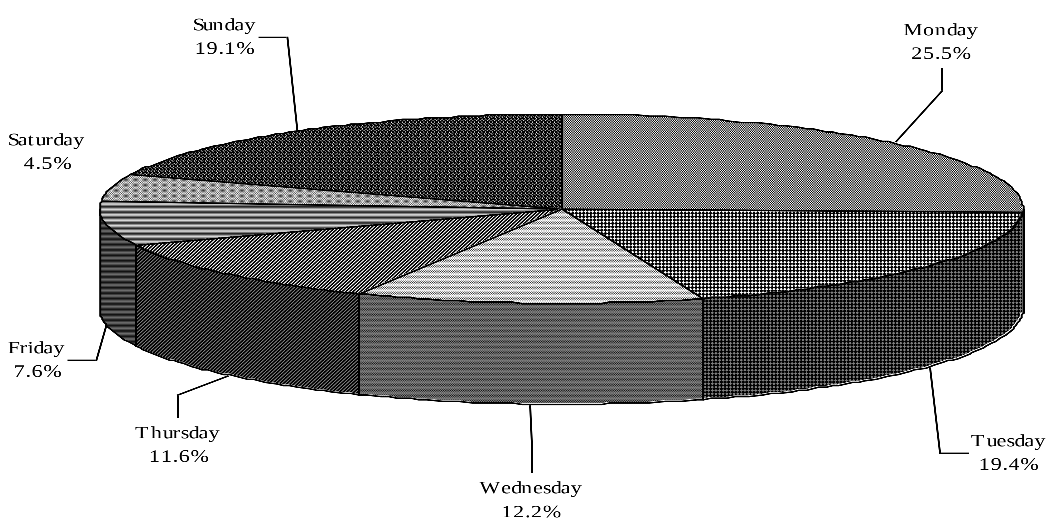
The simultaneous game developed in Chapter Four also suggests that cycle lengths will not be constant, due to the mixed strategies played at prices equal to and one cent above marginal costs. Wang's (2009) also suggest that cycle lengths will differ from cycle to

[72] Peaks at 21, 14 and 3.5 days are echoes of the seven-day cycle, a common occurrence in spectrograms. The longest period encapsulates all cycles longer than 84 days, and is thus picking up longer-term cycles such as changes in crude prices and seasonal variation.
[73] Obviously, if an outlet randomised only between seven and ten-day cycles, then, if it did not raise its price on the seventh day, it would be clear to rivals that it would do so on the tenth. Thus, cycles of other lengths enter the mix as well (shown by their power in the spectrograms), but seven and ten-day cycles dominate. Note that it is not the case that firms utilised seven day cycles for several months, before switching to longer cycles, but rather that cycles of different lengths are mixed together. Wang's (2009) results point to a similar conclusion.

cycle because the owners of brands play a mixed strategy equilibrium in terms of which relents in which round; there is no consistent price leader in terms of relenting.

The use of cycles of different lengths is also evident when one examines the distribution of days upon which prices are raised, shown in Figure 5.12. If the cycle was exactly one week, one day would dominate. If it was exactly ten days, then over time all days would be represented equally. Figure 5.12 shows neither pattern, suggesting that the choice of the day upon which to raise price is more complex. The use of cycles of differing lengths might be expected to contribute to just such a pattern.

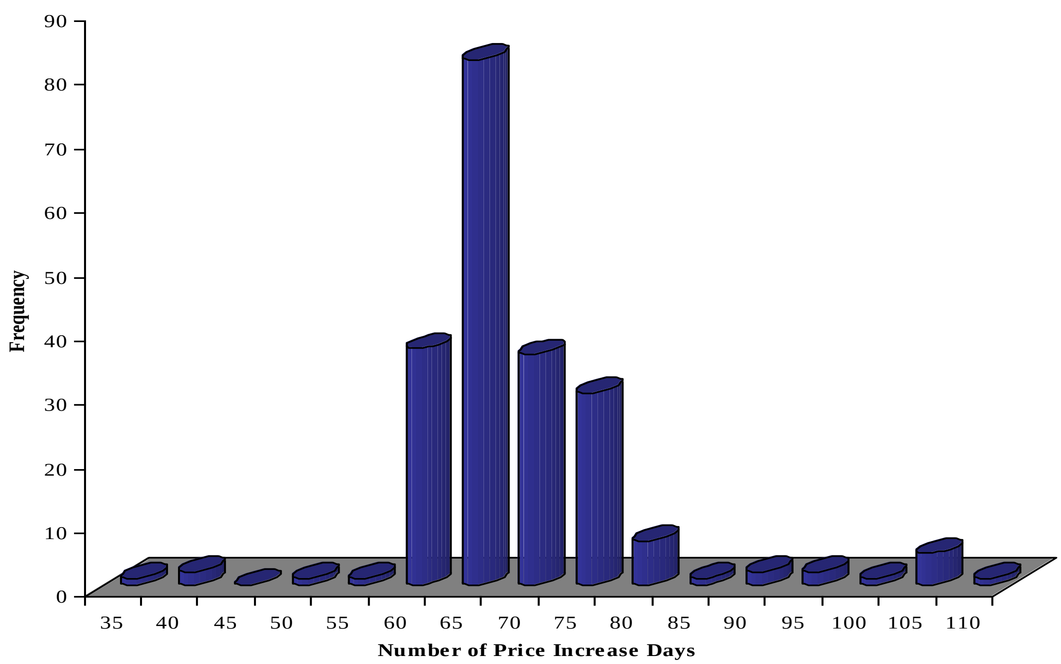
Figure 5.12: Distribution of Price Hikes



Source: FuelWatch data, author calculations

I now examine the shape of the cycles, to ascertain the extent to which this matches the predictions of Edgeworth theory; that is, the extent to which they are saw-toothed.[74] There are two ways in which one might do this. The first is to compare the number of days each station increases price with the number of days it decreases price. Absent of some trend in the data, if the cycle has a regular, sinusoidal shape, one would expect these two to be equal. The less equal they are, the more saw-toothed are the cycles. Figure 5.13 shows the number of price increase days (non-increasing days are just 441 minus this figure) for each of the 208 stations, as a histogram. Most retail petroleum outlets have between 60 and 75 price increase days out of the 441 days in the sample period, indicative of a sharply saw-toothed price pattern.

Figure 5.13: Number of Price Increase Days

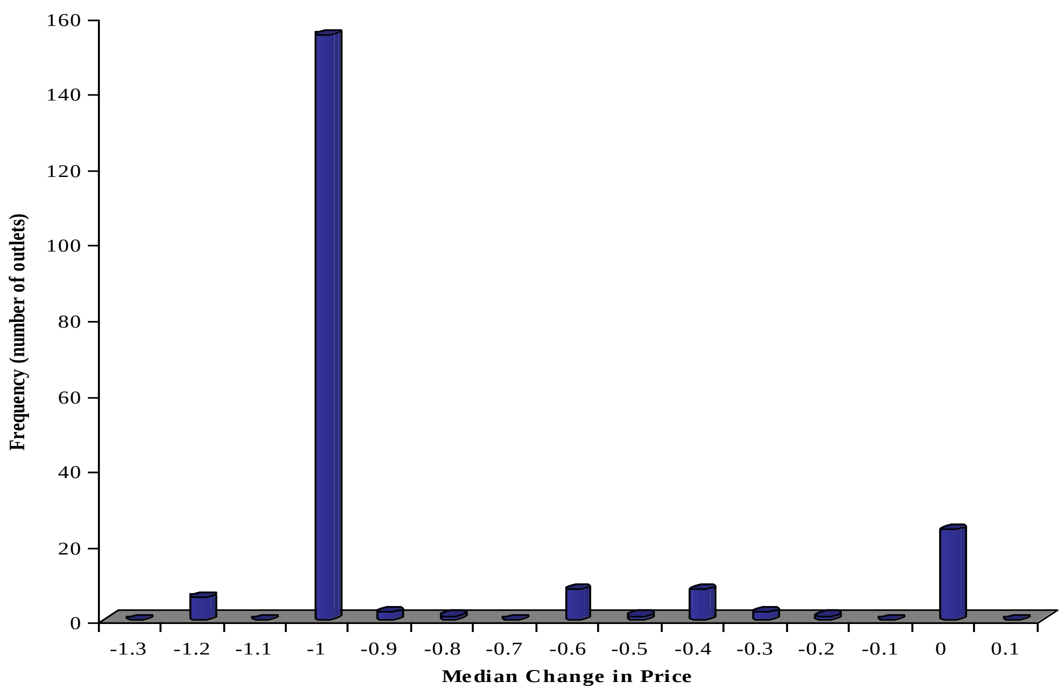


Source: FuelWatch data, author calculations

[74] Alternatively, the inequality could be caused by an underlying trend in prices. However, no such trend emerges in this data over the whole period.

Another way in which one might explore the same phenomenon, (Lewis, 2008) is to look at the median change in price. Where there are many small price decreases and a few large price increases, this will be less than zero, and the distance below zero is roughly comparable with the degree to which the cycle is saw-toothed. In Chapter Six, I use this statistic to summarise the Edgeworth nature of price cycles exploring, as Lewis (2008) does, the factors which contribute towards it. Figure 5.14 shows the distribution of median changes in price amongst the 208 retail petroleum outlets in the sample. Most stations have a value close to minus one; indicative of the saw-toothed Edgeworth cycle pattern.

Figure 5.14: Median Change in Price



Source: FuelWatch data, author calculations

Chapter Six: Regression Analysis of Prices in a Network

This chapter explores the extent to which network structure influences pricing, using the network structure summary statistics developed in Chapter Five. Note that it does not test the theory of Chapter Four directly. Instead, the link is indirect; the theoretical model in Chapter Four provides predictions about price minima if two firms are competing, which I then use to define a rule of bilateral connection, which then forms a network and the place of each firm in this network structure is summarised using measures from sociology that then form the inputs into the regression models presented in this chapter. The links between Chapter Four and this chapter are thus indirect.

I examine the influence of network structure on pricing in two ways. Firstly, I examine the influence of network structure on daily pricing decisions, undertaking two panel regressions, with daily prices and margins (price minus tgp) on the left-hand side and a number of different outlet and market variables, drawn largely from the literature (see Chapter Three), on the right-hand side along with several network structure variables.

Secondly, I examine the influence of network structure on the way in which each outlet prices, describing the shape of its price path. To do this, I undertake two separate regressions. The first is an extension of Lewis (2008), adding network structure to a list of explanatory variables similar to his paper and regressing these against the median change in price. The second regression aims to capture the differing cycle length findings of Chapter Five, by regressing the same set of variables against the spectral power of seven and ten-day cycles, to see whether there are any significant differences in the proportion of these cycles in the strategy choice of a given retail petroleum outlet.

As noted in Chapter Five, my sample is 208 retail petroleum outlets in Perth, and all prices charged by these outlets in the period from January 1st 2003 to March 14th 2004. The former marks the beginning of good daily data on tgps, and the latter marks the last day prior to the conversion of 40 Shell outlets into Coles Express outlets, as part of the joint venture between these two players.

Panel Analyses: Price and Margins

In this section, I examine two panel models of the form:

$$\begin{aligned} RPRICE_{it} &= \alpha + \tau_{it} MC + \omega_{it} RPRICE_{i,t-1} + \xi_{it} RPRICE_{i,t-7} + \beta_i BR_i + \\ &\chi_i TP_i + \delta_i SV_i + \phi_i CS_i + \varphi_{ij} DCHAR_{ij} + \gamma_{ik} NCHAR_{ik} + \\ &\eta_i SUBM_i + \lambda_{im} EGOR_{im} + \pi_i DWD_i + \kappa_i MD_i + \theta_{in} OCO_{in,t-1} + \rho_{io} OCS_{io,t-1} \end{aligned} \quad (6.1)$$

and

$$\begin{aligned} M_{it} &= \alpha + \omega_{it} M_{i,t-1} + \xi_{it} M_{i,t-7} + \beta_i BR_i + \\ &\chi_i TP_i + \delta_i SV_i + \phi_i CS_i + \varphi_{ij} DCHAR_{ij} + \gamma_{ik} NCHAR_{ik} + \\ &\eta_i SUBM_i + \lambda_{im} EGOR_{im} + \pi_i DWD_i + \kappa_i MD_i + \theta_{in} OCO_{in,t-1} + \rho_{io} OCS_{io,t-1} \end{aligned} \quad (6.2)$$

Each of the variables is defined in Table 5.1, with the exception of M, which is the gross retail margin; the daily retail price minus the daily tgp from the same-branded wholesaler.[75] Note that the variables in Equations 6.1 and 6.2 represent families of

[75] All independents are assumed to use Gull as a wholesaler. The assumption is not an important one, given the high degree of similarity between tgps amongst the different brands on each day.

variables from Table YY. Thus $DEMAND_{ij}$ refers to the j^{th} amongst 19 demand-characteristic variables, applied to the i^{th} retail petroleum outlet.

In regressing explanatory factors against prices and margins, one must be cognizant of the fact that the driving forces during the downwards phase of the cycle might differ from the upward phase. Atkinson, Eckert & West (2009), Atkinson (2009) and Eckert (2002) address this issue by treating the upward and downward phases in separate regressions, whilst Eckert & West (2004b) do so by allowing the coefficients to vary over the four phases of the cycle they identify in their work. Noel's (2007a,b, 2008, 2009) approach is more sophisticated; he uses a Markov-Switching regression. This is necessary for Noel because he has only a sample of prices and cannot thus observe turning points. Here, I have a census of prices, and thus I can use a simpler approach; Hansen's (1996, 1999, 2000) Threshold Regression Model.

Threshold regression assumes that the model behaves differently when a certain critical value is above or below its threshold level. This is not particularly new, but the novelty of the approach lies in allowing the data itself to determine where the particular threshold should lie, rather than imposing the threshold exogenously. Here, it is useful because, although it is clear that the upward phase of the price cycle is characterised by large price increases, it is not clear that price decreases will be the sole component of the downward price cycle which may also include price matching or even small price increases due to cost shocks or mistakes. Noel (2007b) alludes to a similar concern. Thus, I use the data to determine where the threshold should be.

