Asymmetric cost transmission and market power in retail gasoline markets

BY Ritvana Rrukaj and Frode Steen

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Asymmetric cost transmission and market power in retail gasoline markets

Ritvana Rrukaj[*] and *Frode Steen*[†‡]

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Abstract

Estimating non-linear autoregressive distributed lag models, we establish short-run cost pass-through in the Swedish retail gasoline market. Our findings reveal a slower correction of disequilibrium error in volume-adjusted prices compared to average pump prices, suggesting that oil companies are more focused on pricing on days and at stations with larger sales. Our results also suggest that earlier studies of pass-through using average prices underestimates the price asymmetry. Exploring heterogeneity in price responses we find that gasoline stations less exposed to local competition impose larger and more prolonged asymmetry on retail gasoline prices. Full-service stations have a higher and more prolonged asymmetry in pricing than automated self-service stations. Despite indicating only roughly three percent rise in consumer prices, this asymmetry accounts for nearly 40% of firms' gross margins, carrying significant implications for market regulation and business strategies.

Keywords: Gasoline markets, asymmetric short- and long-run cost pass-through, market power, volume-adjusted prices, station heterogeneity, local competition

JEL Codes: C12, C13, F14, L11, L71

[*]School of Economics and Business, NMBU Norwegian University of Life Sciences. 1433 Ås, Norway. E-mail:ritvana.rrukaj@nmbu.no.

[†]Department of Economics, NHH Norwegian School of Economics, 5045 Bergen, Norway and the Centre for Economic Policy Design (CEPR). E-mail: frode.steen@nhh.no.

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1 Introduction

Many studies have aimed to examine the behavior of firms in the gasoline market. One strand of literature has focused on Edgeworth price cycles (Edgeworth, 1925; Maskin and Tirole, 1988) and saw tooth-like pricing patterns. Several studies have focused on studying the presence of coordination and coordinated effects. Others have attempted to investigate whether retail gasoline markets have prices where cost changes are asymmetrically passed on to consumer prices. This pattern, often referred to as "rocket and feathers" (Bacon, 1991), has been observed and analyzed in several markets and across many products (Peltzman, 2000). In response to wholesale price changes, consumer prices typically rise quickly, reflecting an immediate pass-through of costs. However, when wholesale prices decrease, the corresponding reduction in consumer prices often occurs at a much slower pace. This phenomenon, known as asymmetric price transmission (ATP), highlights a unique pattern where prices are quick to rise but slow to fall. Bulutay et al. (2021) suggest that such asymmetry can emerge even in markets devoid of traditional frictions and information asymmetries, implicating tacit collusion as a potential underlying driver. Additionally, studies have examined how local variations in competition and differences in gasoline station service levels and amenities can influence the degree of asymmetry observed.[1]

A particular rich dataset is exploited to uncover the extent to which asymmetric cost pass-through relates to such market characteristics. This analysis focuses on how Rotterdam spot market prices are passed on to consumer gasoline prices in Sweden and how quickly this happens. We estimate short- and long-run effects using dynamic time-series models for different station sizes and allow for station heterogeneity both with regards to station service-level and differences in local competition. To this end, earlier studies have

[1]Further exploring the dynamics of asymmetric price adjustments, Loy et al. (2016) analyze how market structures and operational costs influence pricing behaviors. Complementing this, Bayer and Ke (2018) demonstrate that the persistence of asymmetric price adjustments can occur across various market structures, indicating that such phenomena can manifest independently of traditional factors like search costs or private information. This broader perspective underscores the complexity of pricing dynamics and the multiple influences that drive how prices adjust in response to changes in the market environment.

not been able to use volume-adjusted prices in their analyses of pass-through asymmetry because they require detailed data on quantities that are seldom available. Hence, recent and abundant empirical literature has used (average) pump prices or recommended (quoted) prices to show that asymmetric price adjustments exist. A company should be more concerned with obtaining "profitable" asymmetry at stations with higher sales than at stations with lower sales. The volume-adjusted prices will account for this. Hence, to the extent asymmetry is present, we expect to find clearer pass-through asymmetry by applying volume-adjusted prices.

An observation from the "rocket and feather" literature is that lack of competition will allow for short-run asymmetry in pass-through rates. However, the literature is in agreement regarding long-run pass-through, where some authors even impose this in their models (see, e.g., Lewis, 2004; Apergis and Vouzavalis, 2018; Byrne, 2019). To the extent that the degree of competition is linked to short- and long-run asymmetry, we anticipate that the longer the retailers can impose asymmetry from cost changes in the wholesale prices, the higher is their market power. This is in line with Byrne (2019) who posits that rural stations exposed to lower competition exhibit longer asymmetric cost pass-through than stations in cities exposed to more competition from neighboring gasoline stations.

Likewise, differences in competition due to station heterogeneity have been shown to create differences in prices and market power. For instance, Eckert and West (2005) find evidence that station characteristics affect sellers' price setting, and suggest the presence of imperfect competition. Haucap et al. (2017) conclude that prices are positively related to station service levels, and Shepard (1991) finds that stations charge a full-service markup. This suggests the presence of a more persistent short-run pricing asymmetry for manned service stations.

Building on this understanding, our dataset provides a granular look at the Swedish retail gasoline market in 2012.[2] We use daily observations on transaction prices and quantities for 147 gasoline stations. The Swedish market, like many national gasoline markets,

[2] The landscape of pricing strategies has significantly evolved, for instance, Assad et al. (2024) highlights the impact of algorithmic pricing in Germany post-2017.However, our study of the Swedish retail gasoline market in 2012 occurs in a context where such algorithmic pricing mechanisms were not yet prevalent.

is notably concentrated. During our study period, four major companies—Statoil Fuel & Retail AB, St1 Energy AB, OK-Q8, and Preem AB—dominated the market, together holding 99% of the market share. Specifically, Statoil Fuel & Retail AB led with a 34.9% share in gasoline volume, followed by OK-Q8 with 27.9%, St1 Energy AB with 22.6%, and Preem AB with 14.2% (SPBI, 2013).

We apply a non-linear autoregressive distributed lag (NARDL) model developed by Shin et al. (2014) to estimate these dynamic effects. This methodology is a one-step estimation model and can test the presence of cointegration between variables through a bounds-testing process irrespective of whether these variables are I(0) or I(1). Moreover, the asymmetric dynamic multiplier plots obtained from the model would allow us to observe the long- and short-run responses of the gasoline prices to positive and negative oil changes.[3]

We find significant short-run price asymmetry in the Swedish market, both using the average pump prices and the volume-adjusted prices. Moreover, both prices demonstrated a tendency to rise more swiftly in reaction to increases in input costs than they did to decrease following reductions in these costs. However, the adjustment back to equilibrium, in response to this price asymmetry, occurs at a slower pace in volume-adjusted prices compared to average pump prices. This pattern suggests a strategic focus by companies on larger gasoline stations, where the gains from pricing asymmetry are potentially greater compared to smaller stations. This hypothesis is further supported by our analysis of the top and bottom 10-percentiles of stations in terms of daily sales volumes. Our findings indicate that stations with higher sales volumes exhibit a slower adjustment to these pricing asymmetries, with the duration of short-term pass-through asymmetry extending longer than that observed in the lower 10-percentile of stations by volume. This introduces a novel aspect to the literature on asymmetric price responses: volume-weighted prices indicate a more prolonged short-term asymmetry compared to average prices, suggesting that previous studies, which primarily focused on average prices,

[3]We initially commenced our study by utilizing the unrestricted NARDL model, which is adept at identifying asymmetries over both long and short durations. This analysis, detailed in the Appendix, revealed a notable short-run asymmetry at all levels of our study, but no long-run asymmetry. Consequently, we shifted our focus to the restricted NARDL model, and focus on the short-run asymmetries.

may have underestimated the extent of asymmetry effects. Our research highlights the importance of considering volume-weighted pricing in understanding the full scope of price asymmetry in the market.

In the subsequent sections, we delve into the investigation of asymmetric price pass-through in relation to Rotterdam spot prices, focusing on volume-adjusted prices. This exploration differentiates between full-service and self-service stations, stations that are more than 3 km away from their nearest competitor versus those with competitors within a 3 km radius, and stations with the lowest and highest daily sales volumes. Our results reveal a pronounced pricing asymmetry in markets with fewer local competitors. This finding aligns with the results of Byrne's 2019 study conducted in Ontario, Canada, where areas with limited local competition, particularly rural regions, displayed increased pricing asymmetry. Specifically, we observe that stations with fewer local competitors, gauged by the distance to the nearest competing station, tend to exhibit a more persistent short-run asymmetry.[4] We also find notable variation in pricing asymmetry based on service levels. Specifically, self-service stations exhibit less pronounced pricing asymmetry, both in terms of the timing and magnitude of price adjustments, compared to full-service gasoline stations.[5]

Finally, we also perform "back of the envelope" calculations to show the effects of the asymmetric pricing behavior. Our findings reveal a substantial overcharge in the gasoline market: under the average price model, consumers are estimated to have been overcharged by approximately 1.1 billion SEK. This figure increases by an additional 49 million SEK when considering the effect of an extra day and incorporating volume-adjusted prices into the analysis, totalling to increasing the prices by roughly three percent. This also implies that models using average prices may underestimate the total overcharge due to pricing asymmetry by about four percent. However, focusing solely on the margin,

[4]This phenomenon is in line with the results from the works of Verlinda (2008), Deltas (2008), and Byrne (2019), all of whom highlight the tendency of more powerful market players to delay price adjustments in response to fluctuating costs.

[5]Supporting this observation, Nguyen-Ones and Steen (2021) conducted an analysis using a similar dataset and identified an intermediate level of market power in the Swedish market. They found a significant difference in markups between self-service and full-service stations.Their findings, particularly highlighted in model (4) of their Table 6 on page 22, implies 29% lower markup at self-service stations compared to their full-service counterparts.

this overcharge represents more than a tenfold effect on the daily average margin in the gasoline market.[6] The total gross margin amounted to approximately 3 billion SEK in 2012. Consequently, the three percent increase in total gasoline expenditure, equating to around 1.2 billion SEK, accounts for nearly 40% of the total gross margin. This substantial portion underscores that asymmetric pricing is a major strategy for oil companies to boost their profits.

The remainder of this paper is structured as follows: Section 2 provides a comprehensive review of the existing literature, Section 3 describes our dataset and the Swedish retail gasoline market, Section 4 outlines the econometric approach, and Section 5 presents the results and discusses potential policy implications. Finally, Section 6 concludes the paper, summarizing the key insights and contributions of our research.

2 Price dynamics and cost pass-through in gasoline markets

2.1 The empirical literature

This section briefly summarizes some of the research on price dynamics and cost pass-through in the gasoline market. The studies considered typically used international wholesale gasoline spot prices and average consumer level pump prices for gasoline. Most of the studies confirm that the gasoline price dynamics resemble the "rockets and feathers" phenomenon. This phenomenon applies across countries, data periods, and data-use frequency. Some studies use other dynamic modeling approaches but eventually arrive at the same conclusions.

The vast majority of studies use error correction models (ECM) to identify possible asymmetries in short-run consumer price responses due to changes in wholesale prices (for a detailed survey on ECM as an econometric specification in gasoline literature, see Grasso and Manera, 2007). The phenomenon asymmetry in the price responses to cost

[6] This is due to the high exogenous taxes and the Rotterdam wholesale price representing on average 93% of the retail price.

changes has been consistently observed in various studies. Notably, Borenstein et al. (1997) and Borenstein and Shepard (1993) in their seminal works provide evidence of asymmetric price adjustments. Borenstein and Shepard (1993) found empirical support for their model of asymmetric price responses and implicit cooperation, and therefore argue that collusion drives "rockets and feathers." Further building on their investigation, Borenstein et al. (1997) analyzed semi-monthly index prices from regional stations in the US spanning from 1986 to 1992. They again found that prices increase faster with an increase in spot prices than the rate at which they decrease with reductions in spot prices. Building on these foundational models, Loy et al. (2016) and Bulutay et al. (2021) explore how deeper structural elements, such as operational costs and market structures, also contribute significantly to asymmetric pricing behaviors. Their findings indicate that asymmetries can manifest independently of the classic factors like search costs, suggesting a layered complexity in market dynamics.

