# Do wholesale electricity prices pass-through to consumers in contestable retail electricity markets? An examination in Victoria, Australia

**VEPC Working Paper WP2108**
**August 2021**

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**DOI: https://doi.org/10.26196/c6ra-wt76**


## Abstract

Contestable retail electricity markets can cater for consumers' diverse preferences, including price stability. We estimate prices for 18,997 households in Victoria, Australia, using all commonly available retail offers, once per month from January 2019 to March 2021 and relate these prices to monthly estimates of wholesale market prices. We find incumbent and established new entrant retailers incompletely pass-through wholesale prices (around 40 % of wholesale price variation is passed through in retail prices) when measuring cheaper offers (the 10th percentile cheapest offers). However, new entrant retailers completely pass-through wholesale prices. The incomplete pass-through by dominant and established new entrant retailers is also observed in other countries. While this is commonly considered to reflect weak competition, it may reflect consumer preferences for stable prices, even if they are more expensive.


**Keywords**: price stickiness; asymmetry; pass-through; market efficiency; retail competition
**JEL**: D04, D22, D41, C50

**Acknowledgements**
We thank Steven Percy and Amine Gassem without whose data science skills this research would not have been possible.

**Declarations**
Bruce Mountain and Amine Gassem are co-founders of price comparison software now owned by a private retail electricity comparison service. VEPC continues to retain access to the software, which has been used to perform data extraction and processing of electricity bill data used in this study.

**Funding**
This work was supported by a multi-year funding grant from the Government of Victoria for the establishment of the Victoria Energy Policy Centre.

**Competing interests**
The authors have no competing interests to declare.

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## 1. Introduction

In the late 1990s, following an approach initially adopted in Britain a decade earlier, contestable wholesale electricity markets were introduced in the state of Victoria, Australia. In 2003, contestable retail electricity markets were introduced allowing small consumers (households and small businesses) to choose their suppliers (retailers). Following these reforms, there are now five electricity distributors (who provide the shipping service) and around 25 electricity retailers, several of whom also own electricity generators. There is a mandatory wholesale (5-minute) electricity market (the National Electricity Market (NEM)) for the exchange of electricity produced by all large (greater than 30 MW) generators. The electricity retailers currently present a choice of around 200 offers to household customers (Essential Services Commission, 2019).

The Victorian Government promotes retail competition by encouraging consumers to search for better offers, including through the provision of a price comparison website. On the recommendation of the Independent Bipartisan Review (Thwaites, Faulkner, & Mulder, 2017), the Government of Victoria established a "default" offer (the Victorian Default Offer (VDO)) from 1 July 2019, almost exactly a decade after all retail price controls had been withdrawn. The default offer is the centre-piece of regulatory changes and requirements that include: requiring retailers to state any discounts relative to the default offer; requiring retailers to inform customers if they offer a cheaper tariff and how much the customer might save if they switched to it; and (from 1 July 2020) not allowing retailers to increase the prices charged to their existing customers more than once in any 12 month period. The default offer only applies to customers that have never chosen their retailer (about 7% of all customers). Retailers are free to make offers – including ones that are more expensive than the default offer – to all other customers.

We use a large sample of household bills, all publicly available retail offers, and data on wholesale market electricity derivatives traded through the Australian Securities Exchange (ASX) to establish monthly estimates of relevant variables from January 2019 to March 2021. We apply an autoregressive distributed lag (ARDL) model to explain movements in retail prices and test if wholesale pass-through is dynamic, complete and symmetric. We test whether pass-through varies amongst retailers, and at different price points, and whether rising wholesale prices are passed through more quickly than falling wholesale prices.

In this study, we estimate annual bills of each of 18,997 households using around 200 different retail tariff offers available to the households. Annual bills (and the price paid cents per kWh) is measured on a monthly basis based on the retail tariff offers available in each month. This approach allows segmentation of the market at different price points and for different cohorts of retailers. Further, it allows for a richer characterisation of wholesale price pass-through than has been achieved in studies elsewhere. We are also able to estimate the impact of the VDO and isolate its effect on retail offers from the effect of wholesale price changes.

The paper proceeds as follows: Section 2 provides background and examines relevant literature; Section 3 describes our data and provides a preliminary analysis; the model and econometric results are presented in Section 4; Section 5 discusses these results; and Section 6 concludes.

## 2. Background and relevant literature

### 2.1 Background

Retailers determine the prices they charge in their offers (except to the small number of customers to whom the VDO applies). Some retailers change their offers frequently (Mountain & Burns, 2020b). There is no restriction on retailers from frequently offering new tariffs.

The majority of households (87% in 2017) are charged a flat rate tariff comprising a fixed ($ per month) and variable (cents per kWh) charge (Carbon and Energy Markets, 2017). The remaining customers have tariffs with two or three different variable rates. There are very few fixed price offers, although as noted in the introduction regulations were introduced from 1 July 2020 preventing retailers from increasing prices paid by their existing customers more than once each year.

Retailers are charged network tariffs that are applicable to each of their customers but network charges are not separately itemised on customers' bills.[1] Retailers also seek to recover their operating costs and profits in the offers they make. Environmental fees associated with meeting the national Renewable Energy Target, and the Victorian Government's energy efficiency and rooftop photovoltaic support schemes.