A threshold regression model can be expressed thus:

$$\begin{aligned} y_t &= \theta_1' x_t + e_{1t} \quad if \quad q_t \le \gamma \\ y_t &= \theta_2' x_t + e_{2t} \quad if \quad q_t > \gamma \end{aligned} \tag{6.3}$$

where here θ_i refers to the entire right hand side of Equations 6.1 and 6.2 above. The threshold variable q can be any variable the modeller chooses, including the change in the left-hand side variable, which I use here. One can reduce the two equations shown in Equation 6.3 into a single equation by allowing $I_t(\gamma)$ to be an indicator variable which takes a value of one when the second argument above is true and zero otherwise, and by setting $\theta_3 = \theta_2 - \theta_1$, to obtain:

$$y_t = \theta_1' x_t + \theta_3' x_t I_t(\gamma) + e_t \quad with \quad e_t \approx iid\left(0, \sigma_i^2\right) \tag{6.4}$$

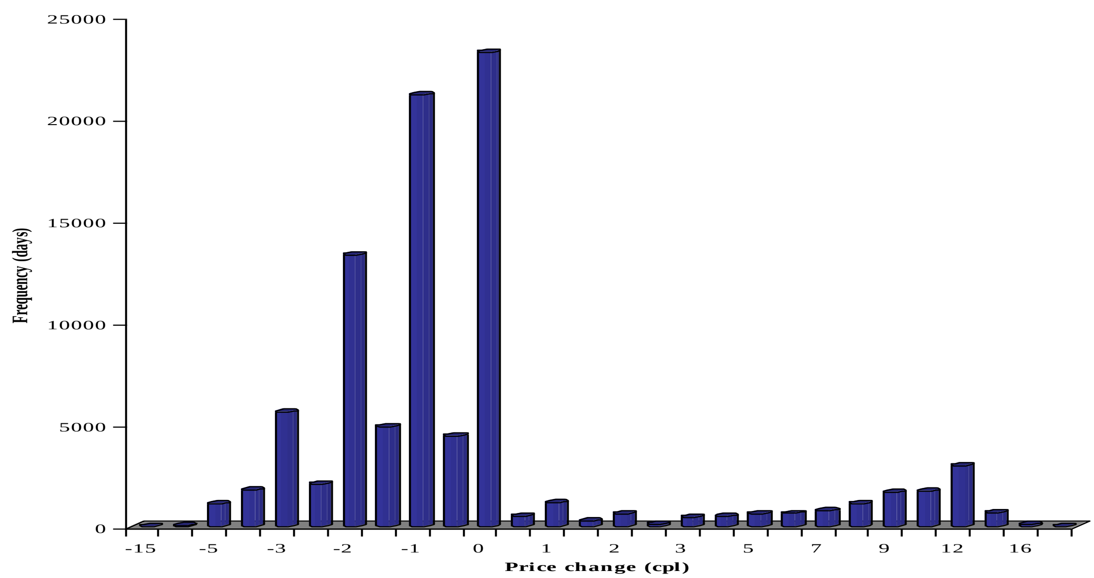
In order to find the correct threshold, Hansen (1999) suggests performing a grid-search over a number of potential thresholds and choosing the threshold that gives the regression containing it the smallest sum of squared errors. The resultant estimates of all of the coefficients will be unbiased and consistent. However, one cannot make that claim about the coefficient of the threshold itself without first understanding more about its distribution, which an OLS regression of the above form will not reveal. In the discussion below, I outline Hansen's (1999) procedure for testing the threshold variable.

Prior to explaining the estimation results of the regression models, I describe briefly the process by which I use Hansen's (1999) method of finding the appropriate threshold, and the testing of that threshold.

Finding the Threshold

In this section, I describe the procedure by which I divide the price series into upward and downward phases of the price cycle using Hansen's (1999) approach, with the daily change in retail petroleum prices as the relevant threshold variable. Figure 6.1 shows the frequency of different daily price changes. Most are negative, and indeed most are relatively small and negative. Small positive price changes are rare, with most of the positive price changes being greater than 5 cpl.

Figure 6.1: Daily Price Changes



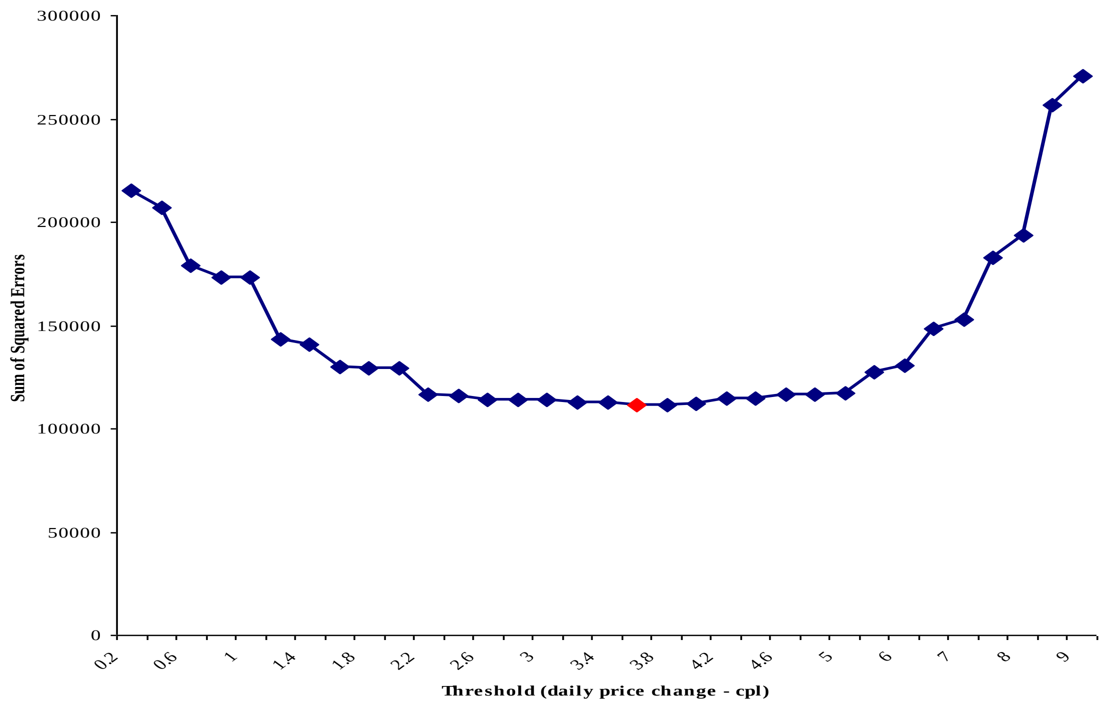
Since I am differentiating between a rising and a falling phase of a price cycle, it makes sense to set the lower bound of the grid search at zero.[76] I set the upper bound at ten cpl,

[76] There are 56 zero or negative price changes sandwiched between two or more positive price changes in the dataset of roughly 98,000 prices. I manually assign these to the upward phase after finding the threshold via Hansen's approach, which does not adversely affect results.

and divide the interval into an uneven grid, with windows of 0.2 cpl from zero to five cpl and 0.5 cpl.[77] This gives 33 different thresholds to test.

A representative set of results for the 33 thresholds is provided in Figure 6.2. It is for the regression model with retail price on the left-hand side, but the margins model has almost exactly the same shape, and the same minimum point.[78]

Figure 6.2: Threshold Test Results – Representative Regression Model



Prior to undertaking a formal test of the validity of this threshold, it is worthwhile examining reasonableness. In general, the Majors tend to increase price aggressively,

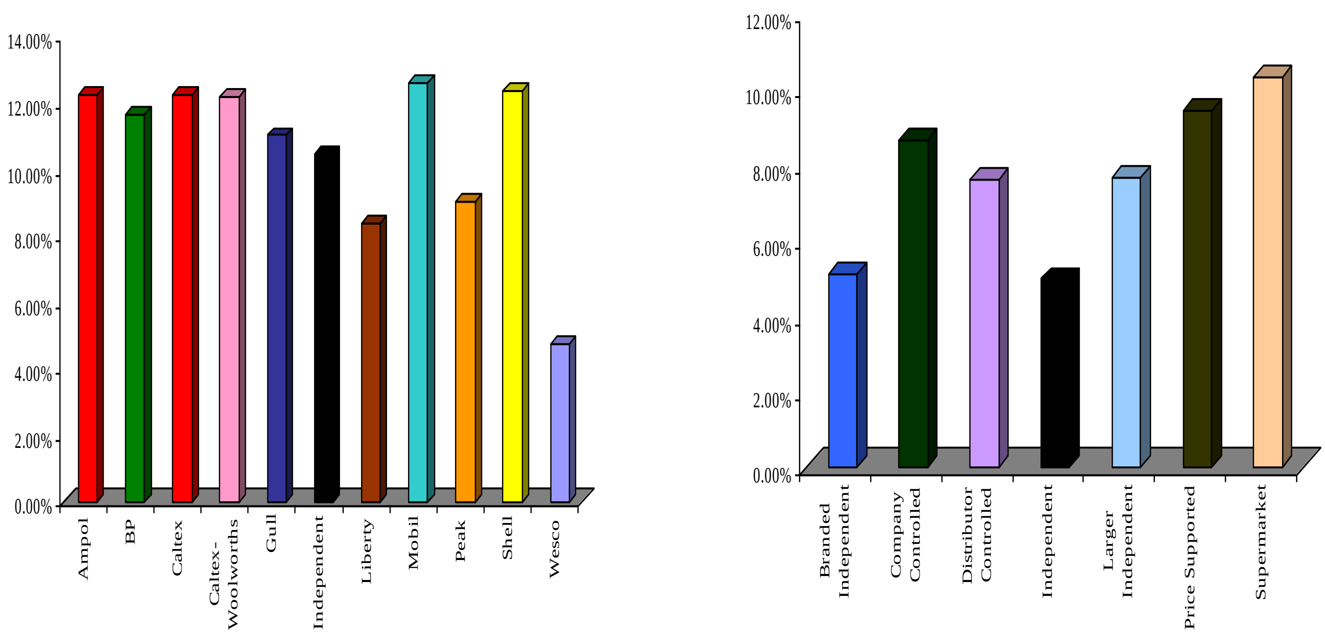
[77] Legally, prices can change by an increment of 0.1 cpl.

[78] For both the price and margins regressions, I explore the consequences of omitting and adding the various right-hand-side variables in Equations 6.1 and 6.2. In terms of finding the appropriate threshold, omission of variables does not seem to have much effect. Almost all of the combinations of right-hand-side variables in Equations 6.1 and 6.2 have a shape like that of Figure 6.2, and the minimum point of 3.6 cpl is also exhibited by almost all of them.

often by upwards of ten percent. In many instances, the independents are more wary, staggering price increases over two or sometimes three days. There is thus a risk that the threshold is dividing the sample not by change in price, but by type or branding.

Figure 6.3 shows the number of price changes above the threshold as a proportion of total price changes for each different brand, and each different ownership/management type. There are some differences, between the majors and independent brands, but there do not appear to be many systematic differences between types of ownership, so it does not appear that the threshold approach is simply sorting outlets by type.

Figure 6.3: Proportion of price changes above the 3.6cpl by Brand & Type



I now present the results of the formal test of whether the threshold of 3.6 cpl is appropriate or not. To test whether the restriction should be imposed (that is, H_0: $\theta_1 = \theta_2$), Hansen (1999) suggests the following test statistic:

$$F_1 = \frac{S_0 - S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{6.5}$$

Where S refers to the sum of squared errors, with the zero subscript indicating the null ($\theta_1 = \theta_2$) and the one subscript indicating the sum of squared errors under the relevant threshold. Since the null hypothesis does not contain the threshold, the test statistic has a non-standard distribution and thus has no critical values. However, Hanson (1999) outlines a bootstrapping procedure which allows one to ascertain the *p*-values associated with this test statistic, and thus whether to accept or reject the null. Following Hansen's (1999) procedure leads to a value for F_1 of 543801.4 for prices and 447339.1 for margins, with *p*-values of 0.0000 for both. This suggests that a threshold exists.

Next, I ascertain whether the threshold of 3.6 cpl determined above is correct or not (that is $H_0 : \gamma = \hat{\gamma}$). This, Hansen (1999) suggests is best achieved by examining the confidence interval around the threshold using the likelihood ratio test statistic:

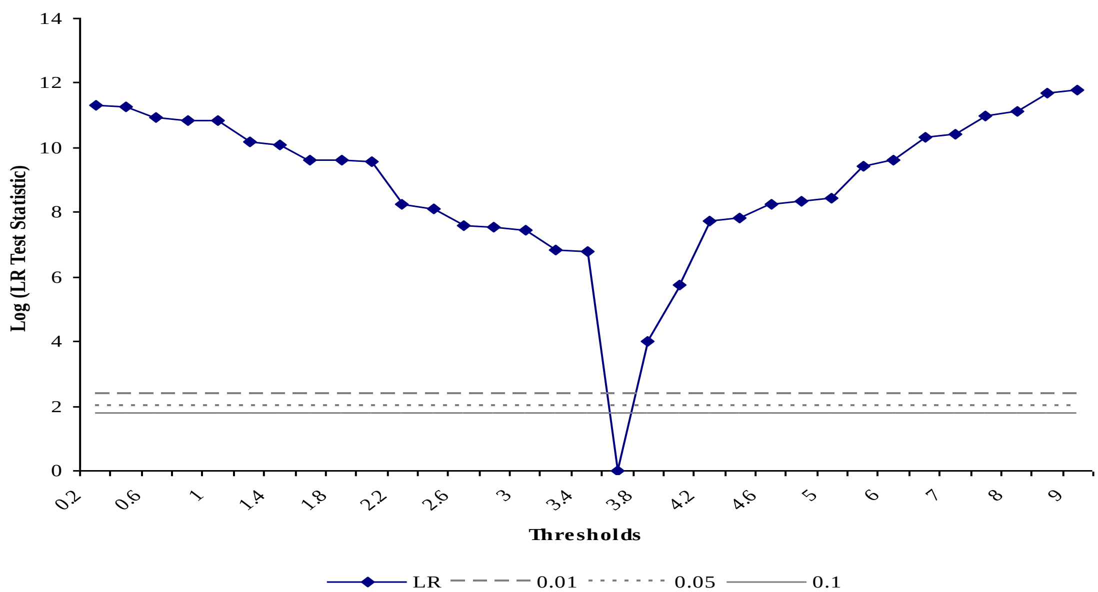
$$LR_1 = \frac{S_1(\gamma) - S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{6.6}$$

S and σ^2 are defined as previously, γ refers to each of the thresholds possible and $\hat{\gamma}$ refers to the threshold chosen of 3.6 cpl. This is compared to critical values defined by:

$$c(\alpha) = -2\log\left(1 - \sqrt{(1-\alpha)}\right) \tag{6.7}$$

Where α is the confidence level. Figure 6.4 expresses this graphically. LR refers to the likelihood ratio test statistic result and the grey lines represent the confidence interval critical values for various values of α. Purely for presentational purposes, both the LR test statistics and the confidence intervals have been expressed in logs, except where $\gamma = \hat{\gamma}$, which remains at zero. As is clear, the confidence interval around the threshold estimate is very tight, suggesting the threshold estimated is the correct one.

Figure 6.4: Confidence Interval around Threshold Estimate



Model Estimation Results

I now turn to the empirical estimation of Equations 6.1 and 6.2 in the threshold regression form of Equation 6.4. In so doing, I explore a number of different forms for each equation. This gives rise to eight basic models, shown in Table 6.1 where the shading indicates which variables are included in which model.[79] Table 6.1 also provides an indication of the information criteria scores for each model, a rough indication of fit. Note that, for the margins model, MC is not included, and it contains the first and seventh lags of the margin, not the retail price.

Table 6.1: Information Criteria Results for Different Models

RPRICE	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
NCHAR	■	■	■	■	■	■	■	■
SUBM	■	■	■	■	■	■	■	■
MC	■	■	■	■	■	■	■	■
RPRICE {1 7}/ M{1 7}*	■	■	■	■	■	■	■	■
BR		■	■	■	■	■	■	■
TP		■	■	■	■	■	■	■
CS		■	■	■	■	■	■	■
DCHAR			■	■	■	■	■	■
DWD				■	■	■	■	■
MD				■	■	■	■	■
OCO{1}*					■	■		■
OCS{1}*					■		■	■
EGOR								■
Retail Price Information Criteria Results								
AIC	*3.39055*	*3.27186*	*3.20489*	*3.12184*	*3.05466*	*3.06379*	*3.06459*	*3.05338*
SBC	*3.39367*	*3.27916*	*3.21615*	*3.13674*	*3.07291*	*3.08016*	*3.08096*	*3.07225*
Hannan-Quinn	*3.3915*	*3.27408*	*3.20833*	*3.12638*	*3.06022*	*3.06878*	*3.06958*	*3.05914*
Margins Information Criteria Results								
AIC	*3.55688*	*3.44541*	*3.37106*	*3.28869*	*3.23614*	*3.24251*	*3.24328*	*3.23422*
SBC	*3.56021*	*3.45292*	*3.38253*	*3.3038*	*3.25417*	*3.25908*	*3.25986*	*3.2533*
Hannan-Quinn	*3.5579*	*3.4477*	*3.37456*	*3.29329*	*3.24163*	*3.24756*	*3.24834*	*3.24004*

**The first and seventh lags of the retail price and margins and the first lags of OCO and OCS*

To test model appropriateness, I undertake a series of likelihood ratio tests, shown in Table 6.2. Model Eight, the most general model, is also the most appropriate.