Further enriching our understanding, Levin et al. (2022) provide a contemporary perspective by linking consumer psychology to pricing reactions. They show how gasoline demand elasticity is significantly affected by reference prices, highlighting why consumers might react more sharply to price increases beyond a historical average, thus contributing to the persistence of 'rockets and feathers' dynamics.

Asplund et al. (2000) investigated the Swedish market, where they analyzed indicative daily pump prices from Shell for the period 1980–1996. Applying an error correction model showed that there is only a gradual adjustment of consumer prices to the cost of gasoline in the short run but a one-to-one relationship in the long run. They also found asymmetry in price responses. The pump prices obtained an immediate significant price change of 0.70 SEK/liter after an increase in the Rotterdam spot price of one SEK. On the contrary, the corresponding reduction in the Rotterdam spot price led to a price change of only 0.35 SEK/liter.[7]

Johnson (2002) analyzed 15 gasoline markets in his study (1996–1998, daily index

[7]Asplund et al. (2000) include both spot prices and tax in their error correction model. They can thus also comment on how the guide price changes as a result of changes in taxes and fees. They find that tax change has an immediate effect on the retail price of gasoline, in the sense that the short-term effect of tax on the recommended price is very close to one both in the short-run and in the long-run.

prices in the US). He calculated average development in the price after a positive and negative shock in the spot price and differences between spot and consumer price. Based on his data, Johnson (2002) found that negative shocks are absorbed far slower in consumer price than positive shocks. Verlinda (2008) analyzed the US market for the period 2000 to 2003. Utilizing weekly station data and in line with other studies, he found asymmetric price responses. Lewis (2011) analyzed the US market but used somewhat longer weekly data (2000–2007) and observed both the station and area levels, also finding asymmetry.

Balmaceda and Soruco (2008) analyzed the petrol market in Chile based on the weekly data of 44 petrol stations in Santiago from 2001 to 2004. They also used an error correction model and demonstrated asymmetry in pricing. Station prices reacted more quickly to an increase in the spot price (6.2% increase over increase in purchase price) than to a decrease in the spot price (the reduction in the station price is 10.2% lower than the reduction in the cost of gasoline). Faber (2015) analyzed Dutch daily station data for the period 2003–2005. He found price symmetry, but only for 38% of the stations in the dataset.

A more recent study, Apergis and Vouzavalis (2018) apply the NARDL model as we use here. They address pricing asymmetry utilizing weekly data that span from January 2009 to July 2016 in the US, UK, Spain, Italy, and Greece. They find mixed results across countries for short- and long-run asymmetries. Asymmetric price responses due to wholesale price changes are found only in Italy and Spain. Byrne (2019) analyzes data from Ontario and estimates gasoline pricing asymmetry across different regional areas. Using weekly data, he finds symmetric pass-through of positive and negative cost shocks in urban markets. However, in rural markets, a short-run asymmetry is observed. 45% of positive shocks and 21% of negative shocks are passed through to prices at the same week, and the rest is corrected fully in the upcoming week. Challenging the conventional paradigms, Bayer and Ke (2018) demonstrate that asymmetric price adjustments are not confined to markets with explicit frictions. Their analysis shows that these phenomena can occur across a variety of market structures, suggesting that intrinsic market behaviors may drive these dynamics as much as external market conditions.

Some studies do not find such asymmetries, but they are in the minority. For example, Bachmeier and Griffin (2003) found, in the US gasoline market, that the results depend on the estimation method and data frequency. In particular, they found that when they use daily data, there is less asymmetry and they used standard two-step estimation of error correction models (see Engle and Granger, 1987). They also found less asymmetry than Borenstein et al. (1997) when using the same estimation method as Borenstein et al. (1997). Unlike Borenstein et al. (1997), Bachmeier and Griffin (2003) had access to a higher-frequency dataset.

The literature unambiguously concludes that all changes in spot prices are absorbed in their entirety in the long-run, which means that one can expect full pass-on (cost transfer) at consumer prices in the long-run. Some studies have even imposed this on their models (see, e.g., Lewis, 2011). The supportive argument is that one should theoretically expect full pass-through, and to the extent that this is not observed, there are biases in the models (Lewis, 2004; Verlinda, 2008).

Although most studies have used error correction models, several studies have looked at price dynamics for gasoline prices where other methods were used. Here too, one typically finds asymmetry in price responses when wholesale costs are measured through spot price change. Noel (2007) used a Markov (switching) model to analyze price cycles across 19 Canadian cities during the period 1989–1999, a phenomenon that has also been observed in many markets, including, for example, the Norwegian market (See Foros and Steen, 2013). Noel (2007) found that the price cycles are less asymmetrical, shorter, and larger (higher variance/amplitude) when more competition is measured as a greater presence of independent gasoline stations in the market. He attributes this to the literature and models around asymmetric price dynamics.

Later, Lewis and Noel (2011) used a similar Markov model and show that passing on costs is even faster in markets with clear Edgeworth cycles. They argue here that cycles are more important for passing on costs than market characteristics. Eckert (2003) found less evidence of asymmetry when he used error correction models to show that cycle movements dominate the asymmetric price response in the Canadian gasoline market from 1989 to 1994. Douglas and Herrera (2010) have a slightly different approach to price dynamics and pricing systems where they analyzed the daily price patterns for nine petrol stations in Philadelphia, Pennsylvania, USA. They extended an earlier study of the same market by Davis and Hamilton (2003), who estimated hazard models that predicted price changes and analyzed pricing systems for the same market. However, Douglas and Herrera (2010) had instead estimated an autoregressive probability model. The model predicts the probability of price change at a time t due to the historical distribution of price changes, including previous price changes and historical distance between the cost of goods and prices. They typically also found asymmetric price responses.

2.2 Sources of asymmetric cost pass-through in gasoline

In gasoline literature, asymmetric cost pass-through has two strands of explanations: search costs and collusive behavior. Consumers' search intensity in gasoline markets is considered to reflect competition in the market. More specifically, this search intensity explains firms' asymmetric price responses to oil price fluctuations (Tappata, 2009). Tappata (2009) argues that when the input prices for gasoline are high in the current period, consumers search very little because they do not expect a significant variation in prices. However, when the input prices are low in the current period, consumers expect that prices will exhibit higher variations in the next period, therefore they increase their search. Moreover, Tappata (2009) develops an oligopolistic model with competitive firms. Consumers have partial information and they endogenously choose to search less when gasoline input prices are anticipated to be high in the market setting. The "rocket and feathers" pattern has also been confirmed empirically by Lewis (2011) and Yang and Ye (2008). Lewis (2011) examines retail price dispersion using station-level data from Southern California, USA. He relates the price dispersion to models of consumer search. Similarly, Yang and Ye (2008) provide a search-based theoretical and empirical analysis of asymmetrical pricing.

Douglas and Herrera (2010) test whether the pricing dynamics can be attributed to uninformed customers, uninformed manufacturers, or strategic pricing, and they concluded that the results do not support that the price patterns are driven by menu costs or information access/collection (search costs). Instead, they believe in finding support for strategic pricing to explain the price dynamics for petrol stations. Therefore, as per their observations, larger price increases due to cost shocks are passed on to customers immediately, while negative cost price shocks take longer to be passed on to customers.

Verlinda (2008) expands the model of Borenstein et al. (1997) by introducing differentiation, where the differentiation takes the form of geographical distances. Increased geographical distances can be seen as increased product differentiation, which reduces competition as the players have more coordination options than just price. This opportunity, in turn, enables them to set prices asymmetrically. Consistent with these findings, Byrne (2019) and Deltas (2008) also empirically documented that increased local market power allows for an increased degree of asymmetric pricing.

Indeed, several authors argue that collusion may be behind the asymmetry in fuel markets' price responses. Clarke and Houde (2013) analyzed a price cartel from 2005 to 2006 that was revealed by the competition authorities in Canada; this cartel collaborated by using a typical asymmetric pricing pattern that followed the dynamics of wholesale price changes. Rather than collaborating around a fixed margin, they collaborated through an asymmetric pricing pattern where they typically increased prices more after an increase in wholesale price. At the same time, when there was a decline in wholesale price, there was a less decrease in prices, thereby increasing their profits. At the same time, they collaborated to delay price increases to increase market shares from competitors outside the cartel. Borenstein et al. (1997) argue more in the direction of implicit collusion, stating that the collaboration on pricing collapses faster when the product cost increases since competitors' potential penalties are lower. Balmaceda and Soruco (2008) report that the results of asymmetric pricing responses due to the markets' transparency and unique design in Chile cannot be explained based on search costs but rather on implicit cooperation. Similarly, Bulutay et al. (2021) explore the persistence of asymmetrical price adjustments in markets without traditional market frictions such as search costs, suggesting that deeper, perhaps strategic elements like tacit collusion may also play a significant role.

In sum, we can say that the literature has not unambiguously clarified which factors influence and drive such asymmetric price responses (Lewis and Noel, 2011). Although previous studies have investigated pricing asymmetry, they focused only on a country or city-level analysis. In what is the closest article to ours, Byrne (2019) addresses pricing asymmetry in different regional markets: urban and rural. In this context, rural markets are found to exhibit more asymmetry in gasoline price responses due to oil price fluctuations. The gasoline price associated with a specific date and market is calculated as the average price across all stations on a given date and at a given market. However, for the station-level analysis, the average price of a station during a week is used.

While our approach has several similarities to the literature, some important features differ. First, due to a rich dataset, we incorporated both daily station prices and volume-adjusted prices. We can analyze both these and compare the results to a corresponding analysis of average prices. To the extent that firms are engaging in pass-through asymmetry, we anticipate the effect to be more pronounced for volume-weighted prices. To the extent that firms are asymmetrically passing through costs to consumer prices, they should be more focused on obtaining this at the stations where and on days when sales are at their highest.

Our analysis speaks to several of the previous studies on heterogenity in the price responses. We investigate pricing asymmetry across different station characteristics, mirroring heterogenous competition levels. In particular, we differentiate between service and self-service gasoline stations across regions and stations with heterogeneous spatial competition.

3 A first look at the market: Data description

The dataset consists of daily data on Rotterdam spot prices, average transaction prices, and gasoline volumes sold for a panel of 147 branded stations across 6 different geographical areas in Sweden. This dataset was obtained from the Swedish Competition

Authority (SCA). The period covered is from January 1, 2012 to December 31, 2012. Four major companies dominated the Swedish gasoline market during our sample period: Statoil Fuel & Retail AB (operating the brands Statoil and Jet), Preem AB, St1 Energy AB (operating the brands St1 and Shell), and OK-Q8 AB. In 2012, they controlled more than 99% of the market: Statoil Fuel & Retail AB holding 34.86% of volumes, OK-Q8 holding 27.93%, ST1 Energy AB holding 22.62%, and Preem AB holding 14.22%, leaving only 0.36% of the sales to others.[8] Of these brands, Jet and St1 only operated self-serviced stations. While Statoil, Preem, OK-Q8, and Shell only represented full-service stations. We require that a station must have demand and price observations available for each day during 2012 to be considered. Forty three stations of Preem did not meet this requirement. Therefore, Preem has been removed from the analysis.[9]

In addition, we have information on the distance of each station to their nearest competitor. For the analysis that follows, an essential variable is the daily Rotterdam spot prices. Throughout this paper, "input prices" will refer to these Rotterdam spot prices unless otherwise indicated. The volume-adjusted prices are computed at different levels, the national, for service vs self-service station, for groups of stations with different numbers of competitors close to them. This price is a function of three components:

1. The station's daily volume of gasoline sold.
2. The station's daily average pump price.
3. Total daily gasoline sold nationally, regionally, across brands, and stations.

For example, the daily volume-adjusted price in Sweden is computed as the sum of revenue of all stations in our sample divided by the corresponding total daily gasoline sales. Table 1 lists the descriptive statistics of the variables used in our analysis.