Australian regulators have not provided precise views on the relationship between wholesale and retail prices in Victoria. The Australian Energy Regulator (AER) suggests that in the period to the start of 2020 rising wholesale electricity prices have been the largest contributor to retail price increases, although they did not provide any additional information on rate of pass-through (Australian Energy Regulator, 2020). In 2019, the Australian Energy Markets Commission (AEMC) projected that in the period to 2022 retail electricity prices would decline by 5% mainly a result of an anticipated 17% decline

[1] The network tariffs for each of Victoria's five electricity distributors are summarised in Appendix Table 1.

in wholesale prices (AEMC, 2019). The Australian Competition and Consumer Commission (ACCC) suggest that changes in spot prices do not flow immediately to retail prices, as a result of retailers' hedging activities (ACCC, 2019). In an earlier report, the ACCC reported a lag of around one to two years between increases in wholesale prices and pass-through to retail prices (ACCC, 2018).

The wholesale electricity market in the NEM is a mandatory and centrally settled single price market where prices are determined every 5-minutes from 1 October 2021 (during the study period here, prices are settled half-hourly based on the average of the 5-minute prices. Retailers typically hedge against movements in the 5-minute spot price by purchasing financial derivatives (swaps and caps) which can be bi-laterally agreed, transacted through over-the-counter markets or (most commonly) traded through the Electricity Futures and Options Market (operated by the Australian Securities Exchange (ASX)). By far, the most commonly traded swap is a quarterly "baseload" (1 MW for each hour in the quarter). In the year to 30 June 2019, quarterly baseload swaps comprised the majority (67%) of ASX-traded contracts (Australian Energy Regulator, 2020).[2]

### 2.2 Relevant literature

Wholesale price pass-through in retail electricity markets is examined by Ofgem (2011) in Great Britain, Mulder and Willems (2019) in the Netherlands, Johnson and Olsen (2008) and Mirza and Bergland (2012) in Nordic electricity markets (Norway, Sweden and Finland), and Brown et al. (2020) and Hartley et al. (2019) in Texas. In this section, we review these studies with a focus primarily on the differences and similarities in the methodologies and in their findings. We return to these studies later to consider the interpretation of their results in contrast to our interpretation of our results.

Empirical studies that examine the pass-through of wholesale to retail prices in electricity markets generally use an error correction model (ECM), autoregressive distributed lag model (ARDL) or partial adjustment model (PAM). ECMs and PAMs can both estimate the long-run and short-run pricing behaviour of retailers in response to changing wholesale prices. For instance, Mirza and Bergland (2012), demonstrate that PAMs are useful in explaining how retail prices change asymmetrically based on the actual and the retailers' expected change in wholesale prices over the short and long-run. Ofgem (2011) and Mulder and Willems (2019) demonstrate that ECMs are suitable to explain symmetric and asymmetric retail pricing behaviour in response to short and long-run changes in wholesale prices if there is a long-run co-integrating relationship between wholesale and retail prices. Hartley et al. (2019), on the other hand, opt to use an autoregressive distributed lag (ARDL 1,0) model that includes dummy

[2] For a review of the existing literature on forward contracts and the contracting process as it operates in Australia, we suggest (Anderson, Hu, & Winchester, 2007).

variables to take into account, for example, seasonal factors and major regulatory changes. Brown et al. (2020), however, use panel regression techniques that take into account the different features of retail tariffs (such as renewable energy content and contract term). Which model is most suitable depends on the nature of the data (including the length and frequency), relevant test results (for instance, whether dependant and independent variables are co-integrated of the same order) and the hypotheses to be tested.

Notwithstanding differences in the methodological approach, empirical studies typically suggest that wholesale price changes do not contemporaneously[3] pass-through to retail prices in the short-run, but will pass-through over the long-run. Mulder and Willems (2019), for instance, examine the Nordic retail electricity market (from 2008 to 2014) using as asymmetric error correction model that includes contemporaneous wholesale prices as an explanatory variable and find no evidence of pass-through in the short-run, but there is evidence of long-run pass-through. In a study of the UK retail electricity market, Ofgem (2011) use an asymmetric error correction model that includes asymmetric contemporaneous wholesale prices as an explanatory variable and find evidence that wholesale prices do not pass through (either symmetrically or asymmetrically) in the short run, and that wholesale prices pass-through asymmetrically in the long-run.

In contrast to the common finding that wholesale prices do not pass through to retail prices contemporaneously, Hartley et al. (2019) use an ARDL (1,0) model and find evidence that wholesale spot prices[4] pass-through contemporaneously to retail prices for competitive (but not for non-competitive segments) of the Texas retail electricity market. Across all five competitive regions, Hartley et al. (2019) find a statistically significant relationship between wholesale and retail electricity prices (although pass-through is weak, varying from 0.0449 to 0.0722). However, a statistically significant relationship between wholesale and retail prices is found in only four of the eight non-competitive (pass-through varies between 0.0335 and 0.179).