[79] All models shown in Table 6.1 have Shell as the omitted brand dummy, Shell Select as the omitted convenience store dummy, company-controlled as the omitted type dummy, Melville as the omitted submarket dummy, Thursday as the omitted day-of-the-week dummy and April as the omitted monthly dummy. In general, selection of dummies to omit does not overly influence results.

Table 6.2: Likelihood Ratio Test Results – Prices and Margins Regressions

Likelihood Ratio Test Results - Prices Regression								
	Model 8	*Model 5*	*Model 7*	*Model 6*	*Model 4*	*Model 3*	*Model 2*	*Model 1*
Model 8								
Model 5	230.8439							
Model 6	1069.395	838.5506						
Model 7	1014.551	783.7067						
Model 4	6320.321	6089.477						
Model 3	13850.56	13619.72			7530.243			
Model 2	19868.21	19637.37			13547.89	6017.647		
Model 1	30673.28	30442.43			24352.96	16822.71	10805.07	
Likelihood Ratio Test Results - Margins Regression								
	Model 8	*Model 5*	*Model 7*	*Model 6*	*Model 4*	*Model 3*	*Model 2*	*Model 1*
Model 8								
Model 5	192.4708							
Model 6	865.7056	673.2348						
Model 7	795.5076	603.0368						
Model 4	4992.3467	4799.8759						
Model 3	12498.595	12306.125			7506.2488			
Model 2	19286.218	19093.748			14293.872	6787.6229		
Model 1	29428.579	29236.108			24436.233	16929.984	10142.361	

Hansen's (1996, 1999, 2000) threshold regression can be estimated in two forms (see Equations 6.3 and 6.4 above). I choose the second, single equation form (Equation 6.4), which is common in the literature.[80] It means that each equation contains θ_3 rather than θ_2. The coefficients and variances for θ_2 are recovered manually. The results for the prices and margins Model Eight regressions are presented in Tables 6.3 and 6.4 overleaf.

[80] See, for example, Foster (2006), Savvides & Stengos (2000), Tsionas & Christopoulos (2003), Huang & Yang (2006), Boetel, Hoffmann & Liu (2007), Papageorgiou (2002), Girma (2005), Chen & Lee (2005) and the empirical examples in Hansen's (1996, 1999, 2000) three papers.

Table 6.3: Regression Model Eight – Price as Dependent Variable

Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat
Constant	-1.5896	-8.6924	TP1	0.6905	30.5696	DWD1	0.2159	14.6318	TCNST	-1.5896	-8.6924	TTP1	-1.3282	-10.6592	TDWD1	0.50285	7.56612
NCHAR1	-0.0869	-1.5632	TP3	0.1866	4.6754	DWD2	0.2115	15.1043	TNCHAR1	-0.3316	-1.2431	TTP3	-0.0069	-0.0357	TDWD2	0.12260	1.79225
NCHAR2	-0.8164	-11.5144	TP4	0.0000	0.0000	DWD3	0.0728	5.6051	TNCHAR2	0.5094	1.4256	TTP4	0.0000	0.0000	TDWD3	0.05595	0.83083
NCHAR4	-0.0019	-1.8069	TP5	0.1876	4.5444	DWD5	-0.2291	-16.8392	TNCHAR4	-0.0008	-0.1529	TTP5	-1.0453	-5.1015	TDWD5	-1.08490	-11.76190
NCHAR5	0.2498	4.8519	TP6	-0.1111	-6.6494	DWD6	-0.1081	-8.4268	TNCHAR5	0.3497	1.4250	TTP6	-0.0951	-1.2003	TDWD6	-0.60024	-4.37781
NCHAR6	0.6470	9.4409	TP7	0.0000	0.0000	DWD7	0.3497	27.5065	TNCHAR6	1.0753	3.1595	TTP7	0.0000	0.0000	TDWD7	1.44851	21.79995
NCHAR8	-0.0033	-4.7218	CS1	0.0131	0.7378	MD1	0.3153	15.4528	TNCHAR8	0.0088	2.5420	TCS1	0.0849	0.8934	TMD1	-1.53188	-16.91409
SUBM1	0.0225	1.0228	CS2	-0.0329	-1.7293	MD2	0.1762	8.4743	TSUBM1	0.2965	2.6703	TCS2	-0.1042	-1.1648	TMD2	-1.34988	-12.27875
SUBM2	-0.0579	-2.5406	CS3	-0.1246	-6.7247	MD3	0.1847	8.0598	TSUBM2	-0.2523	-2.1778	TCS3	0.0594	0.6977	TMD3	-1.49619	-13.38230
SUBM3	-0.0198	-0.4368	CS4	-0.0664	-1.7718	MD5	0.0006	0.0256	TSUBM3	-1.1561	-5.1706	TCS4	0.1793	0.8505	TMD5	-0.72168	-6.52607
SUBM4	0.0479	2.5567	DCHAR1	-0.0003	-6.3876	MD6	-0.0654	-2.6789	TSUBM4	-0.0077	-0.0823	TDCHAR1	0.0008	3.2025	TMD6	-0.53068	-4.42738
SUBM5	0.0823	3.6480	DCHAR2	-0.5543	-7.9318	MD7	0.1782	7.9007	TSUBM5	0.1922	1.6042	TDCHAR2	0.2730	0.7830	TMD7	-0.15699	-1.47928
SUBM6	-0.0135	-0.5540	DCHAR3	-0.0007	-9.8812	MD8	0.1431	6.3027	TSUBM6	-0.0407	-0.3240	TDCHAR3	0.0005	1.4106	TMD8	-1.38848	-10.51760
SUBM7	-0.2772	-5.8900	DCHAR4	0.0002	10.4960	MD9	0.0587	2.7256	TSUBM7	-0.0381	-0.1729	TDCHAR4	0.0000	-0.4947	TMD9	-0.92455	-8.02988
EGOR1	0.1837	9.8298	DCHAR5	-0.0001	-13.7428	MD10	0.4212	19.2140	TEGOR1	0.0801	0.8733	TDCHAR5	0.0001	2.9023	TMD10	-0.36558	-3.26920
EGOR2	0.2137	11.4990	DCHAR6	-0.0002	-4.7878	MD11	0.1215	5.7419	TEGOR2	0.0294	0.3303	TDCHAR6	-0.0006	-2.3239	TMD11	-0.79761	-7.36826
EGOR3	-0.0678	-3.9575	DCHAR7	-0.0001	-3.3662	MD12	0.0819	3.8469	TEGOR3	0.1032	1.2051	TDCHAR7	-0.0011	-4.6351	TMD12	-1.22443	-11.56668
EGOR4	0.0224	1.2282	DCHAR8	0.0005	9.8781	OCO1{1}	0.1927	4.9564	TEGOR4	0.0559	0.6079	TDCHAR8	-0.0006	-2.5593	TOCO1{1}	0.04683	0.70782
EGOR5	0.1228	6.3345	DCHAR9	0.7829	5.4204	OCO2{1}	0.1011	4.8485	TEGOR5	0.1116	1.1611	TDCHAR9	4.8555	6.8145	TOCO2{1}	-0.05780	-0.32147
MC	0.1334	59.2855	DCHAR10	0.0000	-0.6723	OCO3{1}	-0.0154	-1.5580	TMC	0.5881	21.5121	TDCHAR10	-0.0007	-4.1591	TOCO3{1}	0.26736	6.63683
RPRICE{1}	0.8352	532.5761	DCHAR11	0.0003	9.7727	OCO4{1}	0.0598	4.6188	TLRP1	0.3184	10.7253	TDCHAR11	0.0004	2.1507	TOCO4{1}	-0.31623	-4.15985
RPRICE{7}	0.0470	48.2224	DCHAR12	0.0002	4.5647	OCO5{1}	-0.3555	-20.7774	TLRP7	0.1097	19.7641	TDCHAR12	0.0009	4.9198	TOCO5{1}	0.22151	4.30429
BR1	-0.0263	-1.0911	DCHAR13	-0.0005	-12.2808	OCO6{1}	0.0331	2.7531	TBR1	-0.0340	-0.3002	TDCHAR13	0.0003	1.5718	TOCO6{1}	-0.96992	-6.78831
BR2	-0.0231	-1.4855	DCHAR14	0.0000	-1.3373	OCO8{1}	-0.9869	-7.5862	TBR2	-0.8532	-10.7388	TDCHAR14	-0.0005	-6.4897	TOCO8{1}	1.42211	9.68568
BR3	-0.0389	-1.8131	DCHAR15	-0.0002	-11.0519	OCS1{1}	0.0109	0.4700	TBR3	-0.1009	-1.0127	TDCHAR15	0.0005	5.6386	TOCS1{1}	-0.02258	-0.43030
BR4	0.2568	7.8449	DCHAR16	0.0005	9.6149	OCS2{1}	0.1069	6.2534	TBR4	-2.2397	-14.2300	TDCHAR16	0.0000	0.1657	TOCS2{1}	0.01660	0.17286
BR5	-0.1201	-2.8185	DCHAR17	-0.0792	-6.0090	OCS3{1}	-0.0162	-1.7042	TBR5	-1.4772	-7.0084	TDCHAR17	0.0804	1.1438	TOCS3{1}	0.37541	9.96171
BR6	0.7234	18.2268	DCHAR18	-0.0241	-9.6336	OCS4{1}	0.1218	8.7587	TBR6	-2.8131	-15.8592	TDCHAR18	0.0868	6.7438	TOCS4{1}	0.04608	0.64946
BR7	0.0272	0.7347	DCHAR19	0.0344	6.0271	OCS5{1}	-0.1835	-10.7607	TBR7	-0.8025	-4.0479	TDCHAR19	0.0414	1.4190	TOCS5{1}	0.03113	0.71320
BR8	0.0010	0.0282				OCS6{1}	0.1579	13.9256	TBR8	-1.7508	-8.7614				TOCS6{1}	0.02427	0.19261
BR9	0.0566	1.3940				OCS8{1}	0.1543	1.3644	TBR9	-2.4414	-12.2409				TOCS8{1}	0.46609	3.56045
BR11	0.8611	12.0047							TBR11	-2.3256	-6.7568						
						Centred R^2					0.9625						
						R-Bar^2					0.9625						
						Log Likelihood					-137584.8						
						Breusch-Pagan Test Statistic					11791.06						
						Durbin-Watson Test Statistic					1.9077						

Table 6.4: Regression Model Eight – Margins as Dependent Variable

Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat	Variable	Coeff	t-stat
Constant	0.0085	0.0640	TP1	0.6776	27.7914	DWD1	0.2434	15.0828	TCNST	0.0085	0.0640	TTP1	-1.3210	-10.2836	TDWD1	0.4196	6.0642
NCHAR1	-0.0886	-1.4143	TP3	0.1802	4.3311	DWD2	0.2361	15.1974	TNCHAR1	-0.3300	-1.1707	TTP3	0.0229	0.1146	TDWD2	-0.0074	-0.1044
NCHAR2	-0.8130	-10.1459	TP4	0.0000	0.0000	DWD3	0.0686	4.8006	TNCHAR2	0.4887	1.2851	TTP4	0.0000	0.0000	TDWD3	-0.0549	-0.7642
NCHAR4	-0.0020	-1.6927	TP5	0.1749	3.7748	DWD5	-0.1764	-10.8672	TNCHAR4	-0.0011	-0.2016	TTP5	-1.0593	-4.9011	TDWD5	-1.0357	-10.2295
NCHAR5	0.2477	4.3418	TP6	-0.1089	-5.7688	DWD6	-0.1047	-7.6752	TNCHAR5	0.3615	1.3911	TTP6	-0.1063	-1.2741	TDWD6	-0.7397	-5.2657
NCHAR6	0.6392	8.3278	TP7	0.0000	0.0000	DWD7	0.3648	26.5025	TNCHAR6	1.1422	3.2170	TTP7	0.0000	0.0000	TDWD7	1.2258	17.9602
NCHAR8	-0.0033	-4.2468	CS1	0.0108	0.5688	MD1	0.0603	2.8279	TNCHAR8	0.0088	2.4374	TCS1	0.0802	0.8280	TMD1	-1.7992	-19.7590
SUBM1	0.0232	0.9357	CS2	-0.0335	-1.5555	MD2	-0.0471	-2.2232	TSUBM1	0.3193	2.7826	TCS2	-0.0901	-0.9647	TMD2	-1.5746	-14.5109
SUBM2	-0.0535	-2.1113	CS3	-0.1223	-5.9328	MD3	0.1552	6.8974	TSUBM2	-0.2406	-2.0390	TCS3	0.0493	0.5504	TMD3	-1.5461	-14.6038
SUBM3	-0.0200	-0.3950	CS4	-0.0713	-1.5606	MD5	-0.2085	-8.9425	TSUBM3	-1.1902	-5.0694	TCS4	0.1871	0.8000	TMD5	-1.0874	-9.7647
SUBM4	0.0480	2.2601	DCHAR1	-0.0003	-5.6953	MD6	-0.4026	-16.3066	TSUBM4	0.0209	0.2127	TDCHAR1	0.0008	3.1436	TMD6	-0.8628	-7.0917
SUBM5	0.0921	3.6754	DCHAR2	-0.5509	-7.0899	MD7	-0.2248	-9.4797	TSUBM5	0.2272	1.8326	TDCHAR2	0.2732	0.7499	TMD7	-0.2947	-2.7998
SUBM6	-0.0133	-0.4916	DCHAR3	-0.0007	-8.6924	MD8	-0.1375	-5.5979	TSUBM6	-0.0293	-0.2234	TDCHAR3	0.0004	1.0863	TMD8	-1.3932	-10.4461
SUBM7	-0.2584	-4.9157	DCHAR4	0.0002	9.3957	MD9	0.1222	5.2489	TSUBM7	-0.0228	-0.0994	TDCHAR4	0.0000	-0.3485	TMD9	-1.3965	-11.8416
MARG{1}	0.8294	458.0596	DCHAR5	-0.0001	-12.2437	MD10	0.0674	3.0273	TEGOR1	0.7416	8.3320	TDCHAR5	0.0001	2.5677	TMD10	-0.6104	-5.4525
MARG{7}	0.0513	45.3011	DCHAR6	-0.0002	-4.2406	MD11	-0.1005	-4.5869	TEGOR2	-0.1121	-1.3029	TDCHAR6	-0.0006	-2.3180	TMD11	-1.0292	-9.4245
EGOR1	0.1851	8.9245	DCHAR7	-0.0001	-2.8064	MD12	-0.2810	-12.5758	TEGOR3	0.3538	4.1579	TDCHAR7	-0.0011	-4.7050	TMD12	-1.0087	-9.3923
EGOR2	0.2105	10.1262	DCHAR8	0.0005	8.8546	OCO1{1}	0.1935	4.7632	TEGOR4	0.2571	2.7941	TDCHAR8	-0.0007	-2.5091	TOCO1{1}	-0.0061	-0.0868
EGOR3	-0.0645	-3.3890	DCHAR9	0.7465	4.6424	OCO2{1}	0.1075	4.8548	TEGOR5	-0.0466	-0.4907	TDCHAR9	5.0922	7.1571	TOCO2{1}	-0.0057	-0.0272
EGOR4	0.0231	1.1518	DCHAR10	0.0000	-0.3074	OCO3{1}	-0.0165	-1.4678	TMARG1	-0.5162	-14.9566	TDCHAR10	-0.0007	-4.4776	TOCO3{1}	0.2336	5.1185
EGOR5	0.1200	5.5390	DCHAR11	0.0003	8.5527	OCO4{1}	0.0545	3.7464	TMARG7	0.1342	6.0346	TDCHAR11	0.0004	2.4677	TOCO4{1}	-0.3058	-3.7531
BR1	-0.0110	-0.4035	DCHAR12	0.0002	3.9449	OCO5{1}	-0.3187	-17.6819	TBR1	-0.0933	-0.7810	TDCHAR12	0.0009	5.0690	TOCO5{1}	0.1763	3.2014
BR2	-0.0031	-0.1879	DCHAR13	-0.0005	-10.9815	OCO6{1}	0.0731	5.3681	TBR2	-0.8998	-10.9645	TDCHAR13	0.0003	1.4431	TOCO6{1}	-1.1665	-7.9332
BR3	-0.0197	-0.8178	DCHAR14	0.0000	-1.0389	OCO8{1}	-1.1159	-8.4266	TBR3	-0.1937	-1.8449	TDCHAR14	-0.0005	-6.8259	TOCO8{1}	1.4245	9.3798
BR4	0.2637	7.2450	DCHAR15	-0.0002	-10.0685	OCS1{1}	-0.0219	-0.8965	TBR4	-2.3626	-14.1985	TDCHAR15	0.0005	5.5963	TOCS1{1}	0.0666	1.1557
BR5	-0.0979	-2.0515	DCHAR16	0.0005	8.6293	OCS2{1}	0.1043	5.6354	TBR5	-1.5863	-7.1149	TDCHAR16	0.0001	0.2626	TOCS2{1}	-0.1375	-1.2255
BR6	0.7418	16.0577	DCHAR17	-0.0811	-5.3019	OCS3{1}	-0.0197	-1.8249	TBR6	-2.8996	-15.3320	TDCHAR17	0.0815	1.0994	TOCS3{1}	0.3640	8.5715
BR7	0.0439	1.0668	DCHAR18	-0.0244	-8.7835	OCS4{1}	0.0933	6.0239	TBR7	-0.8666	-4.1571	TDCHAR18	0.0889	6.7680	TOCS4{1}	0.0578	0.7402
BR8	0.0334	0.7697	DCHAR19	0.0342	5.3728	OCS5{1}	-0.2018	-11.1367	TBR8	-1.9152	-8.6154	TDCHAR19	0.0454	1.4984	TOCS5{1}	0.0684	1.4499
BR9	0.0864	1.9004				OCS6{1}	0.1256	9.8648	TBR9	-2.5921	-12.2370				TOCS6{1}	0.2571	1.9075
BR11	0.8774	10.8120				OCS8{1}	0.3024	2.5192	TBR11	-2.4017	-6.5422				TOCS8{1}	0.3566	2.5394
						Centred R^2					0.89668						
						R-Bar^2					0.896479						
						Log Likelihood					-145796.9						
						Breusch-Pagan Test Statistic					10242.99						
						Durbin-Watson Test Statistic					1.936846						