The data was collected to be used in a study of the Swedish gasoline market. The stations were picked by the SCA and the oil companies, to be representative of the six

[8] https://www.konkurrensverket.se/globalassets/publikationer/uppdragsforskning/forskrap2013-5.pdf

[9] Our modeling approach does not allow for missing price spells. Removing Preem does not affect the representativeness across regions as all stations were chosen to provide a representative picture across companies and regions.

different regions in Sweden (Foros and Steen, 2013). The regions are “larger cities” (Stockholm, Gothenburg and Malmö—the three largest cities in Sweden), “smaller cities” (cities with a population between approximately 30 000 and 80 000),“the E6 highway”[10] and “rural areas” (population below 10 000). In the sample, national pump prices averaged

Table 1: Summary statistics (daily) at the national level.

Variables	Mean	Std. Dev	Min	Max
Av. Pump Prices (SEK/Liter)	14.760	.440	13.908	15.730
Vol-adj. Prices (SEK/Liter Sold)	14.727	.435	13.870	15.709
Volume (liter)	818 460	87 492	463 580	1 210 900
Input Prices (SEK/Liter)	5.390	.359	4.800	6.151
Service (SEK/Liter Sold)	14.842	.439	14.011	15.819
Self-Service (SEK/Liter Sold)	14.609	.432	17.701	15.579
≤ 3 km (SEK/Liter Sold)	14.692	.433	13.806	15.672
>3 km (SEK/Liter Sold)	14.748	.438	13.900	15.731
Lowest 10% Volume Price (SEK/Liter Sold))	14.789	.448	13.971	15.763
Highest 10% Volume Price (SEK/Liter Sold))	14.586	.423	13.679	15.552

Note: The sample period: January 1, 2012, to December 31, 2012. N=366.

14.760 SEK/liter (including taxes), volume-adjusted prices averaged 14.727 SEK/liter sold, while input prices were approximately 9.3 SEK/liter lower.[11] On average, prices in the service market differ from the automated market prices by approximately 0.2 SEK/liter sold. A smaller difference in prices is observed between stations with the distance to their nearest competitor within 3 km and more than 3 km and also between bottom and top 10-percentiles in terms of daily volume . The daily average pump prices, volume-adjusted prices, and input prices from January 1, 2012 to December 31, 2012 have been plotted in Figure 1. As can be seen, nationally, the daily fluctuations in the pump prices and volume-adjusted prices closely follow the cost movements. The vertical axes to the left contain the gasoline price values, while the vertical axes to the right contain the input price values. The volume-adjusted prices seem to be lower than the observed pump prices, but both exhibit a similar seasonal pattern as the input prices. Following the time series from left to right, we can see that the vertical values’ length is relatively compressed when prices rise and somewhat stretched when the prices fall,

[10]The E6 highway is a part of the international E-road network. It is defined as a separate geographical region as customers who frequently purchase from stations along the highway mostly are highway commuters.

[11]In 2012 the yearly SEK/EURO exchange rate was 8.698, e.g., implying a pump price average of 1.697 EURO.

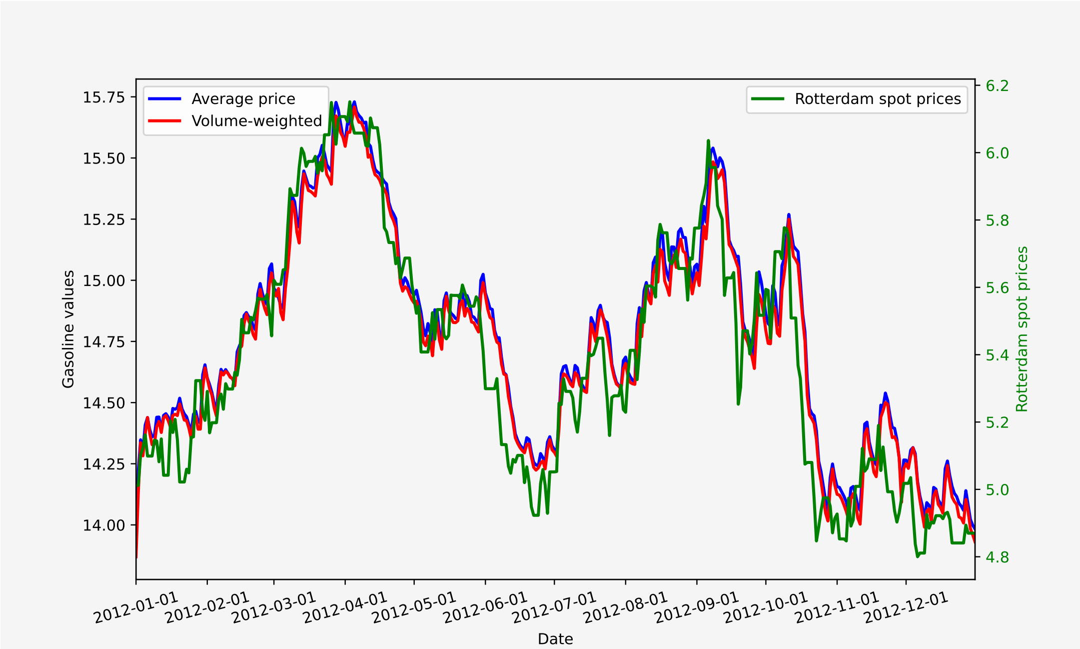

Figure 1: Price patterns in Sweden during 2012

implying rigidity in prices. Nevertheless, the compression is less pronounced than the stretching, indicating an asymmetric behavior.

4 Empirical strategy and methods used

In contexts where variables are non-stationary, the Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models serve as highly effective tools. They are particularly advantageous as they can handle variables that are integrated of order zero (I(0)) and of order one (I(1)). An alternative approach, often used in Error Correction Modeling (ECM), involves examining the first differences of the variables. This method transforms non-stationary I(1) variables into stationary ones, allowing for the application of standard statistical tests and asymptotic properties. However, a significant drawback of this approach is the loss of long-run information contained in the level form of the variables, thereby restricting analysis to only short-run asymmetry.

Our study aims to evaluate both the short-run and long-run effects of input prices on gasoline prices, which justifies our choice of the NARDL model. This model, an extension of the ARDL framework originally proposed by Pesaran and Shin (1998) and further developed by Pesaran et al. (2001), offers the flexibility to incorporate a mix of

I(0) and I(1) regressors. Additionally, it allows for the specification of long-run terms. A key feature distinguishing the NARDL model from the traditional ARDL model is its ability to account for asymmetries in the dependent variable's response to increases (+) and decreases (-) in the independent variable. In the NARDL framework, input prices (denoted as IP) are decomposed into their positive and negative partial sums as follows:

$$IP_t^+ = \sum_{j=1}^{t} \Delta IP_j^+ = \sum_{j=1}^{t} max(\Delta IP_j, 0)$$

and decreases in (IP_t)

$$IP_t^- = \sum_{j=1}^{t} \Delta IP_j^- = \sum_{j=1}^{t} min(\Delta IP_j, 0)$$

where the cumulative sum of positive changes in IP is represented as IP_j^+, while the cumulative sum of negative changes is denoted as IP_j^-. The partial sum processes of positive IP_t^+ and negative IP_t^- changes in IP_t are then included as distinct regressors within the model. This decomposition enables the model to separately capture the effects of positive and negative changes in input prices, thus providing a nuanced understanding of the asymmetric impacts on gasoline prices.

The non-linear model for our study takes the following form:

$$\Delta VP_t = \beta_0 + \sum_{i=1}^{p-1} \gamma_i \Delta VP_t - i + \underbrace{\sum_{i=0}^{q} \delta_i^+ \Delta IP_{t-i}^+ \sum_{i=0}^{q} \delta_i^- \Delta IP_{t-i}^-}_{Short-run} + \theta VP_{t-1} + \underbrace{\varphi^+ IP_{t-1}^+ + \varphi^- IP_{t-1}^-}_{Long-run} + v_t \quad (1)$$

$$\Delta OP_t = \beta_0 + \sum_{i=1}^{p-1} \gamma_i \Delta OP_t - i + \underbrace{\sum_{i=0}^{q} \delta_i^+ \Delta IP_{t-i}^+ \sum_{i=0}^{q} \delta_i^- \Delta IP_{t-i}^-}_{Short-run} + \theta OP_{t-1} + \underbrace{\varphi^+ IP_{t-1}^+ + \varphi^- IP_{t-1}^-}_{Long-run} + v_t \quad (2)$$

where, VP_t represents the daily volume-adjusted gasoline price, and OP_t signifies the daily observed pump price. IP_t is the daily Rotterdam spot price,a key independent variable in our analysis. Additionally, v_t denotes an independently and identically distributed (i.i.d.) process, characterized by a zero mean and constant variance, which captures the random error component in the model. The symbol delta (Δ) is used to indicate first differences, a common transformation in time series analysis to achieve stationarity in non-stationary data. This transformation is crucial for analyzing variables that exhibit trends or seasonal patterns over time.

Furthermore, p, and q represent the lag orders for the dependent and independent variables, respectively. To determine the most appropriate lag lengths, we employ the Akaike Information Criterion (AIC), a widely used statistical method that balances model fit and complexity. We then tested for a cointegrating relationship between the variables VP_t (or OP_t) IP_t^+, and IP_t^- using the following NARDL F-Bounds-test (Banerjee et al., 1998; Pesaran et al., 2001) for an asymmetric long-run cointegration:

$$\text{F-test:} \qquad H_0 : \theta = \varphi^+ = \varphi^- = 0, \text{ and } H_A : \theta \neq \varphi^+ \neq \varphi^- \neq 0$$

In our results, the test for identifying cointegration in the presence of long-run asymmetry is referred to as F_{PSS}, named after the Pesaran, Shin, and Smith test. The critical valuesfor this test are determined by the number of regressors in the model, denoted as k. In our case, where the model includes VP_t (or OP_t), IP_t^+, and IP_t^- , the value of k typically ranges from 1 to 2. If we find sufficient evidence to reject the null hypothesis H_0 (which posits no cointegration), we can conclude that the variables exhibit a cointegrated relationship, indicating that they move together in the long run. This conclusion provides crucial insights into the dynamic interplay between gasoline prices and input prices, especially in how they adjust and align over time in response to varying market conditions.

Building on the framework of Shin et al. (2014), we have computed the long-run asymmetric coefficients for the NARDL model to assess the long-term impact of IP_t on VP_t (or OP_t). These coefficients capture the long-run asymmetry in the relationship between input prices and gasoline prices. Mathematically, it's expressed as: $L_{IP}^+ = \frac{-\varphi^+}{\theta}$; and, likewise, $L_{IP}^- = \frac{-\varphi^-}{\theta}$. These coefficients capture the long-run asymmetry in the relationship between input prices and gasoline prices. Next, if a long-run relationship exists (bounds test), we proceed to test using a Wald test whether the difference in the long-run asymmetric coefficients is statistically significant:

$$H_0 : \frac{-\varphi^+}{\theta} = \frac{-\varphi^-}{\theta} \qquad\qquad H_A : \frac{-\varphi^+}{\theta} \neq \frac{-\varphi^-}{\theta}$$

If the null hypothesis H_0 is rejected, it indicates the presence of long-run asymmetry. This implies that the extent of change in VP_t (or OP_t) when IP_t is not equal when IP_t experiences an increase versus when it decreases.

Following the analysis of long-run asymmetry, the next step involves testing hypotheses related to short-run asymmetry. For this purpose, we will once again employ the Wald test. This test will help determine if the immediate, or short-run, responses to increases and decreases in the influencing factor (typically represented as IP_t in this context) differ significantly, thus indicating short-run asymmetry in the model.

$$H_0 : \sum_{i=0}^{q} \delta_i^+ = \sum_{i=0}^{q} \delta_i^- \qquad\qquad H_A : \sum_{i=0}^{q} \delta_i^+ \neq \sum_{i=0}^{q} \delta_i^-$$

Similarly, if the Wald test for the equality of the sum of (+) and (-) lags of IP is rejected, we conclude that the impact of IP_t on VP_t (OP_t) is asymmetric.