In a similar study of the Texas retail electricity market, Brown et al. (2020) use a large sample of retail tariffs (over 5,000 retail tariffs offered by 80 retailers) and – unlike Hartley et al. (2019) – a forecast of forward-looking wholesale prices in Texas from January 2014 to December 2018. Applying panel regression techniques that take account of differences in the tariff characteristics (such as renewable content and contract term), they find pass-through is incomplete, varying between 43 and 47%. Importantly, they find pass-through varies between large and small retailers and suggest this reflects larger retailers exercising market power. Despite differences in how wholesale prices are measured and

[3] Contemporaneously refers to wholesale prices at time *t* passing through to retail prices at time *t*.
[4] Hartley et al. (2019) use hourly day-ahead spot prices from across the four zonal wholesale areas to construct a single monthly wholesale price series.

the methodological approach used in Brown et al. (2020) and Hartley et al. (2019), both studies find incomplete pass-through in Texas retail electricity market.

Some studies only test if contemporaneous changes in wholesale prices impact retail prices to test for wholesale pass-through in the short-run. However, empirical models including one or more lagged wholesale price variables generally find evidence that wholesale prices pass-through in the short-run. Notwithstanding evidence of short-run wholesale price pass-through, these studies tend to conclude that any pass-through of wholesale prices to retail prices in the short-run is slow and incomplete. Mirza and Bergland (2012), for instance, use a PAM model with five weekly lags in wholesale prices as explanatory variables and find most are statistically significant but pass through varies between 0 and 0.2 per week. Johnson and Olsen (2008) similarly study Nordic electricity markets (Norway, Sweden and Finland) using an ECM that includes short-run (but not long-run) asymmetry and find evidence that changes in wholesale prices begin to pass through to retail prices from one month and for up to three and eight months in Norway and Sweden, respectively. Johnson and Olsen (2008) similarly find that pass-through is generally slow in the short-run, varying from 0.2 to 0.6. The one exception reported by Johnson and Olsen (2008) is that wholesale price increases completely pass-through to retail prices in the first month in Norway (1.13).

Although empirical studies overwhelming demonstrate that wholesale prices do pass-through to retail prices in the long-run, the degree of wholesale price pass-through varies widely across studies. Mulder and Willems (2019), for instance, report incomplete asymmetric pass-through of wholesale to retail prices in the Dutch electricity market: wholesale price reductions and increases are passed on at a rate of 0.142 and 0.279, respectively. Mirza and Bergland (2012) generate higher estimates of wholesale price pass-through in the Norwegian market, but the pass-through is still incomplete in the long-run (they estimate around 85% of wholesale price changes are passed on). Hartley et al. (2019) similarly estimate weak and incomplete pass-through in competitive segments of the Texas retail market (estimates of long-run pass-through vary from 0.0449 and 0.0722).

However, Ofgem (2011) estimate much greater pass-through of wholesale price increases and decreases to UK retail electricity prices in the long-run. Ofgem estimates wholesale price decreases pass-through to retail prices in the long-run at rate of between 0.88 and 1.42, and wholesale price increases at a rate of between 1.12 to 1.82 (pass-through rates increase with the length of the hedging position 12, 18 and 24 months). Johnsen and Olsen (2008) similarly estimate more than complete pass through of symmetric wholesale price changes in the long-run in Norway (1.038) and Sweden (1.39).

Empirical evidence as to whether retailers asymmetrically pass-through wholesale price adjustments to retail tariffs over the long-run is mixed. Ofgem (2011), for example, use an asymmetric error correction model and find that customer bills in the UK responded more quickly to higher wholesale price changes in the long-run compared to lower wholesale prices from 2004 to 2010. Mirza and Bergland (2012) similarly find evidence of asymmetry in wholesale to retail price pass-through in the Norwegian retail electricity market using an asymmetric error correction model and weekly data from 2000 to 2010. Evidence of asymmetric wholesale price pass-through in Nordic market is also reported in an earlier study by Johnsen and Olsen (2008). However, a more recent study by Mulder and Willems (2019) finds no evidence for asymmetric price pass-through in the short or long-run for the Nordic retail electricity market.

However, the evidence of asymmetry and pass-through presented in the literature is greatly impacted by the way retail prices and wholesale prices are measured. For instance, Ofgem (2011) measures retail prices using an estimate of the average monthly bill of a dual-duel customer supplied by Big 6 retailers. Ofgem (2011) concede that their findings are “not necessarily reflective of any specific tariff with an individual supplier”. Hartley et al. (2019) similarly use data on “average” prices based on 1000 kWh residential consumption, following the approach of Hortacsu et al. (2015). Brown et al. (2020) take a broader approach and estimate retail prices based on three monthly usage levels (500, 1000 and 2000 kWh) across a sample of over 5,000 retail tariffs. None of these take into account the heterogeneity of household consumption and the full suite of retail tariffs on offer. Evidence that relates only the Big 6 retailers (as presented by Ofgem (2011)) may not reflect pass-through from wholesale to retail electricity prices across the UK market generally. Brown et al. (2020) make similar concessions in their study.

What wholesale price do retailers face? Many studies rely on the spot price to reflect the price paid for electricity by retailers in testing for wholesale price pass-through. For instance, Hartley et al. (2019) use hourly day-ahead spot prices from across the four zonal wholesale areas to construct a single monthly wholesale price series. Brown et al. (2020) estimates wholesale price using a  forward looking estimate over the period of the retail plan term (using a time-varying intercept, monthly weighted average 15-minute settlement prices, natural gas price and system net load as explanatory variables). However, retailers hedge against movements in the spot price. The approach of Brown et al. (2020), although forward-looking, does not take into account how retailers are likely to hedge their exposure to spot prices.