Both models provide a good fit to the data, with high R-squared values. Neither exhibits evidence of serial correlation, as the Durbin-Watson tests statistics show. However, the Breusch-Pagan tests statistics indicate heteroscedasticity, which I address by using robust standard errors.[81] Since each regression is large (although many variables are dummies), there is potential scope for multicollinearity or misspecification in the regression models. I address this by testing many different formulations of the models, with different independent variables excluded (see Table 6.1 and the sensitivity analysis discussion below). The results, particularly those pertaining to network characteristics, are generally robust to these changes.

The set of variables measuring network structure provide reasonably consistent results across the two models, with centrality at both the global and local levels being negative (albeit only at the ten percent level for global centrality) during the downward phase of the price cycle and local centrality being positive during the upswing. Efficiency and constraint are positive at the local level, and constraint is negative at the global level, during the downswing, whilst neither is significant (except for constraint in the margins regression) during the upswing. This contrast between negative constraint at the global level and positive constraint at the local level, as well as positive efficiency and constraint at the local level is taken up in detail in the discussion of results below. The statistically significant EGOR results have generally positive coefficients during the downswing and the upswing. The lack of significance of the network structure variables

[81] All of the results in Tables 6.3 and 6.4 are for the robust standard errors versions of each regression model, excepting of course the Breusch-Pagan test statistic results.

during the upswing is not surprising if brand headquarters drive prices upwards, as Wang (2006) suggests.

The omitted submarket dummy is SUBM8, the Melville market. The positive coefficients on SUBM4 and SUBM5 (the Northeast and Freeway North markets respectively) submarkets indicate that they price higher than the omitted submarket, whilst the negative coefficients on SUMB2 and SUBM7 (Curtin and the Western Suburbs, respectively) indicate contra pricing patters. The results are interesting, because they suggest that submarkets which are geographically close to one another do not price in a similar fashion.

Marginal costs, lagged prices and lagged margins are all roughly in line with expectations. All suggest that higher levels of marginal cost today, or prices or margins at the relevant lags imply higher levels today for prices or margins, with the exception of one-day lagged margins during the upswing. Note also that the coefficients on one-day lagged prices and margins are roughly 0.8 during the downswing, which highlights the small declines during that phase, and that both have much stronger effects than either marginal cost or seven-day lags. The same is true, vis-à-vis one-week lags during the upswing, but not marginal costs, which become much more important during the upswing, suggesting that the impetus to hike price increases as one nears marginal cost. Noel (2007a,b) has similar findings.

The results on the various station characteristics are reflective of the omitted dummy variables. In the sensitivity analysis section (see below) I explore the consequences of omitting different dummies. The omitted branding dummy is Shell, and the results during the downswing indicate that Caltex-Woolworths (BR4), independents (BR6) Peak (BR9) and Wesco (BR11) have higher prices than Shell, whilst Gull (BR5) has lower prices and the other majors have pricing unrelated to Shell's. During the upswing, the situation is quite different, with all brands having negative coefficients. This indicates that, when Shell initiates a price increase, it tends to do so alone. Wang (2007) has similar findings, indicating that most price increases are lead by a single brand.

For station type, branded independents (TP1), distributor-controlled (TP3) and the larger independents (TP5) tend have higher prices than company-controlled outlets (the omitted variable), whilst price supported outlets (TP6) tend to price lower than the company-controlled outlets. All of these carry the Caltex brand, which appears to indicate that Caltex uses these outlets to lead prices downwards. The negative coefficients on branded independents and larger independents during the upward phase of the price cycle indicate that these types of outlets are never price leaders. Finally, there are no significant coefficients in the convenience store outlets, suggesting none price in a consistently different manner to the omitted dummy (Shell Select).

The demand characteristics provide some results which are consistent, and some which are inconsistent with expected priors. Most of the actual coefficients are very small, even though they are mostly significant, and thus it is unlikely that any demand effects are particularly important. The exception is the number of vehicles per household, which has a small positive coefficient during the downward phase of the cycle, but a very large coefficient during the upward phase. This may be because markets with many cars represent the most profitable markets. The results for the number of people, families and houses have a similar direction, suggesting that markets with more customers in them face higher prices. Other socio-economic indications, such as the number of families with dependent children or headed by a single mother, have the expected negative sign, but the number of rented dwellings, state housing commission houses, the unemployment rate and the availability of public transport all have signs opposite to those expected. This is perhaps indicative of poorer areas being less well-served by retail petroleum outlets, and thus facing less competitive pressure.

Being on a main road, being near a competitor or having many competitors near the retail petroleum outlet all lead to lower prices during the downward phase of the price cycle, which reflects their pro-competition effects. However, the number of competitors within five kilometres has a positive, significant coefficient during the upward phase, indicating that outlets packed more densely together raise price together, potentially a network-density effect.

The day of the week dummies indicate that prices tend to be higher earlier in the week. There is less evidence of seasonal factors, although the evidence from the downward phase of the price cycle tends to suggest that prices are lower in winter than in summer.

Finally, examining the occurrences families, most of these results match expectations. In each case, the variable is the single-period lag of the dummy in question, and thus seeks to explore whether the status of the given station yesterday, known when today's prices are determined, influences the price choice. In the most part, behaviour is mean-reverting, at least in the downward phase; those at the minimum price last period increase their price, as do those with below average prices or in the lower quartile, whilst those in the upper quartile, or with above-average prices, or which were price leaders, tend to decrease their price. This holds for occurrences in the market overall (OCO) and those in the relevant submarket (OCS). The evidence is less clear in the upward phase.

Interpretation and Discussion

In this section, I explore in more detail the possible reasons for the findings outlined above. I focus most particularly on the network characteristic variables, which are the main focus of this analysis, and which provide some of the more counter-intuitive results.

Global constraint (NCHAR2) is negative during the downswing, suggesting that the most constrained outlets in the sample have the lowest prices during the downward phase of the cycle, and perhaps more importantly that the least constrained have the highest prices. The least constrained outlets are generally those which sit between submarkets. They then have higher prices during a downswing, which suggests that these strategic outlets are perhaps acting to restrict the 'spill-over effects' of lower prices in one local market spreading to the next. This is potentially confirmed by the fact that the submarkets neighbouring each other have opposite coefficients, which may indicate that the border outlets act to reduce information flow between submarkets.

Centrality does seem to bring with it better pricing power for the central outlets. Both global (NCHAR4) and local (NCHAR8) centrality have negative coefficients, indicating these central outlets have lower prices during the downswing, and are hence leading prices downwards. However, the most central at the local level also have the highest prices during an upswing, suggesting perhaps that they lead prices upwards. This might be suggestive of the Majors, where they able to control the more central outlets in each submarket, using these more central outlets to initiate price increases in the knowledge that the information will spread rapidly through each sub-market. However, the size of the coefficient is very small; indicating that the effect is not substantial. If the Majors can co-ordinate price increases through simply dictating them to all outlets bearing their brand (as Wang, 2006, suggests), then this is perhaps not surprising.

The results for local efficiency (NCHAR5) and constraint (NCHAR6) present a conundrum. A positive coefficient on efficiency fits with the remainder of the network structure results, as it suggests that those outlets for which the surrounding structure is favourable are able to leverage that structure into market power. In the downswing, where this coefficient is significant, such outlets might price-match, rather than undercutting; exercising market power in the same way that Eckert (2003) suggests for large firms. The firms with the highest efficiency scores are not the most central,[82] suggesting that the centre of each local market is not a locus of market power. Nor are the most efficient outlets owned by the Majors, or overwhelmingly company-controlled. This may be an artefact of historical ownership patterns.

[82] Nor are they the most or least constrained; correlation between all three is rather weak.

A positive coefficient on local constraint fits less well with the remainder of the evidence on structural variables from the regression analyses. One reason may be that the most constrained outlets tend to sit on the periphery of each local market. This means that they are poorly positioned in terms of information flows originating within the given submarket, but it also means that they effectively have only one part of their own localised market (that shared between pairs of outlets, in the manner of Figure 4.1) in the particular sub-market. The other part often represents customers on the edge of the global marketplace, over whom these peripheral outlets can exercise market power. Peripheral outlets may be unconcerned at losing daily battles for market share because they have access to other customers over whom they do not need to fight.

For such outlets, information generated within each local market may not be particularly important and, from this perspective, the positive coefficient is less surprising. Indeed, in the locational choice game, which occurs prior to the pricing choice game analysed in this thesis, peripheral locations may be desirable precisely because they do not require as much information gathering from and competition in each sub-market.

Thus, one potentially has two different forces at work to drive prices higher. For firms with high efficiency scores, their favourable position within each submarket allows them to exploit price information generated within that sub-market to their advantage and derive market power from doing so. Highly constrained firms, by contrast, tend to sit on the periphery of each sub-market and price high because they are able to serve customers located outside that sub-market (or even outside the overall market) over whom they can exercise market power. Such outlets are less interested in pricing information generated from within the sub-market, because it is of less use to them.

The EGOR results provide some confirmation for the efficiency results above. The outlets with the highest efficiency scores, sitting one or two steps away from the centre of each local network, are likely to have a large number of contacts in common with the centre, and hence high redundancy scores. These are the outlets which price higher than the centre, ameliorating the price decreases which originate there.

Sensitivity Analysis

Apart from the eight different models outlined in Table 6.1, I also undertake extensive sensitivity analysis, exploring the consequences of omitting different dummies, and omitting subsets of the families of variables in Table 5.1, where this is possible (that is, not for the station characteristics, daily or monthly dummies).

The results of these changes in the regression models show differences that are not particularly substantial. Removing individual demand characteristic or occurrence variables has almost no effect on the results at all. Omitting different station characteristic dummies has effects on the remainder of the relevant set of station characteristics (removing the BP branding dummy instead of Shell, for example), but generally few effects on other variables. Perhaps the most important effect is that, in some models Global Efficiency (NCHAR1) goes from being negative and insignificant to negative and significant during the downward phase.

Cross Sectional Analyses: Median Changes in Price and Spectral Power

The two cross-section analyses are designed to explore what influences the degree to which each outlet has price cycles with an Edgeworth character, by using the median change in price proxy as in Lewis (2008), and the extent to which each outlet chooses a seven or ten-day cycle.[83] The latter involves two regressions, one with the spectral power of seven-day cycles and one with the spectral power of ten day cycles on the left-hand side of the regression. The regression models examined are thus:

$$MPC_i = \beta_i BR_i + \chi_i TP_i + \delta_i SV_i + \phi_i CS_i + \varphi_{ij} DCHAR_{ij} + \gamma_{ik} NCHAR_{ik} + \eta_i SUBM_i + \lambda_{im} EGOR_{im} \tag{6.8}$$

$$SPM1_i = \beta_i BR_i + \chi_i TP_i + \delta_i SV_i + \phi_i CS_i + \varphi_{ij} DCHAR_{ij} + \gamma_{ik} NCHAR_{ik} + \eta_i SUBM_i + \lambda_{im} EGOR_{im} \tag{6.9}$$

and

$$SPM3_i = \beta_i BR_i + \chi_i TP_i + \delta_i SV_i + \phi_i CS_i + \varphi_{ij} DCHAR_{ij} + \gamma_{ik} NCHAR_{ik} + \eta_i SUBM_i + \lambda_{im} EGOR_{im} \tag{6.10}$$

where MPC_i refers to the median change in price, and $SPM1_i$ and $SPM3_i$ refer to the spectral power of the seven and ten day cycles; that is the amount of price variation explained by these two cycles, respectively. The other variables are as defined in

[83] The discussion in Chapter Five highlights how most retail petroleum outlets mix between seven and ten day cycles in their pricing.

Equations 6.1 and 6.2, and all of the variables are explained in more detail in Table 5.1 and the associated discussion in Chapter Five.

Median Change in Price

The approach taken here is based upon that in Lewis (2008), who points out that if a particular outlet (city in his case) has many small price decreases and a few large price increases, then one would expect the median change in price to be less than zero. The greater the difference of the median from zero, the more saw-toothed the pattern of pricing, or the more Edgeworth its nature.

As with the panel regressions, I test a number of different regression model specifications. These are shown in Table 6.5, where again the shaded cells indicate inclusion of the relevant variable.

Table 6.5: Median Price Change Regression Models

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
NCHAR	■	■	■	■	■	■
SUBM	■	■	■	■	■	■
BR		■	■	■	■	■
CS			■	■	■	■
TP				■	■	■
DCHAR					■	■
EGOR						■
AIC	*0.63853*	*0.31439*	*0.29674*	*-0.34386*	*-0.26584*	*-0.27298*
SBC	*0.86317*	*0.69949*	*0.74602*	*0.2017*	*0.58459*	*0.65768*
Hannan-Quinn	*0.72936*	*0.4701*	*0.47841*	*-0.12326*	*0.07803*	*0.10333*

The likelihood ratio test results are presented in Table 6.6 below. The bold entries indicate that the relevant restriction is found to hold statistically.