If neither long-run nor short-run asymmetries are present, model (1) simplifies to a traditional Error Correction Model (ECM). However, if only short-run or long-run asymmetry is observed, model (1) evolves into specific variations of the Nonlinear Autoregressive Distributed Lag (NARDL) model. Specifically, it becomes the NARDL model with short-run asymmetry (as shown in model 3) or the NARDL model with long-run asymmetry (as detailed in model 4)

$$\Delta VP_t = \beta_0 + \sum_{i=1}^{p-1} \gamma_i \Delta VP_t - i + \sum_{i=0}^{q} \delta_i^+ \Delta IP_{t-i}^+ \sum_{i=0}^{q} \delta_i^- \Delta IP_{t-i}^- + \theta VP_{t-1} + \varphi IP_{t-1} + v_t \tag{3}$$

$$\Delta VP_t = \beta_0 + \sum_{i=1}^{p-1} \gamma_i \Delta VP_t - i + \sum_{i=0}^{q} \delta_i \Delta IP_{t-i} + \theta VP_{t-1} + \varphi^+ IP_{t-1}^+ + \varphi^- IP_{t-1}^- + v_t \tag{4}$$

Similarly, we have developed both models for the changes in ΔOP_t. Concluding this phase, we proceeded to calculate the asymmetric dynamic multipliers. This was done to observe how VP_t (or OP_t) adapt to their new long-run equilibrium following either a positive (+) or negative (-) shift in IP_t.

Next, the asymmetric dynamic multipliers for IP_t^+, and IP_t^- on VP_t (or OP_t) are evaluated as:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial VP_{t+j}}{\partial IP_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial VP_{t+j}}{\partial IP_t^-} \text{ for } h = 0, 1, 2, 3, ...,$$

When considering the horizon h extending to infinity ($h \to \infty$), the dynamic multipliers for positive and negative changes converge to specific values. The multiplier for a positive change in the input price m_h^+ converges to $\frac{-\varphi^+}{\theta}$, and similarly, the multiplier for a negative change m_h^- converges to $\frac{-\varphi^-}{\theta}$. The multipliers m_h^+ and m_h^- reflect the magnitude of increase or decrease in gasoline prices (VP_t, OP_t) due to positive and negative changes in input prices (IP_t), respectively.

Beyond the magnitude, these multipliers also shed light on the duration of the temporary disequilibria following a change in input prices. They indicate how long it takes for gasoline prices to adjust and return to a state of equilibrium after experiencing a shock (either positive or negative) in input prices.

5 Empirical results

Models (1), (2), (3), and (4) were used first for national-level data. The primary objective of this phase was to investigate whether the relationship between daily input prices for gasoline and volume-adjusted retail prices exhibits any differences from the commonly studied relationship between input prices and daily average pump prices, as typically estimated in the empirical gasoline literature. This approach allows us to delve deeper into the nuances of gasoline pricing dynamics. Focusing on volume-adjusted prices gives us an insight into how larger or more frequented gasoline stations might react differently to changes in input prices compared to their smaller counterparts. This could reveal pricing strategies or market behaviors that are not apparent when only average prices are considered.

5.1 Exploring Price Asymmetry in Sweden: A Comparative Analysis of National Average Prices and Volume-Adjusted Prices

We begin by examining the stationarity properties of our price variables using the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979). This test revealed a unit root in all variables at the 1% significance level, indicating they are non-stationary. However, after applying first differences, the variables achieved stationarity. The results of the ADF tests are detailed in Appendix Table 1A. Following the methodology outlined earlier, we initiated our analysis with a general NARDL model specification and, after conducting relevant tests, finalized a single, optimized model.

As the unrestricted NARDL model analysis (results shown in Table 2A of the appendix) reveals no evidence of long-run asymmetry for either volume-adjusted prices or average pump prices, we proceed with a restricted NARDL model that focuses exclusively on short-run asymmetry. The results of this refined analysis are presented in Table 2, offering a national-level perspective.

In this table, the outcomes related to volume-adjusted prices are detailed in Column (2), whereas the findings associated with average pump prices are outlined in Column (4). This arrangement allows for an effective and clear comparison between the two pricing models.

Table 2: **Estimation results of restricted NARDL for the volume-weighted and average prices**

Volume-weighted prices		**Average prices**	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	2.656 ***(0.228)	Constant	3.009 ***(0.238)
VP_{t-1}	-0.325 ***(0.026)	OP_{t-1}	-0.369 ***(0.027)
IP_{t-1}	0.394 ***(0.032)	IP_{t-1}	0.452 ***(0.034)
ΔVP_{t-1}	0.301 ***(0.042)	ΔOP_{t-1}	0.250 ***(0.041)
ΔVP_{t-2}	-0.184 ***(0.040)	ΔOP_{t-2}	-0.151 ***(0.040)
ΔIP_t^+	-0.164 **(0.078)	ΔIP_t^+	-0.203 **(0.080)
ΔIP_{t-1}^+	0.046 (0.074)	ΔIP_{t-1}^+	0.056 (0.076)
ΔIP_{t-2}^+	-0.160 **(0.073)	ΔIP_{t-2}^+	-0.276 ***(0.075)
ΔIP_t^-	-0.544**(0.076)	ΔIP_t^-	-0.679 ***(0.079)
ΔIP_{t-1}^-	-0.211 ***(0.081)	ΔIP_{t-1}^-	-0.247 ***(0.086)
LR_{IP}	1.213*** SEK	LR_{IP}	1.224*** SEK
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.325 ***(0.025)	**Adj. speed**	-0.370 ***(0.027)
Adj. R-squared	0.986	**Adj. R-squared**	0.985
AIC	-3.111	*AIC*	-3.046
F_{PSS}	52.714 ***	F_{PSS}	60.591 ***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

The LR_{IP} results in Table 2 indicate a long-run relationship between input prices and both volume-adjusted prices and pump prices. To further explore this relationship, we proceeded to test for cointegration among our variables using a bounds-testing approach.

The cointegration test, denoted as F_{PSS}, yielded values of -52.714 and 60.591 for the volume-adjusted prices and pump prices, respectively. These results are particularly significant as they allow us to reject the null hypothesis of no cointegration at a 1% significance level.This rejection implies that there is a statistically significant long-run equilibrium relationship between input prices and both types of gasoline prices—volume-adjusted and pump prices. This cointegration suggests that while these prices may deviate in the short term due to various market dynamics, they tend to move together in the long run, influenced by the underlying input prices. Our analysis reveals a one-to-one long-run relationship (LR_{IP}) between volume-adjusted prices and input prices. This relationship suggests that, over the long term, a 1% increase (or decrease) in input prices leads to a 1.213% rise (or fall) in volume-adjusted prices. Similarly, for observed pump prices, the long-run coefficient(LR_{IP}) is determined to be 1.224, indicating a comparable impact.

Furthermore, the speed of adjustment, indicated by the negative sign of the coefficient, is statistically significant in both scenarios. This finding implies that both volume-adjusted and observed pump prices adjust to changes in input prices, with the adjustment for average pump prices occurring at a slightly faster rate. This difference in adjustment speeds highlights subtle variations in how these two pricing metrics respond to market changes over time.

For both cases we find short-run asymmetry. In the short run, our analysis reveals the presence of asymmetry for both volume-adjusted and observed pump prices. This asymmetrical behavior is effectively illustrated in the dynamic multiplier plot provided in Figure 2.

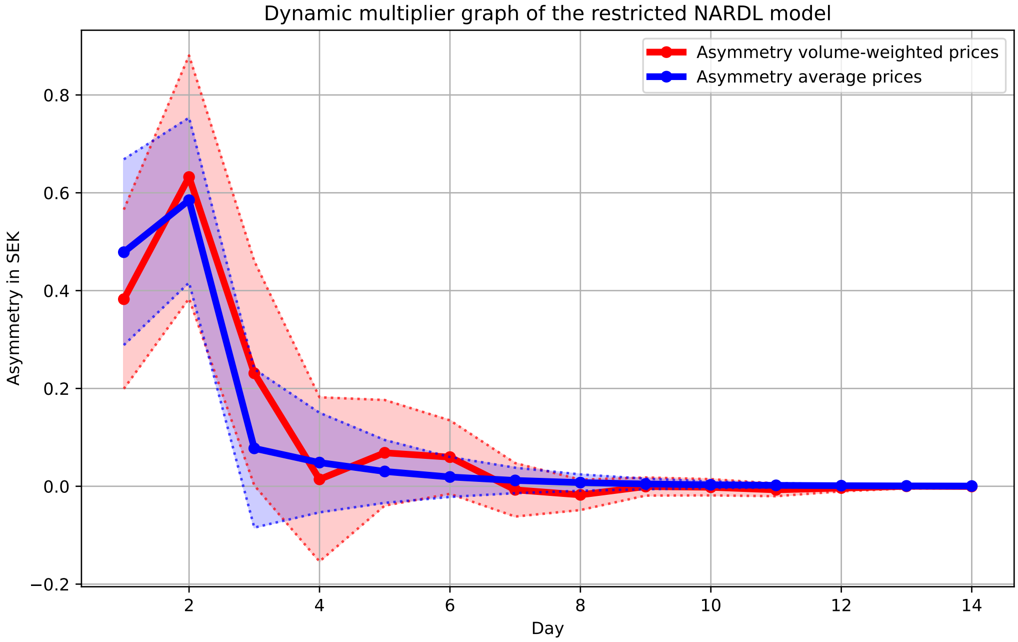

Figure 2: The asymmetry at national level

The dynamic multiplier plot, featuring solid red and blue lines for volume-adjusted and pump prices respectively, illustrates short-run asymmetry in response to changes in IP. The coloured areas around these lines that indicate the disparity between dynamic multipliers for positive and negative IP changes, show the 95% confidence interval bounds. Asymmetry is statistically significant only if the asymmetry line diverges from the zero line outside the confidence interval.

Figure 2 reveals that in the initial stages, the asymmetry line, along with its confidence interval, deviates more noticeably from the zero line than in later stages, indicating stronger short-run asymmetry initially. Over time, this asymmetry diminishes, eventually aligning with a symmetric equilibrium defined by the lower bound of the 95% confidence intervals. Notably, there is a distinct difference in the speed at which volume-adjusted and average pump prices adjust back to long-run equilibrium. Volume-adjusted prices take longer, with equilibrium reached in three days, compared to just two days for average pump prices. This observation aligns with the slower adjustment speed of volume-adjusted prices, as also reflected in the model's estimates and Table 2.

The findings indicate that Swedish firms, when implementing asymmetric cost pass-through strategies, tend to focus more on setting prices at stations or on days with higher sales volumes. This targeted approach suggests a strategic prioritization of pricing at locations or times where sales are more robust. Suggesting that conventional methods of estimating asymmetry, which often rely on average prices, tend to understate the actual degree of asymmetry present in the market. By overlooking the insight captured through volume-adjusted pricing, these traditional estimates may not fully reflect the extent to which asymmetry influences pricing decisions and behaviors in the Swedish gasoline market. In Section 5.4 of our analysis, we delve into the impact of station size on pricing dynamics. Our findings provide clear support for the hypothesis that stations within the top 10-percentile in terms of sales volume exhibit a slower adjustment in their pass-through of costs compared to stations in the bottom 10-percentile of sales volume. This evidence underscores the influence of station size on pricing strategies, with larger, higher-volume stations showing a more gradual response to changes in costs, potentially reflecting their market positioning and pricing power.

Moving forward, we will focus on using volume-adjusted prices as the dependent variable in our analysis of price asymmetry. This approach will be applied to examine the heterogeneity across different dimensions: service levels of stations, levels of spatial competition, and station size as determined by the volume of gasoline sold. This refined focus allows us to more accurately assess how these various factors influence the degree and nature of price asymmetry in the gasoline market.