## 3. Data and Methodology

### 3.1 Data

We construct monthly estimates from January 2019 to March 2021 of retail electricity prices and wholesale prices. Monthly data is commonly used in the empirical literature and sufficient to capture wholesale pass-through to retail prices in competitive retail markets (see, for example, Mirza and Bergland (2012)). We acknowledge that the length of our sample (25 observations) is limited.

Following the approach in Mountain and Burns (2020a), we classify retailers into three categories based on market share. Tier 1 includes the three incumbent retailers (AGL, Energy Australia and Origin Energy). These retailers existed when the market was liberalised in 2003. Tier 1 firms own electricity generation assets that substantially or completely meet the needs of their customers. The three Tier 1 retailers (AGL, Origin and Energy Australia) together supply 54% of households with electricity. Tier 2 retailers are medium-sized new entrant retailers with a minimum of 3% and a maximum of 10% market share (Lumo, Red, Simply, Alinta, Momentum and Powershop). Tier 2 retailers often also own generators although the production from their generators is not likely to fully meet the needs of their customers. Tier 2 retailers supply electricity to 35% of all households. Tier 3 retailers are smaller new entrants (Tango, Sumo, GloBird, First Energy, BlueNRG, Covau, Diamond, People,Qenergy, Elysian, Energylocals and Powerclub) with less than 3% market share. Together they supply electricity to 11% of households.

*Wholesale electricity prices*

In practice retailers can be expected to have a wide range of possible hedging strategies combining swaps, caps and different levels of unhedged spot price exposure or exposure that is hedged through generation ownership (vertical integration). Such wholesale price strategies are, of course, commercially confidential.

Our approach might be considered appropriate for a relatively prudent retailer.[5] We assume that when a retailer releases an offer to the market, it estimates the wholesale price based on a hedged portfolio of

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[5] We explored a range of methods to estimate wholesale prices on a monthly basis, including model-based forecasts of spot price, a methodology proposed by GloBird Energy (a new entrant retailer that does not own generation), and the approach used by consultants Frontier Economics that is relied upon by the Essential Services Commission of Victoria to establish the VDO. We rejected the use of spot prices since these are not known ex-ante; model based estimates can not be relied upon for future estimates and because retailers are known to largely hedge their exposure. With regard to the approach proposed by Frontier Economics and GloBird Energy, we found that these approaches resulted in highly volatile monthly wholesale prices and which back-casting demonstrated were wholly unsuccessful in predicting actual prices, and which would have left retailers with substantial

contracts that leave the retailer with little spot market price risk for the coming 12 months. This is implemented by calculating the average price of quarterly baseload swaps for a forward looking period of 12-months. The price of quarterly baseload swaps is the trade-weighted price based on all trades 12 months prior to the execution of the swap. For instance, to estimate the WEC in January 2019, we take the simple average of the 2019 Q1 base swap 12-month trade weighted price, 2019 Q2 base swap 12-month trade weighted price, 2019 Q3 base swap 12-month trade weighted price and 2019 Q4 base swap 12-month trade weighted price.

*Network costs*

There are two options for accounting for network costs in undertaking an analysis of wholesale price pass-through in retail electricity markets. The first approach is to include network costs as an explanatory variable in the econometric model in order to control for the impact of network costs on retail bills (see, for instance, Mulder and Willems (2019) and Ofgem (2011)). This modelling approach estimates the impact of network costs on retail prices as well as the impact of wholesale prices. The limitation to this approach is that including network costs in the model may affect the estimate of the impact of spot prices on retail prices if the influence of the two explanatory variables (spot prices and network costs) cannot be accurately isolated by the estimation technique and model specification.

The alternative approach is to isolate network costs from consumer bills so that the relationship between wholesale spot prices and retail costs and margins can be isolated and analysed. This approach can only be adopted if unit record data on individual household electricity bills is known (to enable the exact network costs to be correctly isolated from household electricity bills). The first approach is traditionally adopted in the literature because household bill data is generally not known and prices are estimated based on homogenous household consumption profiles and assumptions about tariff type. This study, however, has access to household bill data to enable the exact network costs faced by individual households to be accurately deducted from retail prices. We therefore exclude network metering charges before establishing our retail price series. The advantage of this approach is that our econometric model does not carry the risk that our estimate of the impact of wholesale on retail prices will be influenced by the inclusion of network costs in our model (or changes in the way that retailers seek to recover network costs). The Network Use of Service (NUOS) tariffs and metering charges removed in our estimate of retail prices is presented in Appendix Table 7.

commercial losses had they been pursued. We therefore came to the conclusion that neither of these approaches could credibly be used to establish wholesale price series.

*Priced offers*

Consistent with the methodology of Mountain and Burns (2020b), we generate a time series of priced offers from January 2019 to March 2021 using a sample of 18,996 bills from households on flat rate tariffs (some of whom also have controlled loads). These bills were uploaded voluntarily to the Government of Victoria's price comparison website, and there is no reason to expect any material bias in this sample of bill data (for further details, see Mountain and Burns (2020a)).

We estimate the annual bill for each household using the prices in all available offers (typically around 200 competing offers are available to each household). These offers are obtained by automatically scraping the Victorian Government's price comparison website each day. The offers for one day in each month (typically the 16th day of each month) were selected to obtain the competing offers for each customer for each month. The estimated annual bills for all customers for each month are ranked, and we select the 10th, 50th and 90th percentile bill (excluding network and metering charges, as discussed) for each household for each month to establish three separate datasets each with 18,996 data points.