Table 6.6: Median Price Change Regression Models – Likelihood Ratio Test Results

	Model 6	Model 5	Model 4	Model 3	Model 2	Model 1
Model 6						
Model 5	**11.48482**					
Model 4	**33.2571**	**21.77228**				
Model 3	178.50094	167.01612	145.24384			
Model 2	190.17234	178.68752	156.91524	**11.6714**		
Model 1	277.59364	266.10882	244.33654	99.0927	87.4213	

As indicated in Table 6.6, Model Four is the preferred choice, and its results are summarised in Table 6.7.

Table 6.7: Median Price Change – Regression Model Four Results

Variable	*Coefficient*	*T-Statistic*	*Variable*	*Coefficient*	*T-Statistic*
Constant	-1.04732	-8.25631	BR1	0.05899	0.70147
NCHAR1	-0.11031	-0.58854	BR2	0.03700	0.72697
NCHAR2	-0.33715	-1.51988	BR3	0.05093	0.67496
NCHAR4	0.00426	1.86880	BR4	0.27993	2.74504
NCHAR5	0.26703	1.59974	BR5	-0.03128	-0.24265
NCHAR6	0.33809	1.53300	BR6	0.82450	5.79575
NCHAR8	-0.00083	-0.54209	BR7	-0.01143	-0.10191
SUBM1	0.05362	1.04624	BR8	0.00815	0.05836
SUBM2	-0.09129	-1.41096	BR9	0.27001	2.14117
SUBM3	-0.01592	-0.19248	BR11	0.70771	3.05880
SUBM4	-0.06958	-1.27080	CS1	-0.00554	-0.08641
SUBM5	-0.10595	-2.02266	CS2	-0.04707	-0.67879
SUBM6	-0.11317	-1.83955	CS3	-0.00305	-0.04675
SUBM7	-0.12746	-1.18920	CS4	0.02073	0.14003
			TP1	0.81040	11.73039
			TP3	-0.04194	-0.29146
			TP4	0.00000	0.00000
			TP5	0.29887	2.31416
			TP6	-0.02020	-0.32377
			TP7	0.00000	0.00000
Centred R^2				0.7490	
R-Bar^2				0.7047	
Regression F Statistic				16.9386	
Log Likelihood				69.7611	
Breusch Pagan Test Statistic				55.0298	

In this instance, the F-test and R-squared results suggest, respectively, that the model is valid and fits the data reasonably well. The Breusch-Pagan test statistic suggests homoscedasticity and so I do not use robust standard errors as elsewhere.

The network characteristics appear to have much less influence on median price change than was the case for price and margins in the previous analysis. Now, only NCHAR4, global eigenvector centrality, is significant and only then at the ten percent level. This suggests that the more central outlets are the ones with higher median price changes and hence the ones with smaller cycle amplitudes. To the extent that cycles are pro-competitive, this might indicate central outlets are less competitive, a different conclusion from the panel regressions above, albeit one which is less well supported.

The independent brands and Caltex Woolworths, along with the branded independent and larger independent types tend to have higher median price changes, and hence cycles of smaller amplitude, than the omitted dummies (Shell and company controlled outlets). Other brands and ownership/management types are indistinguishable from the omitted dummy. To the extent that these more independent outlets are more competitive, it would appear that, whilst cycles themselves may be pro-competitive, their amplitude is not positively related to competition. There are some grounds for this conclusion, as firms facing greater competition are unlikely to be able to hike prices as high as those facing less competition.

Very few of the variables in Table 6.7 above are statistically significant. It is thus helpful to consider what happens if variables are added. Adding the demand characteristic variables, creating Regression Model Five, makes little difference to overall results, and indeed, most of the demand characteristics have insignificant coefficients. Adding the EGOR variables and creating Regression Model Six changes little outside the network characteristic variables (and indeed, only EGOR2 is statistically significant, and positive), but it does make some important changes to the network characteristic variables. NCHAR4 loses its significance, but NCHAR2 (global constraint) becomes negative and significant at the five percent level, whilst NCHAR5 (local efficiency) and NCHAR6 (local constraint) become positive and significant at the ten percent level improving the results of Table 6.7. These results are consistent with the results of the two panel regressions.

The negative NCHAR2 coefficient suggests that more constrained outlets are likely to have cycles of greater amplitude, which may be suggestive of outlets sitting at the junction points between sub-markets (the least constrained in the dataset) acting to attenuate price signals travelling between sub-markets.

The positive NCHAR5 and NCHAR6 coefficients may be the result of similar forces describing these two variables in the panel regressions. That is, the stations with higher efficiency scores are able to attenuate pricing signals, whilst the highly constrained outlets on the periphery of the network pay less attention to pricing information originating in the relevant submarket.

I also explore a number of different formulations of the models outlined above omitting different branding, type, convenience store presence and submarket. Overall, the results are robust to these model changes.

Seven and Ten Day Spectral Power

In this section, I explore the factors which contribute to the choice of cycle lengths by each retail petroleum outlet by regressing the same sets of independent variables as in Table 6.5 above against the power of the seven and ten day spectra.[84] The spectra are themselves estimates, a product of a trade-off between bias and consistency (see previous). This means they have a non-constant variance and thus I use robust standard errors in my estimations discussed below.

The different regression model constructions I consider are the same set of six as for the median price regressions, and these are summarised in Table 6.5 above. The likelihood ratio test results for all of these models, in both scenarios, are outlined in Table 6.8. Figures in bold indicate acceptance of the restriction at the five percent level, whilst the italicised figures indicate acceptance of the restriction at the ten percent level.

[84] I use the margins spectra from Figure 5.11, as these are larger in magnitude given that the relatively constant tgp has been stripped out of the price series, causing more variation.

Table 6.8: Likelihood Ratio Test Results – Spectral Power Regression Models

Likelihood Ratio Test Results – Seven Day Price Cycle						
	Model 6	*Model 5*	*Model 4*	*Model 3*	*Model 2*	*Model 1*
Model 6						
Model 5	**12.28286**					
Model 4	*43.76144*	**31.47858**				
Model 3	114.5605	102.27764	70.79906			
Model 2	123.40122	111.11836	79.63978	**8.84072**		
Model 1	311.29152	299.00866	267.53008	196.73102	187.8903	
Likelihood Ratio Test Results - Ten Day Price Cycle						
	Model 6	*Model 5*	*Model 4*	*Model 3*	*Model 2*	*Model 1*
Model 6						
Model 5	**9.71808**					
Model 4	56.42188	46.7038				
Model 3	195.66554	185.94746	139.24366			
Model 2	203.7074	193.98932	147.28552	**8.04186**		
Model 1	436.71754	426.99946	380.29566	241.052	233.01014	

In this instance, the ten-day price cycle results strongly favour Regression Model Five, whilst the seven-day results provide some evidence that Regression Model Four is more acceptable. In order to compare like with like across the two cycles, I use Regression Model Five in both instances. The differences between the two in terms of coefficients for the seven day regressions are not particularly great; with the most important difference being that NCHAR2 and NCHAR4 are significant in Regression Model Five, but not in Regression Model Four. Table 6.9 provides an overview of the results of Regression Model Five for both the seven and ten day cases.

Table 6.9: Seven and Ten Day Spectral Power – Regression Model Five Results

Seven - Day Price Cycles						***Ten - Day Price Cycles***					
Variable	*Coeff.*	*t-stat*	*Variable*	*Coeff.*	*t-stat*	*Variable*	*Coeff.*	*t-stat*	*Variable*	*Coeff.*	*t-stat*
Constant	15.6935	3.2248	TP1	-7.4207	-4.7725	Constant	10.1932	2.9666	TP1	-7.90027	-7.46104
NCHAR1	1.3964	0.5901	TP3	-1.1206	-0.7492	NCHAR1	1.2213	0.8730	TP3	-0.39152	-0.42224
NCHAR2	8.2825	2.2181	TP4	0.0000	0.0000	NCHAR2	6.6673	2.5691	TP4	0.00000	0.00000
NCHAR4	-0.0820	-1.8182	TP5	-4.6258	-2.3006	NCHAR4	-0.0538	-1.8031	TP5	-4.70191	-3.35201
NCHAR5	-5.0727	-2.1955	TP6	0.3555	0.4451	NCHAR5	-4.0269	-2.7092	TP6	-0.13542	-0.31789
NCHAR6	-8.6476	-2.7830	TP7	0.0000	0.0000	NCHAR6	-5.4102	-2.5799	TP7	0.00000	0.00000
NCHAR8	-0.0124	-0.4499	DCHAR1	0.0031	1.1274	NCHAR8	-0.0081	-0.4388	DCHAR1	0.00378	2.21696
SUBM1	-0.4146	-0.3849	DCHAR2	4.2475	1.3189	SUBM1	-0.0045	-0.0065	DCHAR2	0.10420	0.04551
SUBM2	1.3942	1.0280	DCHAR3	0.0045	1.0977	SUBM2	2.0552	2.2799	DCHAR3	0.00174	0.70982
SUBM3	-4.4610	-2.1161	DCHAR4	-0.0009	-0.9218	SUBM3	-2.8790	-2.0824	DCHAR4	-0.00056	-0.75507
SUBM4	0.0343	0.0312	DCHAR5	0.0002	0.4606	SUBM4	0.7634	1.2679	DCHAR5	0.00003	0.07540
SUBM5	0.7627	0.7170	DCHAR6	0.0029	1.3251	SUBM5	1.2644	1.7900	DCHAR6	0.00252	1.56020
SUBM6	-0.1087	-0.0832	DCHAR7	0.0004	0.2129	SUBM6	0.4372	0.5178	DCHAR7	-0.00071	-0.49998
SUBM7	4.5183	1.6181	DCHAR8	-0.0023	-0.9720	SUBM7	2.2679	1.5028	DCHAR8	-0.00057	-0.35805
BR1	-1.8069	-1.7737	DCHAR9	-6.4642	-0.9333	BR1	-9.0679	-10.2682	DCHAR9	1.34370	0.26985
BR2	-5.1517	-7.0662	DCHAR10	0.0011	0.8162	BR2	-5.1842	-10.2087	DCHAR10	-0.00140	-1.51763
BR3	-2.4791	-2.5083	DCHAR11	0.0019	1.1635	BR3	-9.1768	-15.7920	DCHAR11	0.00070	0.65442
BR4	-8.4755	-5.1112	DCHAR12	-0.0026	-1.5559	BR4	-8.1238	-6.2792	DCHAR12	0.00018	0.16694
BR5	-5.1594	-2.3128	DCHAR13	0.0004	0.2048	BR5	-7.2429	-4.7907	DCHAR13	0.00071	0.49815
BR6	-12.8443	-12.1843	DCHAR14	-0.0002	-0.2949	BR6	-13.7604	-11.8007	DCHAR14	-0.00084	-2.00682
BR7	-5.4631	-1.8442	DCHAR15	0.0020	2.3063	BR7	-6.9554	-4.7183	DCHAR15	0.00069	1.06348
BR8	-7.3549	-4.4694	DCHAR16	-0.0053	-1.9396	BR8	-7.4531	-12.6108	DCHAR16	0.00005	0.02877
BR9	-8.3313	-4.1622	DCHAR17	0.7583	0.8401	BR9	-8.4403	-5.9852	DCHAR17	0.71491	1.30862
BR11	-13.3722	-6.4875	DCHAR18	0.3620	2.5098	BR11	-12.9712	-8.8309	DCHAR18	0.36107	3.44100
CS1	-0.1282	-0.1784	DCHAR19	0.0205	0.0800	CS1	-0.1893	-0.3865	DCHAR19	0.08961	0.50854
CS2	1.5066	2.0913				CS2	0.3687	0.8726			
CS3	0.6025	0.7780				CS3	0.4473	1.0915			
CS4	-0.7673	-0.4642				CS4	-0.5706	-0.8174			
Centred R^2				0.818533		Centred R^2				0.894139	
R-Bar^2				0.760741		R-Bar^2				0.860426	
Log Likelihood				-491.45311		Log Likelihood				-405.94114	

Both models provide a reasonably good fit to the data in terms of their R-squared figures. Serial correlation is not an issue in this cross-sectional dataset and, whilst heteroscedasticity may be an issue, the characteristics of the dependent variable force the use of robust standard errors in any case. Hence, Breusch-Pagan test statistic results are not presented here.

The results above are reasonably consistent with those in the median price change regressions. Again, the globally more constrained outlets are more likely to exhibit price cycles of both durations, but are most likely to be using more seven-day cycles in their mix of strategies, which is consistent with cycles having greater amplitude above in that here they are shorter. Similar conclusions as drawn above for median changes in price might also be drawn for NCHAR5 and NCHAR6 in Table 6.9. That is, for differing reasons (discussed above), more constrained and more efficient outlets will have more price cycles in their mix of prices and, here, will favour the shorter cycles more.

NCHAR4 is significant at the ten percent level, and is negative, suggesting that more central outlets are less likely to have either kind of cycle and least likely to have ten-day cycles. This is consistent with the median price change results, where such outlets exhibited cycles of smaller amplitude, and is similarly weak; alterations to the model specification mean this variable loses its significance.

Differences in results for submarkets are not particularly clear, but those for branding are; all brands have less cycle power than the omitted dummy, Shell. Recall from Figures 5.10 and 5.11 in Chapter Five that the Shell outlets had the highest spectral power across these two bands. This same result is reflected in the branding coefficients.

Branded independents (TP1) and larger independents (TP5) are both likely to have cycles of smaller amplitude than the omitted case (TP2 – company controlled outlets), and are very slightly more likely to exhibit ten-day cycles. This is consistent with the results for median price; the more competitive outlets not only have cycles of smaller magnitudes, but they are longer too; albeit by only a little.

There are very few demand characteristics that are significant. The only one which is significant across both regressions is the number of competitors within five kilometres (DCHAR15), and it is positive. This suggests a pro-competitive effect of cycles; once everything else is taken into consideration, a marketplace with more competitors is likely to have evidence of cycles. The fact that the coefficient is the same for both types of cycle suggests that this demand-side factor does not favour one kind of cycle over another.

Omitting different variables, particularly the insignificant CS and DCHAR variables makes little difference to results, except for NCHAR4, which loses its significance in several more restricted versions of the model. The same is true when different branding, type and submarket dummies are omitted, which suggests overall that the results for NCHAR4 are rather weak, but those for the other variables are reasonably robust.

Chapter Seven: Conclusions

This thesis examines the retail petroleum market in Australia, with a particular focus on the Perth market. This case study is chosen due to the excellent data which are available owing to the requirements of the *FuelWatch* scheme. Under *FuelWatch* all retail petroleum outlets must submit all of their prices to a regulator. The comprehensive dataset allows me to ascertain in detail how the prices of individual retail petroleum outlets are inter-related, and to build this pattern of inter-relationships into a network which illustrates the structure of competition in the marketplace. I then summarise the place of each outlet in this structure using measures from mathematical sociology. Finally, I put these measures into regressions on price to their influence on pricing.

Chapter One of the thesis provides a general introduction, and Chapter Two provides a detailed overview of the current characteristics and historical development of the Australian retail petroleum industry. I include an overview of industry regulation and of the sectors immediately upstream from retailing (wholesaling and refining), providing an indication on how these influence the retail sector that forms the basis of the case study. I also provide a detailed assessment of the Perth market and the *FuelWatch* scheme.

Chapter Three is the literature review. An important characteristic of retail petroleum prices in Perth is the way in which they cycle. The phenomenon known as Edgeworth Cycles, has also been observed elsewhere. I provide a brief overview of the theoretical and empirical literature in this field. I also provide an overview of key parts of the rather large literature which focuses on retail petroleum markets, paying particular attention to studies whose findings assist in the development of my models and in interpreting my results. Part of this involves looking at the literature developed by different government agencies in Australia, which is far larger than the academic literature on retail petroleum markets in Australia and which contains useful information for my thesis. In addition, I briefly summarise the literature on spatial markets, focussing on the small part of it which forms a precursor to my own work. Finally, I examine some of the literature in geography and mathematical sociology, which provide important underpinnings to my use of network structure in the empirical models.