5.2 Exploring Station Heterogeneity: A Comparison Between Full-Service and Self-Service Gasoline Stations

Building on previous findings, and in line with Byrne (2019), we observe a correlation between market power and more asymmetric cost pass-through. This observation is further supported by Nguyen-Ones and Steen (2021), who, using a similar dataset that also includes Preem stations, identified higher markups at service stations compared to self-service stations. This pattern aligns with findings from other studies like Eckert and West (2005), Haucap et al. (2017), and Shepard (1991).

In light of these insights, we have developed two distinct price series. The first series represents the daily volume-adjusted gasoline prices at full-service stations, and the second captures prices at automated stations. Our aim is to investigate the asymmetrical response of volume-adjusted prices to fluctuations in input prices within these two distinct types of service stations. This analysis marks a novel contribution to the field, as it is the first to separately estimate the relationship between input prices and volume-adjusted prices for full-service and automated stations.

In our analysis, as indicated in Table 3A of the Appendix, we found no evidence of long-run asymmetries. Consequently, we opted for a restricted NARDL model to focus our investigation. The results of the restricted NARDL are displayed in Table 3. Our analysis reveals an interesting pattern: the duration of asymmetric cost pass-through is correlated with the degree of market power among service stations. Specifically, we observe that manned service stations, typically associated with higher service levels, adjust their pricing asymmetries over a three-day period (Figure 3). In contrast, automated self-service stations, which generally have less market power, exhibit asymmetric cost pass-through for a shorter duration of only two days, as detailed in Figure 3. This finding aligns with several studies that link higher service levels at stations to increased prices or greater market power. For instance: Eckert and West (2005) noted that station characteristics influence pricing decisions, indicating the presence of imperfect competition in the market. Haucap et al. (2017) concluded that service levels at stations are positively correlated with their pricing. Shepard (1991) identified a trend of stations charging a markup for full-service. Nguyen-Ones and Steen (2021) specifically highlighted the higher market power of manned service stations in Sweden.

Drawing from these observations and our own results, it appears that oil companies can more effectively leverage market power at full-service stations. This is evidenced by their ability to sustain asymmetric pass-through of costs for a longer period at these stations.

Table 3: **Estimation results of restricted NARDL for the full-service and self-service stations**

Full-service group		Self-service group	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	2.754*** (0.225)	Constant	3.013*** (0.253)
VP_{t-1}	-0.335*** (0.026)	VP_{t-1}	-0.372*** (0.029)
IP_{t-1}	0.411*** (0.032)	IP^{+}_{t-1}	0.446*** (0.035)
ΔVP_{t-1}	0.323*** (0.042)	ΔVP_{t-1}	0.183*** (0.042)
ΔVP_{t-2}	-0.181*** (0.041)	ΔVP_{t-2}	-0.125*** (0.041)
ΔIP^{+}_{t}	-0.251*** (0.076)	ΔIP^{+}_{t}	-0.108 (0.090)
ΔIP^{+}_{t-1}	0.082 (0.073)	ΔIP^{+}_{t-1}	0.042 (0.086)
ΔIP^{+}_{t-2}	-0.175** (0.072)	ΔIP^{+}_{t-2}	-0.307*** (0.085)
ΔIP^{-}_{t}	-0.549** (0.074)	ΔIP^{-}_{t}	-0.702*** (0.089)
ΔIP^{-}_{t-1}	-0.263*** (0.079)	ΔIP^{-}_{t-1}	-0.249*** (0.096)
LR_{IP}	1.224 SEK	LR_{IP}	1.200 SEK
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.335*** (0.025)	**Adj. speed**	-0.372*** (0.028)
Adj. R-squared	0.987	**Adj. R-squared**	0.981
AIC	-3.158	AIC	-2.805
F_{PSS}	57.245***	F_{PSS}	42.142***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

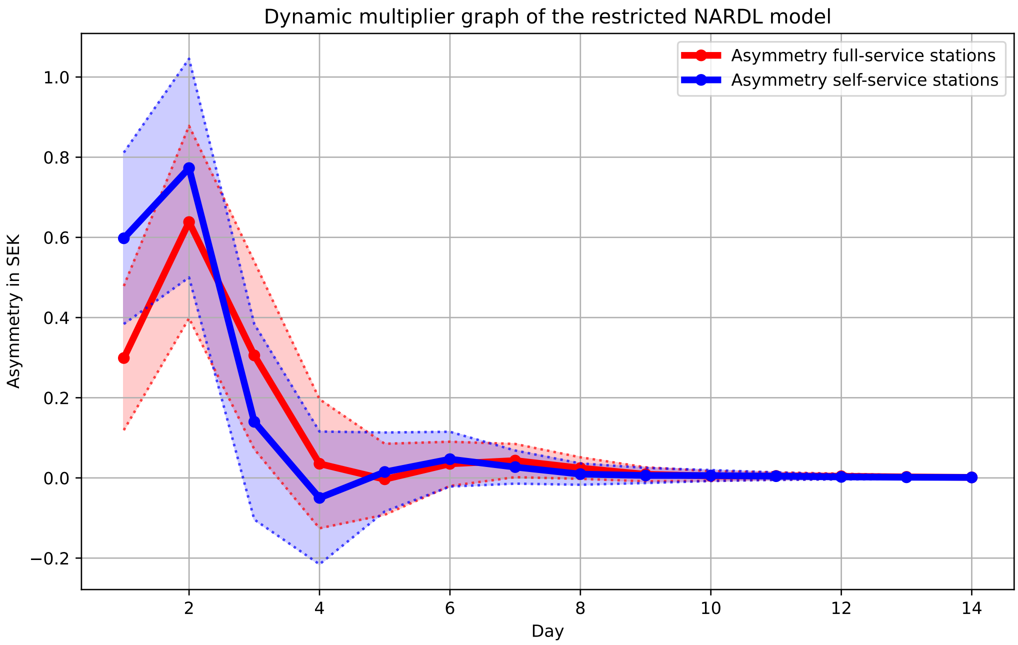

Figure 3: Asymmetry based on the level of service.

5.3 Impact of Local Competition on Pricing Dynamics: A Comparative Analysis of Stations

The extensive literature on retail gasoline markets has consistently highlighted the influence of local competition on pricing dynamics. Key studies in this area include Hastings (2004), Slade (1987), Netz and Taylor (2002), and more recently, Nguyen-Ones and Steen (2021), and Levin et al. (2022). Specifically, Nguyen-Ones and Steen's (2021) application of the Bresnahan-Lau (1982) structural model to the Swedish market reveals that location-based differentiation significantly affects market power at individual stations. They found that an increase in station density reduces each seller's markup, thereby enhancing local competition. This relationship between station density and market competition aligns with findings from Barron et al. (2004, 2008) and Clemenz and Gugler (2006). These studies collectively suggest that a greater number of retail stations, indicative of higher station density, tends to lower average gasoline prices, a sign of intensified local competition. Such insights are crucial for understanding the competitive dynamics within the gasoline retail sector.

In our examination of how the proximity to the nearest competitor influences pricing asymmetry, we specifically analyzed the impact of distance on the pricing strategies of gasoline stations. To do this, we computed the daily volume-adjusted prices for two groups of stations: one group with their closest competitor located within a 3 km radius, and another with the nearest competitor more than 3 km away.

The outcomes of our analysis are systematically detailed in two tables: Table 4A presents the results from the unrestricted NARDL model, while Table 4 showcases the findings from the restricted NARDL model. For both types of stations— those with nearby competitors and those without—it we observe that the volume-adjusted prices and input prices move together over the long-term, showing cointegration between these variables.

Table 4: Estimation results of restricted NARDL for stations with closest competitor

$\leq$ 3km group		$>$ 3km group	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	2.933*** (0.248)	Constant	2.703*** (0.229)
VP_{t-1}	-0.360*** (0.028)	VP_{t-1}	-0.332*** (0.026)
IP_{t-1}	0.435*** (0.034)	IP^{+}_{t-1}	0.405*** (0.032)
ΔVP_{t-1}	0.254*** (0.042)	ΔVP_{t-1}	0.267*** (0.042)
ΔVP_{t-2}	-0.171*** (0.041)	ΔVP_{t-2}	-0.121*** (0.041)
ΔIP^{+}_{t}	-0.140 (0.088)	ΔIP^{+}_{t}	-0.168** (0.077)
ΔIP^{+}_{t-1}	0.043 (0.084)	ΔIP^{+}_{t-1}	0.057 (0.074)
ΔIP^{+}_{t-2}	-0.266*** (0.083)	ΔIP^{+}_{t-2}	-0.193*** (0.073)
ΔIP^{-}_{t}	-0.649*** (0.087)	ΔIP^{-}_{t}	-0.577*** (0.076)
ΔIP^{-}_{t-1}	-0.264*** (0.093)	ΔIP^{-}_{t-1}	-0.191** (0.082)
LR_{IP}	1.208 SEK	LR_{IP}	1.220 SEK
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.360*** (0.028)	**Adj. speed**	-0.332*** (0.026)
Adj. R-squared	0.982	**Adj. R-squared**	0.986
AIC	-2.847	*AIC*	-3.121
F_{PSS}	54.194***	F_{PSS}	53.180***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

Our analysis reveals that a 1% increase (or decrease) in the input price leads to approximately a 1.208% and 1.220% increase (or decrease) in the volume-adjusted price [12]. This finding suggests a nearly one-to-one relationship in the long run.

In the short-run analysis, the Wald tests conclusively reject the hypothesis of additive short-run symmetry with respect to input prices. This finding highlights a distinct pattern of asymmetry in the way gasoline prices respond to input price changes in the short term.

[12]The long-run level coefficient for both cases is denoted as LR_{IP}, and the error correction forms are expressed as EC= VP-(1.208*IP_{t-1}) and EC= VP-(1.220*IP_{t-1}), respectively.

The dynamic multipliers, illustrated in Figure 4, visually represent this asymmetry. They show how the volume-adjusted price (VP) responds over time to changes in the input price (IP), capturing the immediate and subsequent effects of these changes.

The analysis presented in Columns (2) and (4) of our results highlights the negative and statistically significant adjustment speeds in both market segments we studied – those with high local competition (stations within 3 km of their closest competitor) and those with lower local competition (stations more than 3 km away from their nearest competitor). As hypothesized, the adjustment speed is somewhat slower in markets with lower local competition.

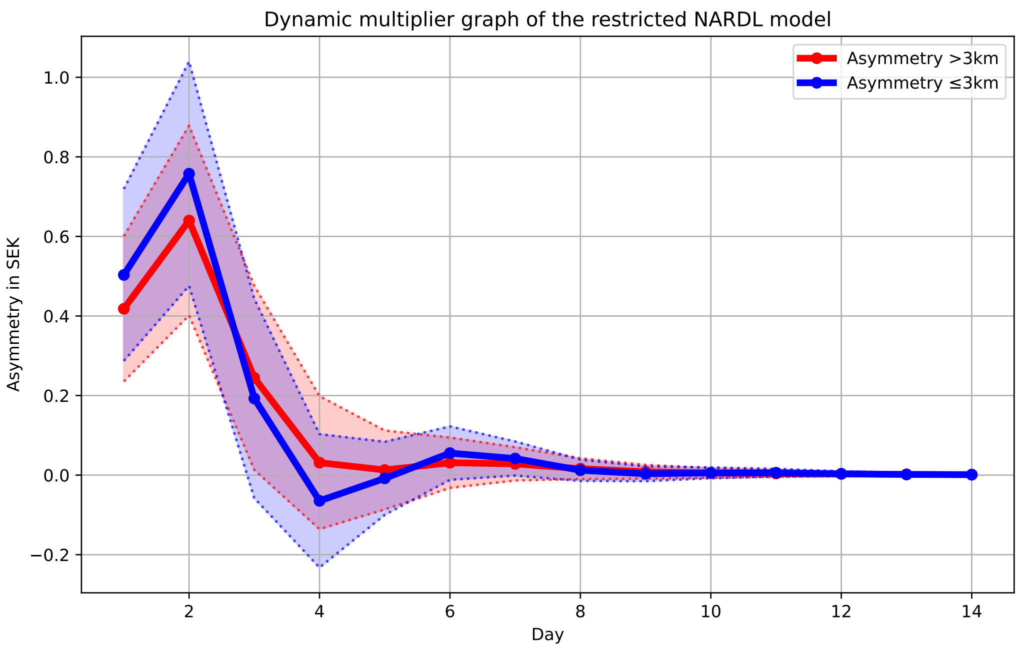

Figure 4: Asymmetric based on the distance to the nearest competitor.