We then calculate the average price of electricity (cents per kWh) based on the annual consumption in each bill, for each of the 10th, 50th and 90th percentile data sets. We then take the median price across each dataset to establish three monthly retail price series. The price series is then segmented by dividing the data for retailers into three tiers (as described above).

Our study is limited to examining how wholesale prices pass-through to flat rate tariff prices, and cannot shed light on wholesale price pass-through to time-of-use tariffs. However, as noted earlier, the overwhelming majority of households in Victoria are on a flat rate tariff (Carbon and Energy Markets, 2017). We have no reason to believe that pass-through conclusions would be different for time-of-use tariff customers.

The time series of priced offers is based on a consistent set of household bill consumption data. This means that any change in the time series of retail bills reflects changes in retail prices only and not changes in household consumption.

*Dummy variables for significant regulatory changes*

Dummy variables are commonly used to account for significant regulatory changes in the empirical literature (see, for example, Hartley et al. (2019)). However, dummy variables to account for such changes are only likely to be useful if the number of regulatory changes over the sample period is not overly large.[6] We take account of any potential impact of the VDO (commencing on 1 July 2019 and described in the introduction) in our model using a dummy variable.

### 3.2 Methodology

As discussed in the literature review, the appropriate model for our study depends on the nature and characteristics of our data on wholesale and retail prices. For instance, if two variables are integrated of the same order and the residuals are stationary, there exists a long-run co-integrating relationship and an ECM is most suitable (Engle & Granger, 1987). We test whether the dependent and explanatory variables are integrated of the same order using the Augmented Dickey Fuller (ADF), Kwiatkowski-Phillips-Schmidt-Shin (KPSS) and Ng-Perron unit root tests (Table 8). Overall, the results are mixed but we generally find evidence the data are stationary in levels and opt to fit an ARDL model. The ARDL approach, unlike other approaches such as ECMs, can include several lagged wholesale prices as explanatory variables. Including lagged wholesale prices as explanatory variables can help capture any dynamic short-run wholesale price pass-through effects that are not contemporaneous and might otherwise not be captured (Hartley et al., 2019). We specify the symmetric ARDL model to explain movements in the retail prices offered by retailers as follows:

$$R_{\theta,t} = \alpha + \sum_1^{\lambda} \beta_\delta R_{\theta,t-\lambda} + \sum_0^{\gamma} \beta_\upsilon W_{t-\gamma} + D_t + \varepsilon_t \quad [1]$$

where:

$R_{\theta,t}$ is retail electricity price (cents per kWh) at time *t*, and $\theta$ takes values from 1 to 4 (where 1 = tier 1, 2 = tier 2, 3 = tier 3, 4 = all retailers),

$W_t$ is wholesale electricity price (cents per kWh) at time *t*,

D is a dummy variable to account for the VDO (where $D_1$ takes a value from 1 July 2019, and 0 otherwise).

We specify the asymmetric ARDL model to explain movements in the retail prices offered by retailers as follows:

$$R_{\theta,t} = \alpha + \sum_1^{\lambda} \beta_\delta R_{\theta,t-\lambda} + \sum_0^{\gamma} \beta_\upsilon W_{t-\gamma}^{+} + \sum_0^{\kappa} \beta_\upsilon W_{t-\kappa}^{-} + D_t + \varepsilon_t \quad [2]$$

where: $W_{t-\gamma}^{+} = \begin{cases} W_{t-\gamma} \\ 0 \end{cases} if \begin{cases} \Delta W_{t-\gamma} > 0 \\ \Delta W_{t-\gamma} < 0 \end{cases}$ and $W_{t-\kappa}^{-} = \begin{cases} 0 \\ W_{t-\kappa} \end{cases} if \begin{cases} \Delta W_{t-\kappa} > 0 \\ \Delta W_{t-\kappa} < 0 \end{cases}$

[6] In the study by Mulder and Willems (2019), the Dutch retail electricity market had experiences a large number of regulatory changes and this made it impossible to empirically assess the impact of these changes on price outcomes.

The Akaike Information Criterion (AIC) is used to determine number of lags in equations [1] and [2].

*Model diagnostics*

We apply a range of model and residual diagnostics and testing to ascertain the suitability and reliability of our model specifications and estimation results. The models' goodness model fit is measured using the adjusted $\bar{R}^2$. The ADF test is used to determine whether the residuals are stationary. We test for pure and impure serial correlation in the residuals at lags 1, 3 and 6 (Breusch-Godfrey Serial Correlation LM test). We also test whether the residuals from the estimated models are normally distributed (Jarque-Bera test) and heteroskedastic (Breusch-Pagan-Godfrey test). To assess the appropriateness of the functional form (specifically, whether a nonlinear term is omitted), we apply the RESET test. To assess whether the symmetric or asymmetric model provides a better explanation of movements in retail prices, we apply a non-nested model selection test (Log Likelihood ratio test). Estimating both symmetric and asymmetric models across all price percentiles and retailer tiers also enables sensitivity analysis to be performed. The results are also assessed in terms of whether they can credibly explain the movements in retail prices across tiers and percentiles observed in recent times. On the basis of these results, we select either the symmetric or asymmetric model for each price percentile and retailer tier that best explains movements in retail prices, and rely upon that model for our hypothesis testing and analysis of findings.