In Chapter Four, I develop a simple model of spatial competition in the duopoly case, which admits Edgeworth cycles as an equilibrium under conditions which seem likely to hold in many cases. I use the conclusions this model makes about how the price minima of two competing firms will be related to develop a rule by which bilateral pairs in a network are connected and then use this network to illustrate the structure of competition in the marketplace. The network thus developed can then be divided into sub-markets and both the market as a whole and each sub-market can be subjected to statistical tests to ascertain whether network structure influences price. This is not the only way in which one could address the issue of network effects on market behaviour,[85] but it is relatively

[85] One could also solve the *n*-outlet game by substituting the profit functions in Chapter Four with the more general function:

$$\pi_i = \sum_{j=1}^{n} \kappa_{ij} \left[qp_i d_{ij} + qp_i \frac{p_j - p_i}{d_{ij} \tan\alpha} \right] \qquad (7.1)$$

where κ_{ij} is an indicator function taking the value of one when the firms i and j are connected and zero otherwise, and d_{ij} being the distance between the two firms. All of the other variables are as defined in Chapter Four. However, not only is this highly complex, but the solutions are unlikely to be unique. Moreover, it does not address the issue of how one determines network shape.

simple and arguably reflects the way in which individual sites actually set prices by paying most attention to the outlets nearest them rather than the market as a whole.

In Chapter Five, I describe my data in considerable detail. In this chapter, I also construct a network for the Perth retail petroleum market based on its price data, cut the network into sub-markets and develop structural summary variables for both the market as a whole and its sub-markets. I also present a series of approaches to ascertain whether the sub-market division is reasonable.

To explore the price paths in more detail, I subject them to spectral analysis in Chapter Five; the first time, to my knowledge, that this has been attempted. The results are interesting, for they indicate the way in which retail petroleum outlets do not follow a neat, regular price cycle, but in fact follow what appears to be a mix of cycles; randomising between cycles of (mostly) seven and ten days. This is more in keeping with the theory behind Edgeworth Cycles, but this pattern of cycles has not been observed empirically before.

In Chapter Six, I undertake a series of regression analyses, to ascertain whether network structure influences price. I do not test the model developed in Chapter Four directly, but rather use it as a means of building the network, using measures from mathematical sociology to describe the place of each outlet in this network and thus examining how network structure influence choices pertaining to price. In the first of these, I regress the network structure variables, assessed at the level of the whole market and at the submarket level, against retail price and retail margins, including a collection of other supply and demand-side variables. I find that network structure is indeed important. Centrality appears to be associated with lower prices in the downswing and higher prices in the upswing, whilst local efficiency and constraint appear to be highlighting two different sets of outlets which have higher prices for different reasons; market power based upon informational advantage for the efficient and the advantages of peripheral location for the constrained. The efficiency results may represent similar forces as outlined by Eckert (2003) via price-matching by more powerful firms. The constraint results suggest that information generated in a particular sub-market is not necessarily the most valuable aspect of the retail petroleum pricing game being played, and that being able to locate on the periphery may deliver advantages as well.

The second set of regression equations endeavours to assess whether network structure characteristics influence the shape of the cycle. In this, I follow a path taken now by a few authors in the literature of regressing a number of independent variables against the median change in price, and I also use my own dependent variables; the spectral power of seven and ten day cycles. These summarise the degree to which each kind of cycle is prevalent in the pricing of a retail petroleum outlet. One might characterise median change in price as summarising cycle amplitude, and the seven and ten day cycles as summarising its length. I find again that the most constrained outlets have attenuated and shorter cycles because, in a sense, they have only one foot in the market, whilst the more efficient outlets achieve a similar result because they are able to exploit their superior position in the information flows generated within a particular sub-market.

The results of the thesis may find useful application in competition policy; most particularly in merger assessment or other cases where competition policy agencies are endeavouring to improve the competitive structure of an industry. A good example is the 1995 merger between Ampol and Caltex in Australia. As part of the terms of that merger, the ACCC required the parties to reduce their retail presence by divesting themselves of a certain number of retail petroleum outlets in each of Australia's state capitals. The ACCC did not specify, however, which outlets should be divested. To the extent that each market has no spatial element, this does not matter. However, if one can characterise the spatial nature of the market as a network, then this allows a much more fine-grained appreciation of the distribution of market power within that market. This, in turn, provides competition policy agencies with more information to ascertain which assets should best be divested to maximise the pro-competitive outcomes of industry intervention.

Bibliography

Adams AF 1997, ‘Search costs and price dispersion in a localized, homogenous product market: Some empirical evidence’, *Review of Industrial Organization,* vol. 12, pp. 801-8.

Al-Gudhea, S, Kenc, T & Dibooglu, S 2007, ‘Do retail gasoline prices rise more readily than they fall?: A threshold cointegration approach’ *Journal of Economics and Business*, vol. 59, issue 6, pp. 560-74.

Alvine FC & Patterson JM 1974, *Highway Robbery: An analysis of the gasoline crisis,* Indiana University Press, Bloomington Indiana.

Anderson SP & de Palma A 1988, 'Spatial price discrimination with hetero-geneous products.' *Review of Economic Studies* vol. 55, issue 4, pp. 573-92.

Anderson SP & de Palma A 1992a, ‘Spatial equilibrium with footloose firms’, *Journal of Regional Science*, vol. 32 issue 3, pp. 309-20.

Anderson SP & Engers M 1994, ‘Spatial competition with price-taking firms’, *Economica*, vol. 61, issue 242, pp. 125-36.

Anderson SP & Neven DJ 1991, ‘Cournot competition yields spatial agglomeration’, *International Economic Review*, vol. 32, issue 4, pp. 793-808.

Anderson SP 1989, ‘Socially optimal spatial pricing’, *Regional Science and Urban Economics*, vol. 19, pp. 60–86.

Anderson SP, de Palma A & Thisse, JF 1992, ‘Social surplus and profitability under different spatial pricing policies’, *Southern Economic Journal,* vol. 58, issue 4, pp. 934-49.

Anderson SP, de Palma A & Hong GS 1992, ‘Firm mobility and location equilibrium’, *The Canadian Journal of Economics*, vol. 25, issue 1, pp. 76-88.

Anderson SP, de Palma A & Thisse JF 1989, ‘Spatial price policies reconsidered’, *Journal of Industrial Economics*, Vol. 38, issue 1, pp. 1-18.

Anderson, RW & Johnson, RN 1999, ‘Antitrust and sales-below-cost laws: The case of retail gasoline’, *Review of Industrial Organization*, vol. 14, pp. 189-204.

Arakawa K 2006, ‘A model of shopping centers’, *Journal of Regional Science*, vol. 46, issue 5, pp. 969–90.

Archibald, R & Gillingham, R 1980, ‘An analysis of the short-run consumer demand for gasoline using household survey data’, *Review of Economics and Statistics*, vol. 62, issue 4, pp. 622-28.

Arévalo Tomé R & Chamorro-Rivas JM 2007, ‘Credible collusion in a model of spatial competition’, *Papers in Regional Science*, vol. 86, issue 4, pp. 633-42.

Atkinson, B 2009, ‘Retail gasoline price cycles: Evidence from Guelph, Ontario using bi-hourly, station-specfic retail price data’, *The Energy Journal*, vol. 30, issue 1, pp. 85-110.

Atkinson, B, Eckert, A & West DS 2009, ‘Price matching and the domino effect in a retail gasoline market’, *Economic Inquiry*, vol.47, issue 3, pp. 568-88

Australian Bureau of Agricultural and Resource Economics, various years a, *Australian Commodity* Statistics, accessed 26th October 2009 from <www.abareconomics.com/publications_html/data/data/data.html>.

Australian Bureau of Agricultural and Resource Economics, various years b, *Australian Energy*, accessed 26th October 2009 from <www.abareconomics.com/publications_html/data/data/data.html>.

Australian Bureau of Statistics 2006, *2006 Census of Population and Housing*, ABS, Canberra.

Australian Bureau of Statistics, various years, Average Retail Prices of Selected Items, Eight Capital Cities, ABS Catalogue number 6403.0.55.001, accessed 26th October 2009 from < http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/6403.0.55.001Main+Features1Jun%202009?OpenDocument>.

Australian Competition and Consumer Commission 1996, *Inquiry into the Petroleum Products Declaration*, Australian Government Publishing Services, Canberra.

Australian Competition and Consumer Commission 2001, *Reducing Fuel Price Variability*, ACCC Publishing Unit, Canberra.

Australian Competition and Consumer Commission 2002, *Terminal Gate Pricing Arrangements in Australia and Other Fuel Pricing Arrangements in Western Australia*, accessed 26th October 2009 from <www.accc.gov.au/content/index.phtml/itemId/321849>.

Australian Competition and Consumer Commission 2007, *Petrol Prices and Australian Consumers: Report of the ACCC inquiry into the price of unleaded petrol*, ACCC, Canberra, accessed 29th October 2009 from <www.accc.gov.au/content/index.phtml/itemId/806216>.

Australian Institute of Petroleum 2007, *Downstream Petroleum Industry 2007*, accessed 22nd October 2009 from < www.aip.com.au/industry/facts.htm>.

Bachemeier, LJ & Griffin, JM 2003, ‘New evidence on asymmetric gasoline price responses’, *Review of Economics and Statistics*, vol. 85, issue 3, pp. 772-6.

Bacon, RW 1991, ‘Rockets and feathers: the asymmetric speed of adjustment of UK retail gasoline prices to cost changes’, *Energy Economics*, vol. 13, issue 3, pp. 211-18.

Balke, NS, Brown, SPA, & Yucel, MK 1998. ‘Crude oil and gasoline prices: An asymmetric relationship?’ Federal Reserve Bank Dallas Economic Review, 1st quarter 1998, pp. 2–11.

Balmaceda, F & Soruco, P 2008, ‘Asymmetric dynamic pricing in a local gasoline retail market’, *Journal of Industrial Economics*, vol. 56, issue 3, pp. 629-653.

Baltagi, BH & Griffin, JM 1983, ‘Gasoline demand in the OECD: An application of pooling and testing procedures’, *European Economic Review*, vol. 22, pp. 117-37.

Barabassi AL 2002, *Linked: The New Science of Networks (how everything is connected to everything else and what it means for science, business and everyday life),* Perseus Publishing, Cambridge Massachusetts.

Barron, JM, Taylor, BA & Umbeck, JR 2000, ‘A theory of quality-related differences in retail margins: Why there is a “premium” on premium gasoline’, *Economic Inquiry,* vol. 83, issue 4, pp. 550-69.

Barron, JM, Umbeck, JR & Waddell, GR 2002, ‘The link between seller density, price elasticity and market prices in retail gasoline markets’, *US Federal Trade Commission Conference on Factors that Affect Prices of Refined Petroleum Products,* Washington DC, May 8-9 2002, accessed 21st October 2009 from <www.ftc.gov/bc/gasconf/comments2/barronumbeckwaddell2002.pdf>

Bartels, CPA 1977, ‘The structure of regional unemployment in the Netherlands: An exploratory statistical analysis’, *Regional Science & Urban Economics,* vol. 7, pp. 103-35.

Baum, JAC, Calabrese, T & Silverman, BS 2000, ‘Don’t go it alone: Alliance network composition and startups’ performance in Canadian biotechnology’, *Strategic Management Journal*, vol. 21, pp. 267–94.

Benassi, M & Gargiulo, M 2000, ‘Trapped in your own net? Network cohesion, structural capital & the adaptation of social capital’, *Organization Science*, vol. 11, issue 2, pp. 183-96.

Blair, RD & Dougherty, LK 2003, ‘Florida’s Motor Fuel Marketing Practices Act’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp. 205-12.

Blass, AA & Carlton, DW 2001, ‘The choice of organizational form in gasoline retailing and the costs of laws limiting that choice’, *Journal of Law and Economics*, vol. 44, issue 1, pp. 511-24.

Boetel, BL, Hoffmann, R & Liu, DJ 2007, ‘Estimating investment rigidity within a threshold regression framework: The case of US hog production sector’ *American Journal of Agricultural Economics*, vol. 89, issue 1, pp. 36–51.

Bonacich, P 1972, ‘Factoring and weighting approaches to status scores and clique identification’, *Journal of Mathematical Sociology*, vol. 2, pp. 113-20.

Bonacich, P 1987, ‘Power and centrality: A family of measures’, *American Journal of Sociology*, vol. 92, pp. 1170–82.

Boots, BN 1985, ‘Size effects in the spatial patterning of non-principal eigenvectors of planar networks’, *Geographical Analysis*, vol. 17, issue 1, pp. 74-81.

Borenstein, S & Shepard, A 1996, ‘Dynamic pricing in retail gasoline markets’, *RAND Journal of Economics*, vol. 27, issue 3, pp. 429-51.

Borenstein, S 1991, 'Selling costs and switching costs: Explaining retail gasoline margins', *RAND Journal of Economics*, vol. 22, issue 3, pp. 354-69.

Borenstein, S, Cameron, AC & Gilbert, R 1997 'Do gasoline prices respond asymmetrically to crude oil prices?' *Quarterly Journal of Economics* vol. 111, issue 4, pp. 305–339.

Borgatti, SP & Everett, MG 2005, 'A Graph-theoretic perspective on centrality', *Social Networks*, vol. 28, pp. 466–84.

Borgatti, SP 1997, 'Structural holes: Unpacking Burt's redundancy measures', *Connections*, vol. 20, issue 1, pp. 35-8.

Borgatti, SP, Everett, MG & Freeman, LC 2002, *Ucinet for Windows: Software for Social Network Analysis*, Analytic Technologies, Harvard, Massachusetts.

Braid RM 1993, 'Spatial price competition with consumers on a plane, at intersections and along main roadways', *Journal of Regional Science*, vol. 33, issue 2, pp. 187-205.

Braid RM 1996, 'The optimal location of branch facilities and main facilities with consumer search', *Journal of Regional Science*, vol. 36, issue 2, pp. 217-34.

Breunig, RV & Gisz, C 2009, 'An exploration of Australian petrol demand: Unobservable habits, irreversibility and some updated estimates', *Economic Record*, vol. 85, issue 268, pp. 73-91.

Brillinger DR, 1975, *Time Series, Data Analysis and Theory*, Holt, Rinehart & Winston, New York.

Brons, M, Njiekamp, P, Pels E & Reitveld, P 2006, 'A meta-analysis of the price elasticity of gasoline demand: A system of equations approach', Tinbergen Institute

Discussion Paper 2006-106/3, accessed 27th October 2009 from <www.tinbergen.nl/ti-publications/discussion-papers.php?paper=821>.

Brookfield, HC 1973, 'On one geography and a Third World', *Transactions of the Institute of British Geographers*, vol. 58, pp. 1-20

Brown, J, Hastings, J, Masur, ET & Villa-Boas, SB 2008, 'Reformulating competition? Gasoline content regulation and wholesale gasoline prices', *Journal of Environmental Economics and Management*, vol. 55, pp. 1-19.

Brown, SPA & Yucel, MK 2000, 'Gasoline and crude oil prices: Why the asymmetry?', *Federal Reserve Bank of Dallas Economic and Financial Review*, 3rd quarter 2000, pp. 23-9.

Bureau of Transport and Regional Economics 2006, *Freight Measurement and Modelling in Australia*, BTRE Report 112, BTRE, Canberra.

Burt, RS & Ronchi, D 2007, 'Teaching executives to see social capital: Results from a Weld experiment, *Social Science Research*, vol. 36, pp. 1156–83.

Burt, RS 1992, *Structural Holes: The Social Structure of Competition*, Harvard University Press, Cambridge Massachusetts.