Additionally, the error correction term in our model sheds light on how the proximity to the nearest competitor influences the speed at which asymmetry in cost pass-through is adjusted. Specifically, being located in a market where the nearest competitor is more than 3 km away significantly slows the speed of pass-through asymmetry. This finding suggests that stations with fewer nearby competitors have more leeway in maintaining asymmetric pricing strategies over a longer period. Our dynamic multipliers further illustrate these differences. In markets where the distance between stations is 3 km or less, there is a rapid return to long-run symmetry, typically occurring within just two days. Conversely, stations that are more than 3 km away from their closest competitor can sustain short-run asymmetric cost pass-through for up to three days (Figure 4).

5.4 Impact of Sales Volume on Pricing: Analysis of High and Low Gasoline Volume Stations

Our earlier findings highlighted a more pronounced asymmetry in pricing when using volume-weighted prices. To investigate this further, we focused on stations at the extremes of sales volumes, examining the top and bottom 10-percentiles in terms of daily sales volumes. This approach led us to analyze 15 stations each from the lowest and highest mean daily sales volume categories. The low-volume group, characterized by an average daily sales volume of 1 622 liters, contrasts starkly with the high-volume group, which boasts a significantly larger average daily sales volume of 13 819 liters – nearly nine times higher.

For a more granular analysis, we estimated separate NARDL models for each of these 30 stations to compare their pricing behaviors. To ensure robustness in our analysis, we assumed three lags for the prices and four lags for the input price. Additionally, we allowed for 200 iterations to obtain standard errors, providing a comprehensive statistical foundation for our comparisons and conclusions. This detailed approach enables us to gain deeper insights into how station volume affects pricing strategies and asymmetries.

Among both the high-volume and low-volume groups, comprising 15 stations each, we identified that six stations in each group do not exhibit short-term asymmetry in their pricing. Scrutinizing on the five stations with lowest volume within each of these 15-station groups, we find that four out of these five have no asymmetry among the lowest high-volume stations, whereas only two out of five has no asymmetry within the lower five among the low-volume stations.

Next, we shifted our focus to examining the average prices for each of these volume groups – both high-volume and low-volume stations. Initially, our analysis using the unrestricted NARDL model, as presented in Table 5A, did not reveal any long-run asymmetries. This outcome led us to refine our approach by employing a restricted NARDL model, which focuses on specific significant asymmetries, particularly in the short run. The results of this more focused analysis using the restricted NARDL model are shown in Table 5.

Additionally, Figure 5 presents the asymmetric dynamic multipliers for both high-volume and low-volume stations.

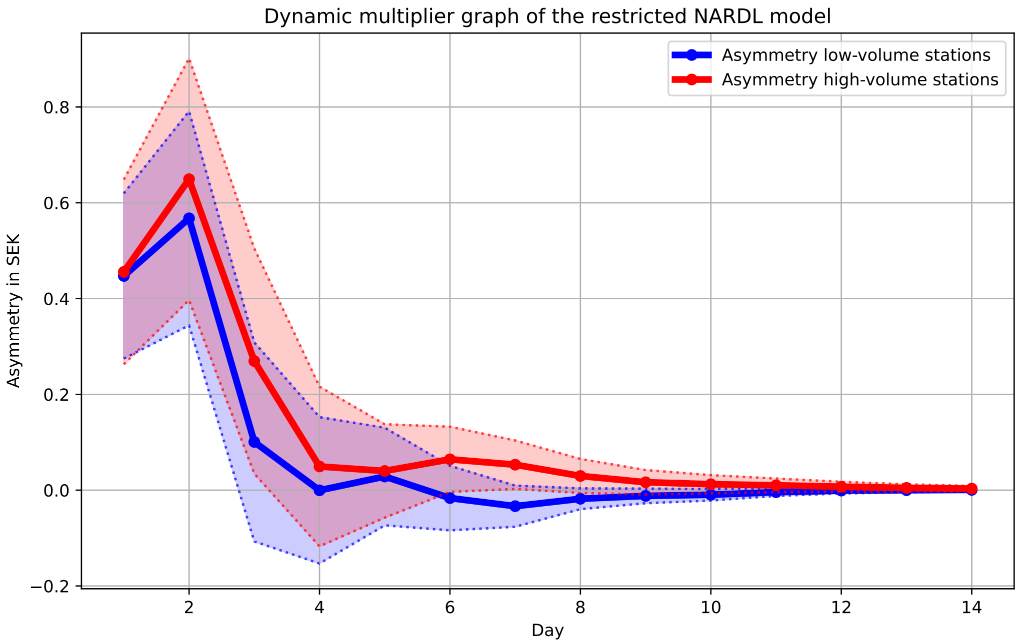

Figure 5: Asymmetry between low- and high-volume groups

We observe that high-volume stations exhibit three days of asymmetric pricing in the short term, while low-volume stations demonstrate a shorter period of asymmetry, lasting only two days. The dynamic multipliers depicted in Figure 5 further illustrate these differences. In the figure: the high-volume stations' asymmetry (represented by the red curve) is more pronounced compared to the low-volume stations (indicated by the blue curve), especially during the initial three to four days.

Additionally, a notable observation is that the lower bound of the confidence interval for the low-volume group reaches zero earlier than that of the high-volume group. This indicates that the low-volume stations return to symmetric pricing faster than the high-volume stations.

Table 5: Estimation results of restricted NARDL for the low- and high-volume stations

Low-volume group		High-volume group	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	2.812*** (0.219)	Constant	2.501*** (0.225)
VP_{t-1}	-0.349*** (0.026)	VP_{t-1}	-0.304*** (0.026)
IP^{+}_{t-1}	0.434*** (0.033)	IP^{+}_{t-1}	0.357*** (0.030)
ΔVP_{t-1}	0.221*** (0.041)	ΔVP_{t-1}	0.303*** (0.044)
ΔVP_{t-2}	-0.079** (0.041)	ΔVP_{t-2}	-0.210*** (0.044)
ΔVP_{t-3}	0.107*** (0.040)	ΔVP_{t-3}	0.106*** (0.042)
ΔIP^{+}_{t}	-0.233*** (0.072)	ΔIP^{+}_{t}	-0.082*** (0.079)
ΔIP^{+}_{t-1}	0.018 (0.070)	ΔIP^{+}_{t-1}	0.002 (0.076)
ΔIP^{+}_{t-2}	-0.259*** (0.069)	ΔIP^{+}_{t-2}	-0.166** (0.076)
ΔIP^{-}_{t}	-0.680** (0.072)	ΔIP^{-}_{t}	-0.539*** (0.079)
ΔIP^{-}_{t-1}	-0.158** (0.079)	ΔIP^{-}_{t-1}	-0.188** (0.084)
LR_{IP}	1.245 SEK	LR_{IP}	1.174 SEK
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.349*** (0.026)	**Adj. speed**	-0.304*** (0.025)
Adj. R-squared	0.989	**Adj. R-squared**	0.984
AIC	-3.255	*AIC*	-3.041
F_{PSS}	59.125***	F_{PSS}	47.922***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

Finally we also look at the adjustment pattern in prices. We estimate individual Autoregressive Distributed Lag (ARDL) error correction models for all 147 stations in our study. For consistency with our previous models, we maintained the same lag structure: three lags for prices and four lags for input prices. A key finding from this analysis is a distinct pattern in the speed of price adjustments across stations of varying sales volumes. Larger volume stations exhibited a slower adjustment speed. Quantitatively, this relationship is captured by a correlation coefficient of -0.24 between the mean daily station volume and the adjustment speed, indicating that higher sales volumes are associated with slower price adjustments.

Further focusing on the extremes of our dataset – the 15 stations with the lowest volumes and the 15 with the highest – we observed a notable difference in mean adjustment speeds. The low-volume group showed a mean adjustment speed of -0.35, while the high-volume group had a slower average adjustment speed of -0.29. This finding implies that high-volume stations adjust nearly 20% slower towards long-run equilibrium compared to their low-volume counterparts.

The collective findings from our analysis provide noteworthy support for the idea that station size and sales volume influence on pricing strategies, particularly in how quickly stations respond to market changes and move towards long-run equilibrium. This conclusion emerges from two key aspects of our research: the low- and high-volume groups analysis and our analysis across all 147 stations, where we estimated individual adjustment speeds. The correlation between station volume and adjustment speed suggest that stations with higher volumes adjust more slowly towards long-run equilibrium.

5.5 Implications of Asymmetric Oil Price Pass-Through on Gasoline Market Economics

Utilizing NARDL models in our primary analysis, we have uncovered clear evidence of short-run price asymmetry in the Swedish national market. This asymmetry is evident in both average pump prices and volume-adjusted prices. A key observation is that prices tend to increase more sharply following hikes in input costs than they decrease following a reduction in these costs.

Figure 2, located in Section 5.1 of our paper, visually shows this asymmetry. It contrasts the differences in the response of average prices and volume-weighted prices to changes in input prices. One of the most significant findings is that the correction of disequilibrium errors in volume-adjusted prices takes a day longer than in the average pump price model. This extended duration of asymmetry correction in volume-adjusted prices suggests a strategic focus by companies on larger gasoline stations. Such stations, presumably due to their higher sales volumes, might be more impactful on revenue, leading companies to prioritize pricing strategies at these locations.

Indeed this also impacts how we interpret the effects of asymmetric pricing behavior. If we consider only average prices, we underestimate the effect of the asymmetry. In our case, for Sweden aggregated, we find one more day of asymmetry. This extra day accounts for a significant part of the overcharge created by the asymmetric pricing behavior. In Table 6, we present a detailed "back-of-the-envelope" calculation to quantify the effects of this asymmetry. Utilizing both the average price model and the volume-weighted price model (as depicted in Figure 2), we estimate an average overcharge for the 2 to 3 days as indicated by these model.[13]

It is important to note that the estimated overcharge, as well as the prices and margins, vary between these two models. When these overcharges are calculated, the estimated overcharge for the model based on average prices amounts to approximately 1 166 386 thousand SEK. This significant figure underscores the economic impact of asymmetric pricing behaviors in the market.

Table 6: "Back-of-the-envelope" calculations (in 1000 SEK).

Models	Day 1	Day 2	Day 3	Total effect SEK
1. The average price model				
Price increase due to asymmetry (%)	3,3 %	4,8 %		
Margin increase due to asymmetry (%)	45,8 %	67,7 %		
Annual cost of asymmetry in SEK in Sweden	470 475	695 911		**1 166 386**
2. The vol-weighted price model				
Price increase due to asymmetry (%)	2,6 %	4,3 %	1,5 %	
Margin increase due to asymmetry (%)	37,1%	61,5%	22,4%	
Annual cost of asymmetry in SEK in Sweden	372 460	617 499	225 436	**1 215 394**
Difference in overcharge in 1000 SEK				**- 49 008**
Difference in overcharge in %				**-4,03%**

The inclusion of an additional day of asymmetry and the use of volume-adjusted prices in our model leads to a notable increase in the estimated overcharge. Specifically, this accounts for an additional 49 008 thousand SEK[14]. This difference highlights a crucial point: the model that relies solely on average prices tends to underestimate the total overcharge caused by asymmetric pricing. In fact, this underestimation amounts to ap-

[13] Average price and margin increase due to asymmetry on Day 1 (Day 2). For instance, this overcharge can be calculated as asymmetry on Day 1 (Day 2) divided by the daily average price: 0.48/14.76= 3.3% (0.71/14.76= 4.8%), and by the daily average margin 0.48/1.0478=45.8% (0.71/1.0478=67.7%). To translate these percentages into a monetary impact, we used the daily gasoline consumption data for Sweden in 2012, multiplying it by the asymmetry value to obtain the cost in SEK: 470 475 187 SEK for Day 1 and 695 911 214 SEK for Day 2. To estimate the annual cost of asymmetry in the Swedish gasoline market, we multiply the daily cost by 120, which represents the number of days with input price increases in our sample. This method is applied both to the model based on average prices and the model using volume-weighted prices. The key distinction in the volume-weighted price model is the inclusion of asymmetry on Day 3, along with the use of the volume-weighted average price (14.73 SEK) and margin (1.024 SEK).