*Our research questions*

If Victoria's retail electricity market is highly competitive, wholesale prices will pass-through to retail prices quickly, completely, symmetrically and not vary across retailers and/or offers. We also test whether the VDO affected prices. Using equations [1] and [2], we test the following hypothesis:

H1: Pass-through is dynamic

H2: Pass-through is complete

H3: Pass-through is symmetric

H4: Pass-through varies across retailers and offers

H5: VDO impacted retail prices

We test H1 by testing the statistical significance of the estimated coefficient on the lagged WECs in equation [1]. If the lagged estimated coefficient on the lagged WECs in equation [1] are statistically significant, we conclude pass-through is dynamic.

H2 is assessed by testing whether the estimated coefficient on the WECs variables in equation [1] are equal to one. If the estimated coefficient is not statistically different to one, we conclude pass-through is complete.

We test H3 by testing whether the estimated coefficients on the asymmetric WECs in equation [2] are statistically equal. If the estimated coefficient on the positive and negative asymmetric WEC variables are not statistically different, we conclude pass-through is symmetric.

H4 is assessed by comparing the significance and magnitude, as well as evidence of dynamics and asymmetry, in the estimated coefficients on the WEC variables across the different retailer tiers and percentile offers.

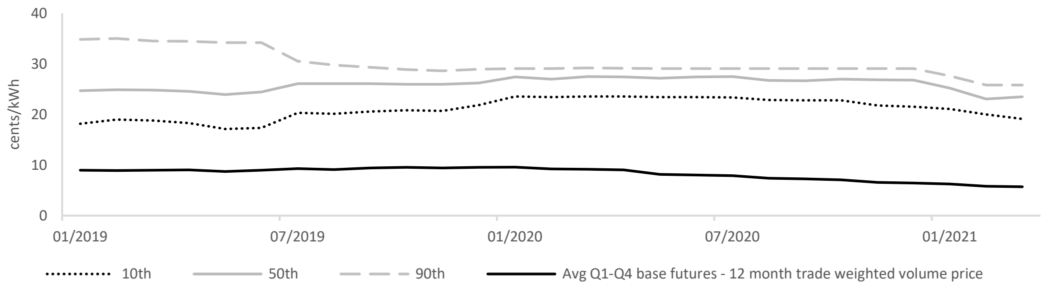
Finally, we test H5 by testing whether the estimated coefficient on the VDO dummy variable is statistically significant. If the estimated coefficient on the VDO variable is statistically significant, we conclude the VDO impacted retail prices.

## 4. Preliminary analysis

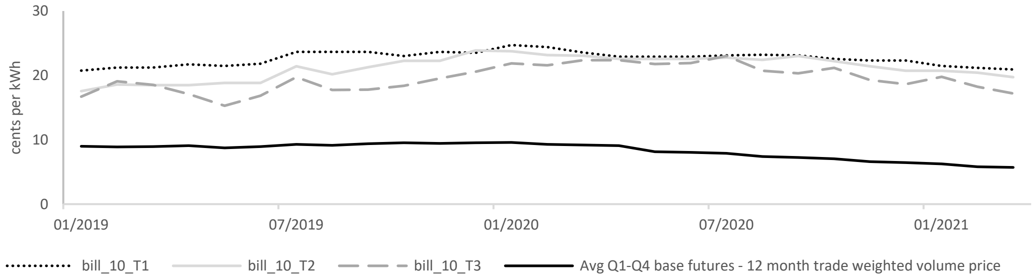
Having established the monthly wholesale prices and retail prices across the $10^{th}$, $50^{th}$ and $90^{th}$ percentile and the three retailer tiers from January 2019 to March 2021, we observe that trends in retail prices vary markedly measured at the different percentiles and retailer tiers as shown in Figure 1. Overall, the price of the $90^{th}$ percentile price has fallen, the $10^{th}$ percentile has risen, and median offers have remained largely unchanged. Tier 3 retailers have the highest $90^{th}$ percentile and lowest $10^{th}$ percentile prices. On the other hand, Tier 1 retailers offer the most expensive $10^{th}$ percentile offers, and some of the lowest $90^{th}$ percentile offers. Visually, the introduction of the VDO had a measureable impact on the $10^{th}$ and $90^{th}$ percentile offers, and to a lesser extent on median offers.

**Figure 1. Wholesale prices and net retail electricity prices, by retailer tier and price percentile, January 2019 to March 2021**

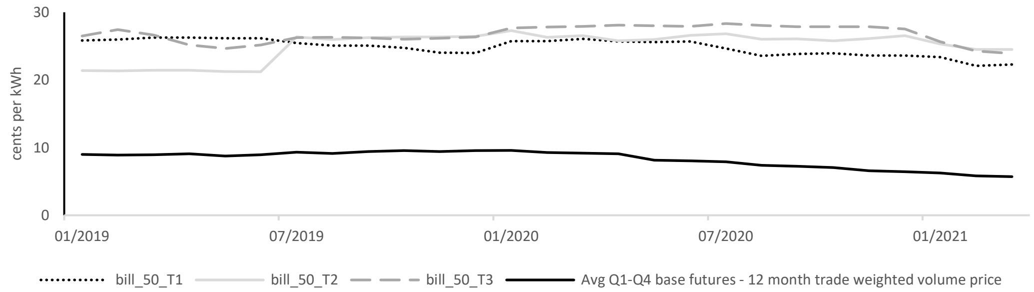
*1.A - all retailers, by percentile offer*