Burt, RS 1997a, 'A note on social capital and network content', *Social Networks*, vol. 19, pp. 355-373.

Burt, RS 1997b, 'The contingent value of social capital', *Administrative Science Quarterly*, vol. 42, issue 2, pp. 339-365.

Burt, RS 1999, 'The social capital of opinion leaders', *Annals of the American Academy of Political and Social Science*, Vol. 566, pp. 37-54.

Burt, RS 2000, ‘The Network Structure of Social Capital’ RI Sutton & BM Staw (eds) *Research in Organizational Behavior*, vol. 22, Elsevier Science, Greenwich, Connecticut, pp. 345–423.

Burt, RS 2002, ‘The Social Capital of Structural Holes’, MF Guillen, R Collins, P England & M Meyer (eds.), *The New Economic Sociology: Developments in an emerging field*, Russell Sage, New York, pp. 148-90.

Burt, RS 2004, ‘Structural Holes and Good Ideas’, *American Journal of Sociology*, vol. 110, issue 2, pp. 349–99.

Burt, RS 2005 *Brokerage and Closure: An Introduction to Social Capital*, Oxford University Press, Oxford.

Burt, RS, Jannotta, JE & Mahoney, JT 1998, ‘Personality correlates of structural holes’, *Social Networks*, vol. 20, pp. 63-87.

Busken, V & Van de Rijt, A 2008, ‘Dynamics of Networks if Everyone Strives for Structural Holes’, *American Journal of Sociology*, vol. 114, issue 2, pp. 371–407.

Cason, TN, Friedman, D & Wagener, F 2005, ‘The dynamics of price dispersion, or Edgeworth variations’, *Journal of Economic Dynamics & Control*, vol. 29, pp801-22.

Castanias, R & Johnson, H 1993, ‘Gas wars: Retail gasoline price fluctuations’, *Review of Economics and Statistics*, vol. 75, issue 1, pp.171-4.

Chakravorty, U, Naughes, C & Thomas, A 2008, ‘Clean Air regulation and heterogeneity in US gasoline prices’, *Journal of Environmental Economics and Management*, vol. 55, pp. 106-22.

Chatfield, C, 2006, *The Analysis of Time Series: An introduction (6th ed)*, CRC Press, Boca Raton Florida.

Chen ST & Lee CC 2005, ‘Government size and economic growth in Taiwan: A threshold regression approach’, *Journal of Policy Modeling*, vol. 27, pp. 1051–66.

Chen, LH, Finney, M & Lai, KS 2005, ‘A threshold cointegration analysis of asymmetric price transmission from crude oil to gasoline prices’, *Economics Letters*, vol. 89, issue 2, pp. 233-9.

Chouinard, H & Perloff, JM 2004, ‘Incidence of federal and state gasoline taxes’, *Economics Letters*, vol. 83, issue 1, pp. 55-60.

Chouinard, H & Perloff, JM 2007, ‘Gasoline price differences: Taxes, pollution regulation, mergers, market power and market conditions’, *B.E. Journal of Economic Analysis & Policy*, vol. 7, issue 1, article 8, accessed 21st October 2009 from <www.bepress.com/bejeap/vol7/iss1/art8>.

Clemenz, G & Gugler, K 2002, ‘Locational choice and price competition: Some empirical results for the Austrian retail gasoline market’, *Empirical Economics*, vol. 31, pp. 291-312.

Cliff, A, Haggett, P & Ord K 1973, ‘Graph Theory and Geography’, RJ Wilson & LW Beineke (eds.) *Applications of Graph Theory*, Academic Press, London, pp. 293-326.

Coleman, JS 1988, ‘Social capital and the creation of human capital’, *American Journal of Sociology*, vol. 94 pp. S94-120.

Coloma, G 2002, ‘The effect of the Repsol-YPF merger on the Argentine gasoline market’, *Review of Industrial Organization*, vol. 21, pp. 399-418.

Coloma, G 2003, ‘Price discrimination and price dispersion in the Argentine gasoline market’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp. 169-78.

Comanor, WS & Riddle, JM 2003, ‘The costs of regulation: Branded open supply and uniform pricing of gasoline’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp.135-55.

Cooper, TE & Jones, JT 2007, ‘Asymmetric competition on commuter routes: The case of gasoline pricing’, *Southern Economic Journal*, vol. 74, issue 2, pp. 483-504.

Dahl, C & Sterner, T 1991, ‘Analysing gasoline demand elasticities: A survey’, *Energy Economics*, vol. 13, issue 3, pp. 203-10.

d'Aspremont CJ, Gabszewicz, J & Jacques-Francois Thisse JF 1979 'On Hotelling's "Stability in Competition." ', *Econometrica* vol. 47, pp.1145-50.

Davidson, S 2008, ‘Secret econometric business: Watching Fuelwatch and the ACCC’, *Agenda*, vol. 15, issue 4, pp. 5-18.

Delpatchirya, S & Beal, D 2001, ‘Petrol prices disparity: Did the removal of price surveillance create price competition’, *Economic Papers*, vol. 21, issue 1, pp. 56-65.

Deltas, G 2008, ‘Retail gasoline price dynamics and local market power’, *Journal of Industrial Economics*, vol. 56, issue 3, pp. 613-628.

Department of Industry, Science and Resources 1999, *Downstream Petroleum Products Action Agenda*, DISR, Canberra.

Department of Industry, Tourism and Resources 2002, *Downstream Petroleum Industry Framework 2002*, DITR, Canberra.

Dixon, DF 1964, ‘Gasoline marketing in the United States: The first fifty years’, *Journal of Industrial Economics*, vol. 13, issue 1, pp. 23-42.

Dorta-Gonzales P Santo- Peñate DR & Súarez-Vega R 2004, 'Cournot oligopolistic competition in spatially separated markets: The Stackelberg equilibrium', *Annals of Regional Science*, vol. 38, pp. 499–511.

Dorta-Gonzales, P, Santo-Peñate, DR & Súarez-Vega, R 2005, 'Spatial competition in networks under delivered pricing', *Papers in Regional Science*, vol. 84, issue 2, pp. 271-80.

Doyle, JD Muehlegger, E & Samphantharak, K 2008, 'Edgeworth cycles revisited', NBER Working Paper 14162, accessed 15th October 2009 from <www.nber.org/papers/w14162>

Driffield, N & Ionnadis, C 2000, 'Effectiveness and effects of attempts to regulate the UK petrol industry', *Energy Economics*, vol. 22, issue 3, pp. 369-81.

Duffy-Deano, K 1996, 'Retail price asymmetries in local gasoline markets', *Energy Economics*, vol. 18, issue 1-2, pp. 81-92.

Eckert, A & West, DS 2004a, 'A tale of two cities: Price uniformity and price volatility in gasoline retailing', *Annals of Regional Science,* vol. 38, pp. 25-46.

Eckert, A & West, DS 2004b, 'Retail gasoline supply across spatially dispersed gasoline stations', *Journal of Law and* Economics, vol. 47, April 2004, pp. 245-73.

Eckert, A & West, DS 2005, 'Price uniformity and competition in a retail gasoline market', *Journal of Economic Behaviour and Organization*, vol. 56, pp. 219-37.

Eckert, A 2002, 'Retail price cycles and response asymmetry', *Canadian Journal of Economics*, vol. 35, issue 1, pp. 52-77.

Eckert, A 2003, 'Retail price cycles and the presence of small firms', *International Journal of Industrial Organization, vol.* 21, pp. 151-70.

Eckert, A 2004, ‘An alternating-move price-setting duopoly model with stochastic shocks’, *International Journal of Industrial Organization*, vol. 22, pp. 997-1015.

Edgeworth, F 1925, ‘The pure theory of monopoly’ in F. Edgeworth, *Papers Relating to Political Economy*, MacMillan, London, pp.111-42.

Eiselt HA & Laporte G 1989, ‘Competitive spatial models’, European Journal of Operational Research, vol. 39, pp. 231-42.

Epsey, M 1996, ‘Explaining the variation in elasticity estimates of gasoline demand in the United States: A meta-analysis’, *Energy Journal*, vol. 17, issue 3, pp. 49-60.

Epsey, M 1998, ‘Gasoline demand revisited: An international meta-analysis of elasticities’, *Energy Economics*, vol. 20, issue 3, pp. 273-95.

Foros, O & Steen, F 2008, ‘Gasoline prices jump up on Mondays: an outcome of aggressive competition?’ Norwegian School of Economics and Business Administration, Discussion Paper NHH SAM 04/2008.

Foster, N 2006, ‘Exports, growth and threshold effects in Africa’, *Journal of Development Studies*, vol. 42, issue 6, pp. 1056–1074.

Freeman, LC 1979, ‘Centrality in social networks: Conceptual clarification’, *Social Networks*, vol. 1, pp. 215-39.

Freeman, LC 1993, ‘Finding groups with a simple genetic algorithm’, *Journal of Mathematical Sociology*, vol. 17, issue 4, pp. 227-41.

Galeotti, M Lanza, A & Manera, M 2003, ‘Rockets and feathers revisited: An international comparison on European gasoline markets’, *Energy Economics*, vol. 25, issue 2, pp. 175-90.

Gallini, N 1983, 'Demand for gasoline in Canada', *Canadian Journal of Economics*, vol. 16, issue 2, pp. 299-324.

Gilbert, RJ & Hastings, JS 2005, 'Market power, vertical integration and the wholesale price of gasoline', *Journal of Industrial Economics*, vol. 53, issue 4, pp. 469-92.

Girma, S 2005, 'Absorptive capacity & productivity spillovers from FDI: A threshold regression analysis', *Oxford Bulletin of Economics And Statistics*, vol. 67, issue 3, pp. 281-306.

Girvan, M & Newman, MEJ 2003a, 'Finding and evaluating community structure in networks', *Physical Review E,* vol. 69, pp. 026113.

Girvan, M & Newman, MEJ 2003b, 'Community structure in social and biological networks' *Proceedings of the National Academy of Sciences*, vol. 99, issue 12, pp. 7821–6.

Gleiser, PM & Danon, L 2003, 'Community structure in jazz', *Advances in Complex Systems*, vol. 6, issue 4, pp. 565-73, DOI: 10.1142/S0219525903001067

Godby, R Lintner, AM, Stengos, T & Wandschneider, B 2000, 'Testing for asymmetric pricing in the Canadian retail gasoline market', *Energy Economics*, vol. 22, issue 3, pp. 349-68.

Goodwin, P, Dargay, J & Hanly, M 2004, 'Elasticities of road traffic and fuel consumption with respect to price and income: A review', *Transport Reviews*, vol. 24, issue 3, pp. 275-92.

Gould, P 1967, 'The geographical interpretation of eigenvalues', *Transactions of the Institute of British Geographers*, vol. 42, pp. 53-85.

Graham, DJ & Glaister, S 2002, ‘The demand for automobile fuel: A survey of elasticities, *Journal of Transport Economics and Policy*, vol. 36, issue 1, pp. 1-26.

Granger, CWJ & Hatanaka, M 1964, *Spectral Analysis of Economic Time Series*, Princeton University Press, Princeton New Jersey.

Granot D Granot F & Raviv T 2010, ‘On competitive sequential location in a network with a decreasing demand intensity’, *European Journal of Operational Research*, vol. 205, pp.301–12.

Granovetter, M 2005, ‘The impact of social structure on economic outcomes’, *Journal of Economic Perspectives*, vol. 19, issue 1, pp. 33-50.

Granovetter, MS 1973, ‘The strength of weak ties’, *American Journal of Sociology*, vol.78, pp.1360-80.

Green, EJ & Porter, RH, 1984, ‘Non-cooperative collusion under imperfect price information’, *Econometrica*, vol. 52, issue 1, pp. 87-100.

Gupta B, Pal D & Sarkar J 1997, ‘Location equilibrium for Cournot oligopoly in spatially separated markets’, *Journal of Regional Science*, vol. 37, issue 2, pp. 195-212.

Gupta, B, Lai, FC, Pal, D, Sarkar, J & Yu, CM 2004, ‘Where to locate in a circular city’, *International Journal of Industrial Organization*, vol. 22, pp. 759-82.

Hadi AS & Ling, RF 1998, ‘Some cautionary notes on the use of principal components regression’, *The American Statistician*, vol. 52 issue 1, pp. 15-19.

Hansen, BE 1996, ‘Inference when a nuisance parameter is not identified under the null hypothesis’, *Econometrica*, vol. 64, issue 2, pp. 413-30.

Hansen, BE 1999, ‘Threshold effects in non-dynamic panels: Estimation, testing and inference’, *Journal of Econometrics*, vol. 93, pp. 345-68.

Hansen, BE 2000, 'Sample splitting and threshold estimation', *Econometrica*, vol. 68, issue 3, pp. 575-603.

Harding, D 2008, 'FoolWatch - Further discussion of econometric analysis undertaken by ACCC', MPRA Paper 16048, University Library of Munich, Germany.

Harding, D 2008, 'FoolWatch: A case study of econometric analysis and evidenced-based-policy making in the Australian Government,' MPRA Paper 16041, University Library of Munich, Germany.

Hastings, J 2004, 'Vertical relationships and competition in retail gasoline markets: Empirical evidence from contract changes in Southern California', *American Economic Review*, vol. 94, issue 1, pp. 317-28.

Hay, A 1975, 'On the choice of methods in the factor analysis of connectivity matrices: A reply', *Transactions of the Institute of British Geographers*, vol. 66, pp. 163-7.

Hill, JC 1998, 'A note on the matrix formulation of gerrymanders', *Environment and Planning B: Planning and Design*, vol. 25, pp. 495-505.

Hoover, EM 1937, 'Spatial price discrimination', *Review of Economic Studies*, vol. 4, issue 2, pp. 182-91.

Hosken, DS, McMillan, RS & Taylor CT 2008, 'Retail gasoline pricing: What do we know?', *International Journal of Industrial Organization*, vol. 26, pp. 1425-36.

Hotelling, H 1929, 'Stability in competition', *Economic Journal*, vol. 39, pp. 41-57.

Huang, BN & Yang, CW 2006, 'Demand for cigarettes revisited: an application of the threshold regression model', *Agricultural Economics*, vol. 34, pp. 81–86.

Hubbard, TN 2008, 'Introduction to the symposium on the dynamics of gasoline pricing', *Journal of Industrial Economics*, vol. 56, issue 3, pp. 578-580.

Hyde, CE 2002, ‘Evaluating mergers in the Australian petroleum industry’, *Economic Record*, vol. 78, issue 242, pp. 299-311.

Ibarra, H 1993, ‘Network centrality, power, and innovation involvement: Determinants of technical and administrative roles’, *Academy of Management Journal*, vol. 36, issue 3, pp. 471-501.

Industry Commission 1994, *Petroleum Products,* IC Report 40, Australian Government Printing Service, Melbourne.

Ingram, P & Roberts, PW 2000, ‘Friendships among competitors in the Sydney hotel industry’, *American Journal of Sociology*, vol.106, issue 2, pp. 387–423.

Johnson, RN & Romeo, CJ 2000, ‘The impact of self-service bans in the retail gasoline market’, *Review of Economics and Statistics*, vol. 82, issue 4, 625-33.

Johnson, RN 2002, ‘Search costs, lags and prices at the pump’, *Review of Industrial Organization,* vol. 20, pp. 33-50.

Katz, M & Shapiro, C 1994, ‘Systems competition and network effects’, *Journal of Economic Perspectives*, vol. 8, issue 2, pp. 93-115.

Kayser, HA 2000, ‘Gasoline demand and car choice: Estimating gasoline demand using household information’, *Energy Economics,* vol. 22, issue 3, pp. 331-48.

Keely, M & Elzinga, KG 2003, ‘Uniform gasoline price regulation: Consequences for consumer welfare’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp. 157-68.