[14] Calculated as the difference in the annual cost due to asymmetry in pricing between the model estimated using average prices (1 166 386 401 SEK) and the model using volume-weighted prices (1 215 394 233 SEK).

proximately 4.1%. In fact, the overcharge amounts to 2.7% of the total expenditure on gasoline in Sweden in 2012. As compared to the gross margin, this overcharge represents a more than ten-fold larger effect. This is obviously due to the significant taxes that, together with the Rotterdam price, leave the companies with a very low gross margin per liter. Thus, we also calculate the total gross margin for 2012 to compare it to these overcharges. The total margin is around 3[15] billion SEK; therefore, there is an overcharge of around 1.2 billion SEK. Hence, the 2.7% increase in total expenditure for gasoline represents close to 40% of the overall gross margin, suggesting that for the oil companies, asymmetric pricing presents a major avenue for increasing profits. Since the last part of the retail price is determined by taxes and the Rotterdam wholesale price, this increase in the margin is not very noticeable for consumer expenditures, who end up paying less than 3% extra for their gasoline.

6 Summary and discussion

Having access to a comprehensive dataset from the Swedish retail gasoline market has enabled us to conduct a thorough examination of potential differences in asymmetric responses between average pump prices and volume-adjusted prices in reaction to variations in input prices. Our observations reveal a notable aspect of pricing dynamics in this market. Specifically, when employing volume-adjusted prices in our analysis, we found that the correction of the disequilibrium error – the process of returning to long-run equilibrium – takes a longer time compared to the average pump prices. This extended duration for error correction in the volume-adjusted price model suggests a strategic focus by oil companies. It appears that these companies place greater emphasis on pricing strategies on days and at stations with higher sales volumes.

In the rest of our empirical analysis, we continue using only volume-adjusted prices as the dependent variable. We analyze how asymmetry in pricing is influenced by various factors such as service-level heterogeneity: we investigate how the different service

[15]The total margin for 2012 is calculated by multiplying the daily average margin with the daily gasoline consumption for the year 2012, and then by the number of days in that year. This calculation, represented as 1.0478 * 366 * 8 167 972, yields a total of 3 132 374 788.55 SEK.

levels of gasoline stations (e.g., full-service versus self-service) impact the asymmetry in pricing; degree of competition: we analyze how the proximity of competitors and the density of gasoline stations in a given area influence the extent and nature of asymmetric pricing; and volume sales: we continue to delve into the impact of sales volume on pricing asymmetry. This involves comparing stations with high sales volumes to those with lower volumes to determine how size and sales activity influence their approach to pricing, especially in response to changes in input costs.

The results for our models are overall consistent with what Byrne (2019) found. Asymmetric price responses are more pronounced in markets with fewer stations (like he finds in his rural markets. When controlling for local competition pressure by dividing stations into those being exposed to nearby competitors within 3 km, and those stations where this is not the case, we find a similar result. The stations not exposed to as much local competition have less prolonged short-run asymmetry compared to stations with nearest competitors more than 3 km away.

Additionally, we investigated the presence of asymmetric price responses for full-service and self-service stations. The results indicate that the pricing asymmetry is larger and more prolonged for full-service stations. This result, that is, stations with higher service levels have larger pricing asymmetry, supports the results found by Verlinda (2008). It is also in line with the findings of Byrne (2019), that is, evidence suggesting that market power increases cost pass-through asymmetry. Several studies have concluded that a higher service level is associated with higher prices and market power, suggesting that the prolonged asymmetry found here can be attributed to differences in competition level (see, e.g., Eckert and West, 2005; Haucap et al., 2017; Shepard, 1991; Nguyen-Ones and Steen, 2021).

When scrutinizing on the low-high volume stations in the respective 10-percentiles, we confirm this. The 15 highest-volume stations have a slower adjustment of prices, and possesses short-term asymmetry in their pricing for longer, as compared to the 15 lowest-volume stations. This seems to imply that the oil companies are more focused on their pricing for larger stations when it comes to cost past-through. This is also in line with what one would anticipate, since the potential profit gains form asymmetric pass-through are higher the larger the station volumes are. This difference using average and volume weighted prices is to our knowledge new to the literature on asymmetric price responses, and suggest that effects established in earlier studies using average prices indeed underestimate the asymmetry effects.

Even though the unrestricted NARDL model does not indicate the presence of long-run asymmetry, the key parameters such as adjustment speed and the duration of short-run asymmetry remain consistent between the unrestricted and restricted versions of the NARDL model. The fact that these key parameters do not change between the models lends robustness to our findings. It indicates that our results regarding short-run dynamics are not sensitive to whether we impose long run asymmetry or not in the model.

Overall, our results are largely consistent with the existing literature that relates market power with the presence of asymmetric cost pass-through to the retail price of gasoline. Moreover, the analysis confirms that gasoline prices in Sweden during the sample period display the "rocket and feathers" pattern by responding more rapidly to the input price increases than decreases. When input price increased, retailers were able to quickly pass-through the input price increases to volume-adjusted price. Conversely, when input prices decreased, the retailers delayed the pass-through.

As we saw in the section above, the economic impact on retailer's gross margins is substantial, still only affecting average prices and expenditure marginally. In transparent oligopolies, where taxes and exogenous costs make up a significant part of the retail price and overall demand typically is inelastic, incentives to impose asymmetric pricing are very high.

The literature seems to conclude that market power leads to larger pricing asymmetry (see, e.g., Byrne, 2019; Verlinda, 2008; Deltas, 2008). Indeed, we support their findings. The volume-adjusted price converges with its long-run equilibrium position through a slower adjustment speed in the full-service stations, stations with no competitor within 3 km, and big stations in terms of gasoline daily sales.

For all models, and in line with the literature, we find a return to long-run pricing asymmetry. Another interesting feature of using daily data is that for all models, we find that the return to long-run asymmetry is always achieved within one week, both for average pump prices and for using volume-weighted prices. Several studies using more aggregated data find longer adjustment periods, probably primarily due to lower data frequency. Though our dataset is shorter than these other studies, the price asymmetry we are looking for is a short term phenomenon that fits our panel of daily station prices well, allowing us to both test for heterogenity across stations, and volume weight our prices.

We have aggregated across stations using different selection criteria; service level, local competition level, and daily gasoline sales. Since we have access to a detailed panel of transaction prices and volumes per day for as many as 147 gasoline stations, as a next step we estimated dynamic models for each station and related the results to variables measuring the particularities of the stations' demographics with regards to local demand, competition level, and station heterogeneity. This took us further in the direction of what Byrne (2019) did while estimating price dynamics across stations and comparing the results across local markets in Canada. Finally, our findings underscore the importance of considering volume-weighted prices in analyses to capture the full extent of the economic impact of pricing asymmetry in the gasoline market.

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7 Appendix

Table A1. Augmented Dickey-Fuller test for unit root.

Variables	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
VP	-1.634	-3.451	-2.875	-2.570
OP	-1.692	-3.451	-2.875	-2.570
IP	-1.528	-3.451	-2.875	-2.570
Variables	**Test Statistic**	**1% Critical Value**	**5% Critical Value**	**10% Critical value**
ΔVP	-14.295	-3.451	-2.875	-2.570
ΔOP	-15.409	-3.451	-2.875	-2.570
ΔIP	-18.936	-3.451	-2.875	-2.570

Table A2. Estimation results of unrestricted NARDL for the volume-weighted and average prices

Volume-weighted prices		Average prices	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	4.693 ***(0.380)	Constant	5.251 ***(0.399)
VP_{t-1}	-0.328 ***(0.026)	OP_{t-1}	-0.367 ***(0.027)
IP^{+}_{t-1}	0.391 ***(0.031)	IP_{t-1}	0.446 ***(0.034)
IP^{-}_{t-1}	0.393 ***(0.031)	IP_{t-1}	0.447 ***(0.034)
ΔVP_{t-1}	0.298 ***(0.042)	ΔOP_{t-1}	0.225 ***(0.041)
ΔVP_{t-2}	-0.186 ***(0.040)	ΔOP_{t-2}	-0.151 ***(0.040)
ΔIP^{+}_{t}	0.226 ***(0.071)	ΔIP^{+}_{t}	0.249 ***(0.073)
ΔIP^{+}_{t-1}	0.047 (0.074)	ΔIP^{+}_{t-1}	0.053 (0.076)
ΔIP^{+}_{t-2}	-0.160 ***(0.073)	ΔIP^{+}_{t-2}	-0.273 ***(0.075)
ΔIP^{-}_{t}	-0.160 **(0.070)	ΔIP^{-}_{t}	-0.233 ***(0.072)
ΔIP^{-}_{t-1}	-0.222 ***(0.081)	ΔIP^{-}_{t-1}	-0.241 ***(0.085)
Long-run asym.	no	**Long-run asym.**	no
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.328 ***(0.025)	**Adj. speed**	-0.367 ***(0.027)
Adj. R-squared	0.985	**Adj. R-squared**	0.985
AIC	-3.115	*AIC*	-3.057
F_{PSS}	40.662 ***	F_{PSS}	43.423 ***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

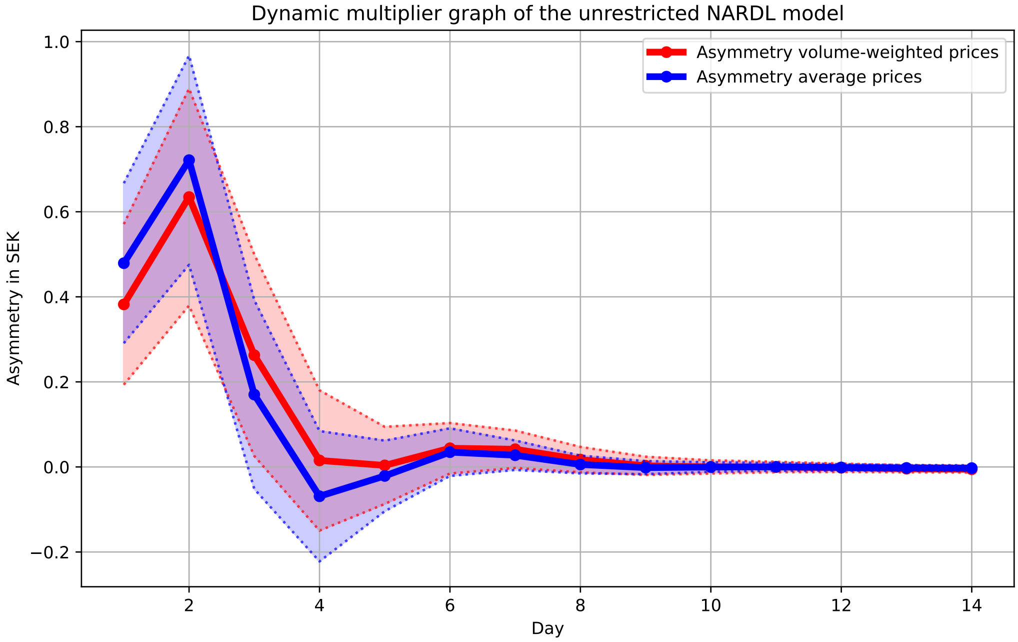

Figure A1. Asymmetry based on the national level analysis.