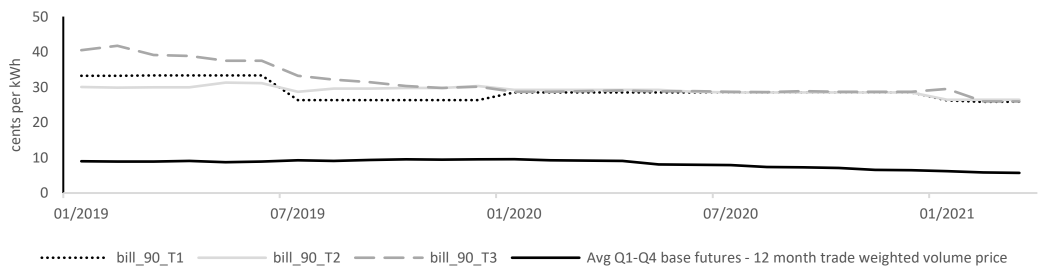

*1.B – 10th percentile offers, by retailer tier*




*1.C – 50th percentile offers, by retailer tier*




*1.D – 90th percentile offers, by retailer tier*




Summary statistics further highlight there are substantial differences in prices offered (level and variance) across retailers and offers (Table 1).

**Table 1. Summary statistics for wholesale and retail prices, January 2019 to March 2021**

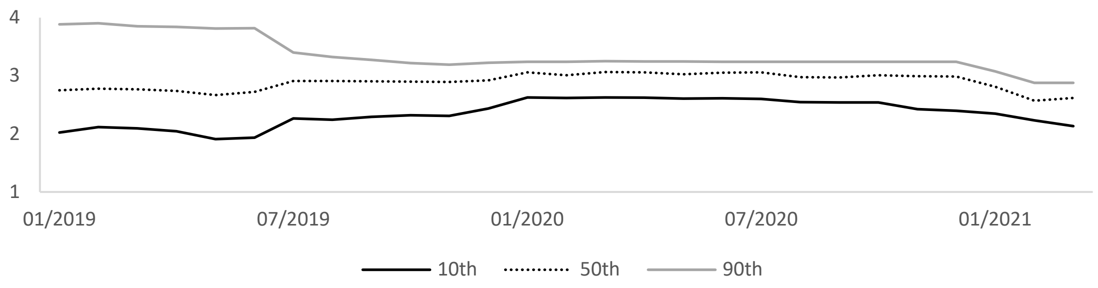
| | Wholesale price | 10th percentile offers | | | | 50th percentile offers | | | | 90th percentile offers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | All retailers | Tier 1 | Tier 2 | Tier 3 | All retailers | Tier 1 | Tier 2 | Tier 3 | All retailers | Tier 1 | Tier 2 | Tier 3 |
| Average | 8.28 | 21.09 | 22.62 | 21.22 | 19.53 | 25.96 | 24.83 | 25.04 | 26.73 | 30.07 | 28.80 | 29.07 | 31.41 |
| Max | 9.58 | 23.56 | 24.71 | 23.87 | 23.01 | 27.49 | 26.26 | 27.29 | 28.33 | 35.02 | 33.32 | 31.29 | 41.72 |
| Min | 5.70 | 17.13 | 20.74 | 17.55 | 15.28 | 23.06 | 22.08 | 21.21 | 23.91 | 25.82 | 25.82 | 26.43 | 25.94 |
| Std dev. | 1.26 | 2.08 | 1.10 | 1.84 | 2.06 | 1.31 | 1.24 | 2.10 | 1.30 | 2.64 | 2.65 | 1.22 | 4.53 |

The level of, and changes in, the ratio of retail to wholesale prices can indicate whether competition is improving market outcomes. A declining ratio of retail to wholesale suggests that competition is reducing costs and prices (Hartley et al., 2019). In Figure 2, we show the ratio of retail to wholesale across retail offers and retailers from January 2019 to March 2021. In early 2019, the ratio of 10$^{th}$ percentile offers to wholesale prices was around 2 – meaning the gross mark-up for retailers' cheapest offers was around 100%. This compares to 90$^{th}$ percentile offers, where the retailer mark-up was around 300% over the same period. Compared to the study of Mulder and Willems (2019) which reports a mark-up of around 50%, the ratio of retail to wholesale prices in Victoria is relatively much higher.