Kilkenny M & Thisse JF 1999, ‘Economics of location: A selective survey’, *Computers and Operations Research,* vol. 26, pp.1369- 94.

Kirchgassner, G, & Kubler, K 1992, ‘Symmetric or asymmetric price adjustments in the oil market: An empirical analysis of the relations between international and domestic prices in the Federal Republic of Germany , 1972–89’, *Energy Econ*omics, vol. 14, issue 3, pp. 171–185.

Kruse, JB, Rassenti, S, Reynolds, SS & Smith, VL 1994, ‘Bertrand-Edgeworth competition in experimental markets’, *Econometrica*, vol. 62, issue 2, pp. 343-71.

Langenfeld, J Li, W & Schink, G 2003, ‘Economic literature on price discrimination and its application to the uniform pricing of gasoline’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp. 179-94.

Lau, SP 2001, ‘Aggregate pattern of time-dependent adjustment rules II: Strategic complementarity and endogenous non-synchronization’, *Journal of Economic Theory* vol. 98, pp. 199-231.

Lederer PJ & Hurter AP 1986, ‘Competition of firms: Discriminatory pricing and location’, *Econometrica*, vol. 54, issue 3, pp. 623-40

Lederer, P & Thisse, JF, 1990, ‘Competitive location on networks under delivered pricing’, *Operations Research Letters*, vol. 9, pp. 147-53.

Leufkens K & Peeters R 2008, ‘Focal prices and price cycles in an alternating duopoly experiment’ Maastricht research school of Economics of Technology and Organization Working Paper, July 2008.

Levitan, R & Shubik, M 1972, ‘Price duopoly and capacity constraints’, *International Economic Review*, vol. 13, issue 1, pp. 111-22.

Lewis, M 2008a ‘Price dispersion and competition with differentiated sellers’, *Journal of Industrial Economics*, vol. 56, issue 3, pp. (p 654-678)

Lewis, MS 2009, ‘Temporary wholesale gasoline price spikes have long-lasting retail effects: The aftermath of Hurricane Rita’, *Journal of Law and Economics*, Vol. 52, issue 3, pp. 581-605

Li, S, von Haefen, R & Timmins, C 2008, ‘How do gasoline prices affect fleet fuel economy?’, NBER Working Paper 14450, accessed 21st October 2009 from <www.nber.org/papers/w14450>.

Lie, J 1997, ‘Sociology of markets’, *Annual Review of Sociology*, vol. 23, pp. 341–60.

Macfarlane, I (MP) 2006, *Petroleum Retail Legislation Repeal Bill 2006: Explanatory Memorandum*, Circulated by the authority of the Hon Ian Macfarlane, MP, Minister for Industry, Tourism and Resources.

MacLeod, WB, Norman, G & Thisse, JF 1988, ‘Price discrimination and equilibrium in monopolistic competition’, *International Journal of Industrial Organization*, vol. 6, pp. 429-46.

Marvel, HP 1976, ‘The Economics of information and retail gasoline pricing: An empirical analysis’, *Journal of Political Economy*, vol. 84, issue 5, pp.1033-60.

Marvel, HP 2003, ‘On the economics of branded open supply’, *International Journal of the Economics of Business*, vol. 10, issue 2, pp. 213-24.

Maskin, E & Tirole, J 1988, ‘A theory of dynamic oligopoly II: Price competition, kinked demand curves and Edgeworth Cycles’, *Econometrica*, vol. 56, issue 3, pp. 571-99.

Matsushima N & Matsumura T 2003, ‘Mixed oligopoly and spatial agglomeration’, Canadian Journal of Economics, vol. 36, issue 1, pp. 62-87.

Mayer T 2000, ‘Spatial Coumot competition and heterogeneous production costs across locations’, *Regional Science and Urban Economics*, vol. 30, pp. 325-52.

McBride, ME 1983, 'Spatial competition and vertical integration: Cement and concrete revisited', *American Economic Review*, vol. 73, issue 5, pp. 1011-22.

Milgram, S & Travers, J 1969, 'An experimental study of the small world problem', *Sociometry*, vol. 32, issue 4, pp. 425-43.

Netz, JS & Taylor, BA 2002, 'Maximum or minimum differentiation? Location patterns of retail outlets', *The Review of Economics and Statistics*, vol. 84, issue 1, pp. 162–75.

Nicol, CJ 2003, 'Elasticities of demand for gasoline in Canada and the United States', *Energy Economics*, vol. 25, issue 2, pp. 201-14.

Noel, MD 2007a, 'Edgeworth price cycles, cost-based pricing and sticky pricing in retail gasoline markets', *Review of Economics and Statistics*, vol. 89, issue 2, pp. 324-34.

Noel, MD 2007b, 'Edgeworth price cycles: Evidence from the Toronto retail gasoline market', *Journal of Industrial Economics*, vol. 55, issue 1, pp. 69-92.

Noel, MD 2008, 'Edgeworth price cycles and focal prices: Computational dynamic Markov equilibria', *Journal of Economics and Management Strategy*, vol. 17, issue 2, pp 345-77.

Noel, MD 2009, 'Do gasoline prices respond asymmetrically to cost shocks? The confounding effect of Edgeworth cycles', *RAND Journal of Economics*, vol. 40, issue 3, pp. 582-95.

O'Huallachain, B 1985, 'Complementary linkages and the structure of regional economies', *Geographical Analysis*, vol. 17, issue 2, pp. 130-42.

Osborne, MJ & Pitchik, K 1987, 'Equilibrium in Hotelling's model of spatial competition', *Econometrica*, vol.55, issue 4, pp. 911-22.

Pal, D & Sarkar, J 2002, 'Spatial competition among multi-store firms', *International Journal of Industrial Organization,* vol. 20, pp.163-90.

Pal, D & Sarkar, J 2006, 'Spatial Cournot Competition among Multi-Plant Firms in a Circular City', *Southern Economic Journal*, vol. 73, issue 1, pp. 246-58.

Papageorgiou, C 2002, 'Trade as a threshold variable for multiple regimes', *Economics Letters*, vol. 77, issue 1, pp. 85–91.

Pires, CP & Sarkar, S 2000, 'Delivered nonlinear pricing by duopolists', *Regional Science and Urban Economics*, vol. 30, pp. 429-56.

Puller, SL & Greening, LA 1999, 'Household adjustment to gasoline price data: An analysis using 9 years of US survey data', *Energy Economics,* vol. 21, issue 1, pp. 37-52.

Radchenko, S 2005a, 'Lags in the response of gasoline prices to changes in crude oil prices:The role of short-term and long-term shocks', *Energy Economics*, vol. 27, issue 4, pp. 573-602.

Radchenko, S 2005b, 'Oil price volatility and the asymmetric response of gasoline prices to oil price increases and decreases' *Energy Economics*, vol. 27, issue 5, pp. 708-30.

Radicchi, F, Castellano, C, Cecconi, F, Loreto, V & Parisi, D 2004, 'Defining and identifying communities in networks', *Proceedings of the National Academy of Sciences*, vol. 101, issue 9, pp. 2658–63.

Rauch, JE & Casella, A (eds) 2001, *Networks and Markets*, By Russell Sage Foundation, New York.

Reagans, R & Zuckerman, EW 2001, 'Networks, diversity, and productivity: The social capital of corporate R&D teams', *Organization Science*, vol. 12, issue 4, pp. 502-517.

Rotemberg, JJ & Saloner, G 1986, 'A supergame-theoretic model of price wars during booms' *American Economic Review*, vol. 76, issue 3, pp. 390-407.

Rowley, T Behrens, D & Krackhardt, D 2000, 'Redundant governance structures: An analysis of structural and relational embeddedness in the steel and semiconductor industries', *Strategic Management Journal*, vol. 21, pp. 369–386.

Royal Commission on Petroleum 1976, *The Marketing and Pricing of Petroleum Products in Australia*, Report No. 4 of the Commission, Australian Government Publishing Service, Canberra.

Ryall, M D & Sorenson O 2007, 'Brokers and competitive advantage,' *Management Science*, vol. 53, 566–583.

Salop, SC 1979, 'Monopolistic competition with outside goods', *Bell Journal of Economics*, vol. 10, pp**.** 141-56.

Savvides, A, & Stengos, T 2000, 'Income inequality and economic development: evidence from the threshold regression model', *Economics Letters*, vol. 69, issue 2, pp. 207–12.

Scherer, FM 1996, *Industry Structure, Strategy and Public Policy*, Harper Collins, New York.

Sen, A 2003, 'Higher prices at Canadian gas pumps: International crude oil prices of local market concentration? An empirical examination', *Energy Economics*, vol. 25, issue 3, pp. 269-88.

Senate Standing Committee on Economics 2006, *Petrol Prices in Australia*, Senate Printing Unit, Parliament House, Canberra.

Shepard, A 1991, ‘Price discrimination and retail configuration’, *Journal of Political Economy*, vol. 99, issue 1, pp. 30-53.

Shepard, A 1993, ‘Contractual form, retail price and asset characteristics in gasoline retailing’, *RAND Journal of Economics*, vol. 24, issue 1, pp. 58-77.

Simpson, J & Taylor, C 2008, ‘Do gasoline mergers affect consumer prices? The Marathon Ashland Petroleum and Ultramar Diamond Shamrock decision’, *Journal of Law and Economics*, vol. 51, pp. 135-52.

Skidmore, M, Peltier, J & Alm, J 2005, ‘Do state motor fuel sales-below-cost laws lower prices?’, *Journal of Urban Economics*, vol. 57, pp. 189-211.

Slade, ME 1986, ‘Conjectures, firm characteristics and market structure’, *International Journal of Industrial Organization*, vol. 4, pp. 347-69.

Slade, ME 1987, ‘Interfirm rivalry in a repeated game: An empirical test of tacit collusion’, *Journal of Industrial Economics*, vol. 35, issue 4, pp. 417-516.

Slade, ME 1989, ‘Price wars in price-setting supergames’, *Economica*, vol. 56, issue 223, pp. 295-310.

Slade, ME 1990, ‘Strategic pricing models and interpretation of price-war data’, *European Economic Review*, vol. 34, pp. 524-37.

Slade, ME 1992, ‘Vancouver’s gasoline-price wars: An empirical exercise in uncovering supergame strategies’, *Review of Economic Studies*, vol. 59, issue 2, pp. 257-76.

Spiller, PT & Huang, CJ 1986, ‘On the extent of the market: Wholesale gasoline in the Northeastern United States’, *Journal of Industrial Economics*, vol. 35, issue 2, pp. 131-45.

Storchman, K 2005, ‘Long run gasoline demand for passenger cars: The role of income distribution’, *Energy Economics*, vol. 27, issue 1, pp. 25-58.

Straffin, PD 1980, ‘Linear algebra in geography: Eigenvectors of networks’, *Mathematics Magazine*, vol. 53, issue 5, pp. 269-76.

Ter Wal, ALJ & Boschma, RA 2009, ‘Applying social network analysis in economic geography: framing some key analytic issues’, *Annals of Regional Science,* vol. 43, issue 3, pp. 739-56.

Thisse JF & Vives X 1988, ‘On the strategic choice of spatial price policy’, *American Economic Review,* vol. 78, pp. 122-37.

Tinkler, KJ 1971, ‘The physical interpretation of eigenfunctions of dichotomous matrices’, *Transactions of the Institute of British Geographers,* vol. 55, pp. 17-46.

Tinkler, KJ 1975, ‘On the choice of methods in the factor analysis of connectivity matrices: A reply’, *Transactions of the Institute of British Geographers,* vol. 66, pp. 168-71.

Tsai, W & Ghoshal, S 1998, ‘Social capital and value creation: The role of intra-firm networks’, *Academy of Management Journal,* vol. 41, issue 4, pp. 464-476.

Tsai, W 2000, ‘Social capital, strategic relatedness and the formation of intra-organizational linkages’, *Strategic Management Journal*, vol. 21, pp. 925–939.

Tsionas, EG & Christopoulos, DK 2003, ‘Maastricht convergence and real convergence: European evidence from threshold and smooth transition regression models’, *Journal of Policy Modeling,* vol. 25, pp. 43–52.

UK Monopolies and Mergers Commission 1990, *The Supply of Petrol,* HMSO, London.

Universal Business Directories 2002, *UBD Street Directory, Perth: 44th Edition (CD ROM)*, Universal Publishing, Perth.

Van-Meerbeck,W 2003, ‘Competition and local market conditions on the Belgian retail gasoline market’, *De Economist*, vol. 151, issue 4, pp. 369-88.

Verlinda, JA 2008, ‘Do rockets rise faster and feathers fall slower in an atmosphere of local market power? Evidence from the retail gasoline market’, *Journal of Industrial Economics*, vol. 56, issue 3, pp. 581-612.

Vickery WS 1964, *Microstatics*, Harcourt Brace and World, New York.

Vita, MG 2000, ‘Regulatory restrictions on vertical integration and control: The competitive impact of gasoline divorcement policies’, *Journal of Regulatory Economics*, vol. 18, issue 3, pp. 217-33.

Vives, X 1993, ‘Edgeworth and modern oligopoly theory’, *European Economic Review*, vol. 37, pp. 463-76.

WA Senate Committee of the Pricing of Petroleum Products, 2000, *Getting a Fair Deal for Western Australian Motorists*, WA Legislative Assembly, Perth WA.

Walker, J & Woodward, L 1996, ‘The Ampol/Caltex Australia merger: Trade practices issues’, *Trade Practices Law Journal*, vol. 4, pp. 21-48.

Wallner, K 1999, “Sequential moves and tacit collusion: Reaction-function cycles in a finite pricing duopoly’, *Journal of Economic Theory* vol. 84, pp. 251-67.

Wang, Z 2005a, ‘Strategy, timing and oligopoly pricing: Evidence from a repeated game in a timing-controlled gasoline market’, Northeastern University, Department of Economics Working Paper, September 2005, accessed 28th October 2009 from <www.economics.neu.edu/papers/>.

Wang, Z 2005b, ‘Edgeworth price cycle and oligopoly coordination: Trial evidence from Australia’, Northeastern University, Department of Economics Working Paper, September 2005.

Wang, Z 2006, ‘Endogenous timing in oligopoly pricing: Evidence from a repeated game in the field’, Northeastern University, Department of Economics Working Paper, October 2006, accessed 28th October 2009 from <www.economics.neu.edu/papers/>.

Wang, Z 2007, ‘Do firms play mixed strategies? Evidence from relenting patterns in wars of attrition’, Northeastern University, Department of Economics Working Paper, May 2007.

Wang, Z 2008, ‘Collusive communication and pricing coordination in a retail gasoline market’, *Review of Industrial Organization*, vol. 32, issue 1, pp. 35-52.

Wang, Z 2009, **‘**Station level gasoline demand in an Australian market with regular price cycles’**,** *Australian Journal of Agricultural and Resource Economics*, vol. 53, issue 4, pp. 467-83.

Watts, DJ & Strogatz, SH 1998, ‘Collective dynamics of 'small-world' networks’, *Nature,* vol. 393, issue 6684, pp. 440-442.

Wilkinson, D & Huberman, BA 2002, ‘A method for finding communities of related Genes’, mimeo.

Wilkinson, R 1983 *A Thirst for Burning: The story of Australia’s oil industry*, David Ell Press, Sydney.

Yu CM & Lai FC 2003, ‘Cournot competition in spatial markets: Some further results’, *Papers in Regional Science,* vol. 82, pp. 569-80.

Yu CM 2007, ‘Price and quantity competition yield the same location equilibria in a circular market’, *Papers in Regional Science*, vol. 86, issue 4, pp. 643-55.

Zuckerman, EW 2003, ‘Networks and Markets: Review of the book by James E. Rauch & Alessandra Casella’ *Journal of Economic Literature*, vol. 41, issue 2, pp. 545-65.