Table A3.Estimation results of unrestricted NARDL for the full-service and self-service stations

Full-service group		Self-service group	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	4.819*** (0.378)	Constant	5.304*** (0.420)
VP_{t-1}	-0.335*** (0.026)	VP_{t-1}	-0.374*** (0.029)
IP^+_{t-1}	0.406*** (0.032)	IP^+_{t-1}	0.441*** (0.035)
IP^-_{t-1}	0.407*** (0.032)	IP^-_{t-1}	0.444*** (0.035)
ΔVP_{t-1}	0.322*** (0.041)	ΔVP_{t-1}	0.180*** (0.042)
ΔVP_{t-2}	-0.182*** (0.041)	ΔVP_{t-2}	-0.127*** (0.041)
ΔIP^+_t	0.157*** (0.070)	ΔIP^+_t	0.334*** (0.083)
ΔIP^+_{t-1}	0.082 (0.073)	ΔIP^+_{t-1}	-0.044 (0.085)
ΔIP^+_{t-2}	-0.173** (0.072)	ΔIP^+_{t-2}	-0.307*** (0.085)
ΔIP^-_t	-0.144** (0.068)	ΔIP^-_t	-0.268*** (0.082)
ΔIP^-_{t-1}	-0.266*** (0.079)	ΔIP^-_{t-1}	-0.261*** (0.096)
Long-run asym.	no	**Long-run asym.**	no
Short-run asym	yes	**Short-run asym.**	yes
Adj. speed	-0.335*** (0.025)	**Adj. speed**	-0.374*** (0.028)
Adj. R-squared	0.987	**Adj. R-squared**	0.981
AIC	-3.156	*AIC*	-2.807
F_{PSS}	43.265***	F_{PSS}	42.142***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

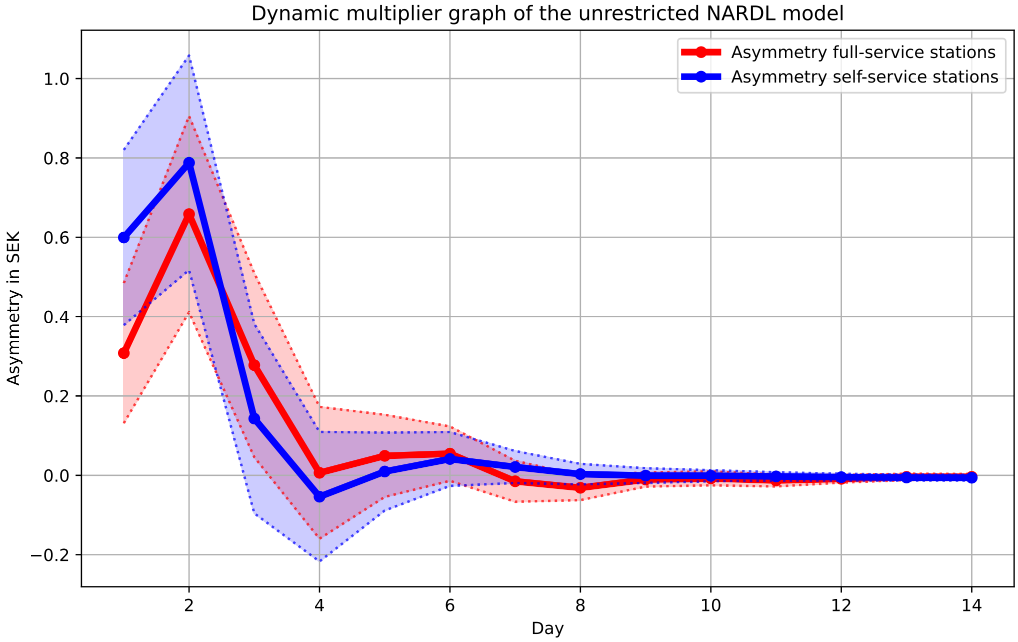

Figure A2. Asymmetry based on the level of service.

Table A4.Estimation results of unrestricted NARDL for stations with closest competitor $\leq$ 3km and $>$ 3km

$\leq$ 3km group		$>$ 3km group	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	5.175*** (0.412)	Constant	4.761*** (0.384)
VP_{t-1}	-0.363*** (0.028)	VP_{t-1}	-0.333*** (0.026)
IP^{+}_{t-1}	0.430*** (0.034)	IP^{+}_{t-1}	0.401*** (0.032)
IP^{-}_{t-1}	0.431*** (0.034)	IP^{-}_{t-1}	0.402*** (0.032)
ΔVP_{t-1}	0.251*** (0.042)	ΔVP_{t-1}	0.264*** (0.042)
ΔVP_{t-2}	-0.172*** (0.041)	ΔVP_{t-2}	-0.123*** (0.041)
ΔIP^{+}_{t}	0.290*** (0.081)	ΔIP^{+}_{t}	0.233*** (0.071)
ΔIP^{+}_{t-1}	0.044 (0.084)	ΔIP^{+}_{t-1}	0.059 (0.074)
ΔIP^{+}_{t-2}	-0.266*** (0.083)	ΔIP^{+}_{t-2}	-0.192*** (0.073)
ΔIP^{-}_{t}	-0.226*** (0.080)	ΔIP^{-}_{t}	-0.180*** (0.070)
ΔIP^{-}_{t-1}	-0.276** (0.092)	ΔIP^{-}_{t-1}	-0.197** (0.082)
Long-run asym.	no	**Long-run asym.**	no
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.364*** (0.028)	**Adj. speed**	-0.333*** (0.026)
Adj. R-squared	0.981	**Adj. R-squared**	0.986
AIC	-2.851	AIC	-3.121
F_{PSS}	41.731***	F_{PSS}	40.500***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

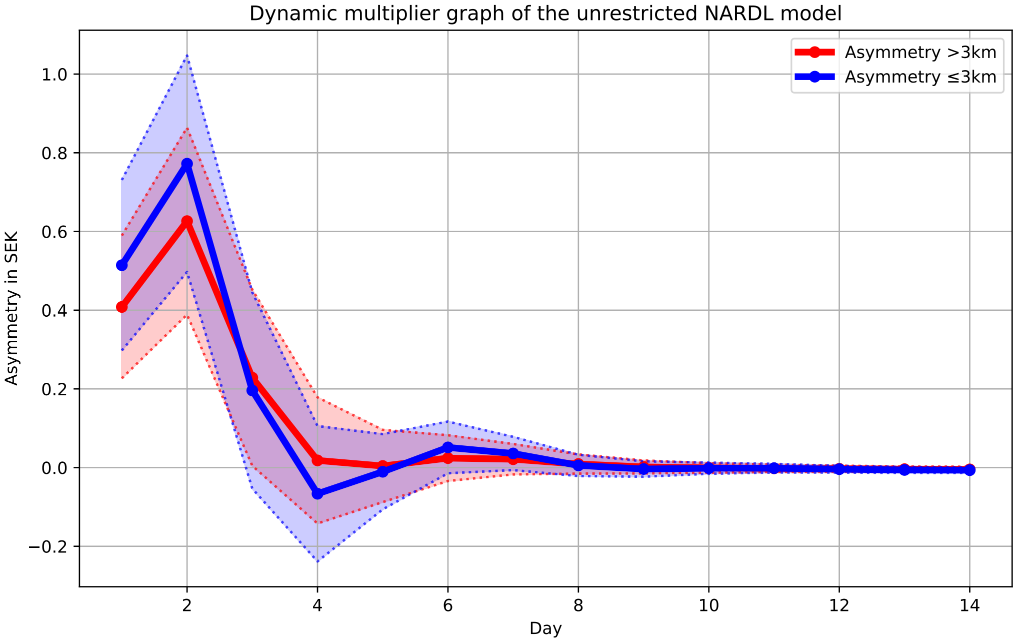

Figure A3. Asymmetric based on the distance to the nearest competitor.

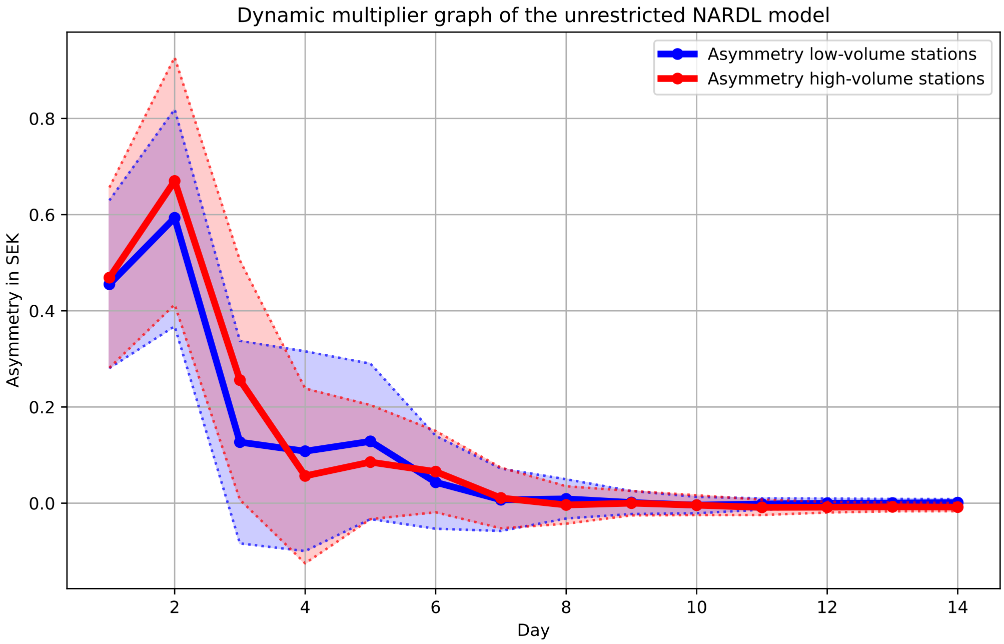

Figure A4. Asymmetry between low- and high-volume groups

Table A5.Estimation results of unrestricted NARDL for the low- and high-volume stations

Low-volume group		**High-volume group**	
Variables	**Coefficients**	**Variables**	**Coefficients**
Constant	4.854*** (0.392)	Constant	4.360*** (0.369)
VP_{t-1}	-0.340*** (0.027)	VP_{t-1}	-0.308*** (0.026)
IP^{+}_{t-1}	0.425*** (0.035)	IP^{+}_{t-1}	0.353*** (0.030)
IP^{-}_{t-1}	0.425*** (0.035)	IP^{-}_{t-1}	0.356*** (0.030)
ΔVP_{t-1}	0.224*** (0.041)	ΔVP_{t-1}	0.298*** (0.042)
ΔVP_{t-2}	-0.097** (0.043)	ΔVP_{t-2}	-0.211*** (0.043)
ΔVP_{t-3}	0.107*** (0.040)	ΔVP_{t-3}	0.101*** (0.041)
ΔIP^{+}_{t}	0.209*** (0.067)	ΔIP^{+}_{t}	0.270*** (0.073)
ΔIP^{+}_{t-1}	0.034 (0.071)	ΔIP^{+}_{t-1}	0.003 (0.076)
ΔIP^{+}_{t-2}	-0.250*** (0.069)	ΔIP^{+}_{t-2}	-0.166** (0.075)
ΔIP^{+}_{t-3}	0.098 (0.069)		
ΔIP^{-}_{t}	-0.247** (0.065)	ΔIP^{-}_{t}	-0.194*** (0.073)
ΔIP^{-}_{t-1}	-0.153** (0.079)	ΔIP^{-}_{t-1}	-0.201** (0.083)
Long-run asym.	no	**Long-run asym.**	no
Short-run asym.	yes	**Short-run asym.**	yes
Adj. speed	-0.340*** (0.026)	**Adj. speed**	-0.308*** (0.025)
Adj. R-squared	0.988	**Adj. R-squared**	0.984
AIC	-3.248	*AIC*	-3.045
F_{PSS}	50.987***	F_{PSS}	37.047***

*Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

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NORGES HANDELSHØYSKOLE
Norwegian School of Economics

Helleveien 30
NO-5045 Bergen
Norway

T +47 55 95 90 00
E nhh.postmottak@nhh.no
W www.nhh.no