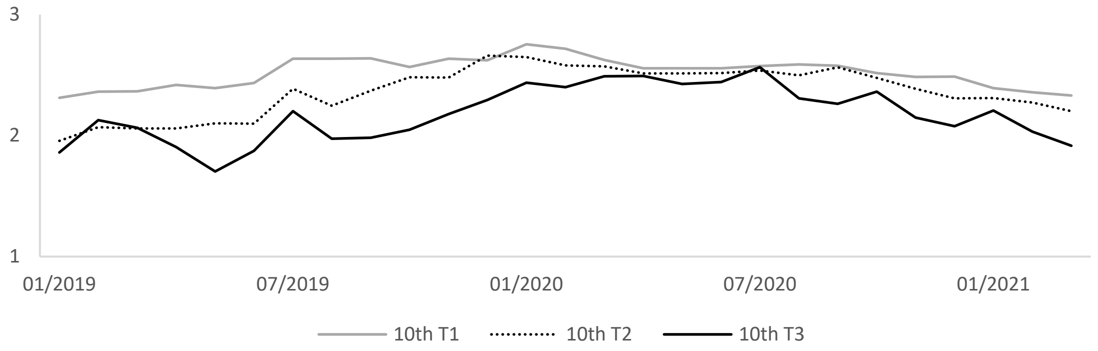
From January 2019 to March 2021, the mark-up on the most expensive offers fell substantially (down from approximately 4 to 3). There has been little change in the mark-up of median offers, while the mark-up increased for the cheapest offers slightly. Overall, we find the lowest mark-up is on Tier 3 retailers' 10$^{th}$ percentile offers, whereas highest mark-up is on Tier 3 retailers' 90$^{th}$ percentile offers.

**Figure 2. Ratio of retail to wholesale prices, January 2019 to March 2021**

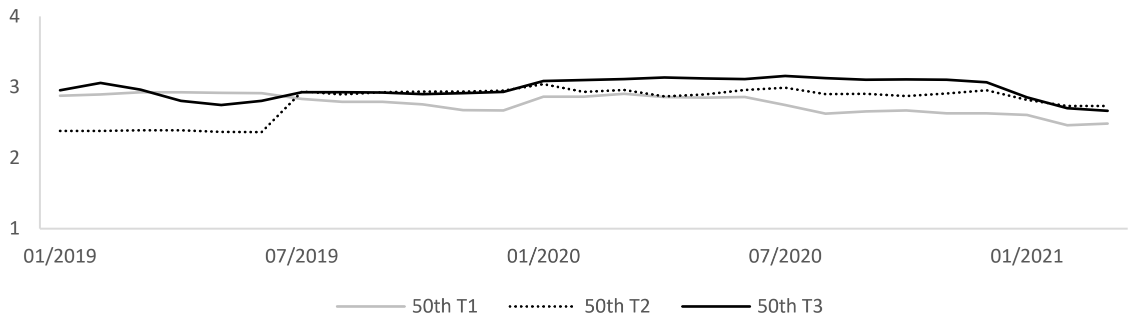
*2A. All retailers*




*2B. 10th percentile offers*




*2C. 50th percentile offers*




*2D. 90th percentile offers*

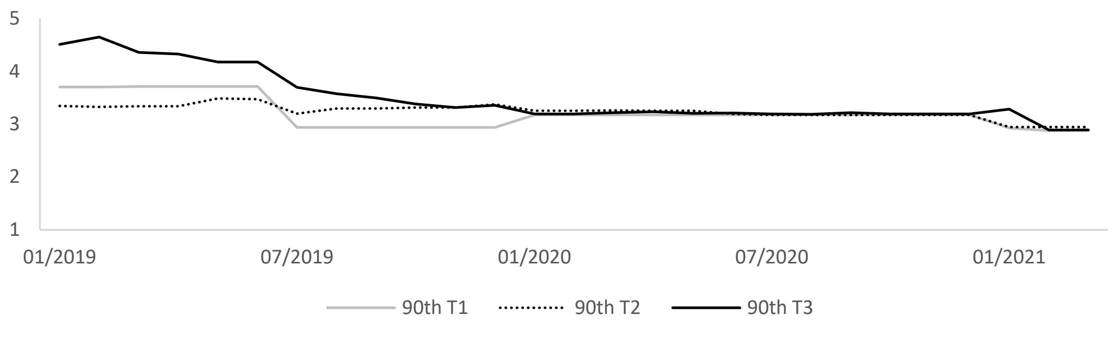
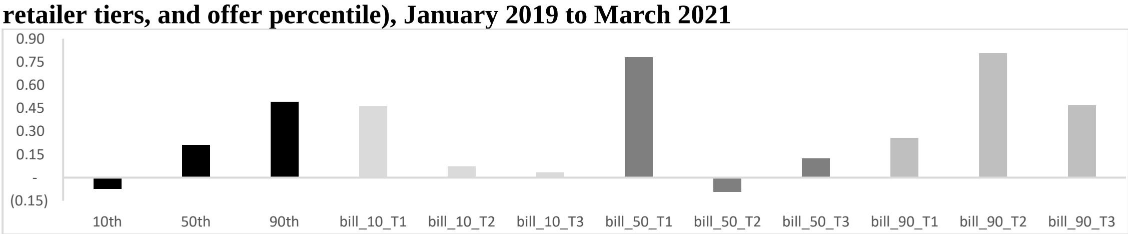


Figure 2 presents the contemporaneous correlation between wholesale and retail prices (cents per kWh) for 10th, 50th and 90th percentile offers for each retailer tier), from January 2019 to March 2021. Overall, there is a positive contemporaneous correlation between wholesale and retail prices. However, there are some important and notable differences in terms of the strength and direction of the association between retail and wholesale prices. Correlation is strongest for most 90th percentile offers made by Tier 2 retailers, and median offers by Tier 1 retailers. On the other hand, correlation is weakest for 10th percentile offers made by Tier 3 retailers. There is a weak but negative correlation between wholesale prices and 10th percentile offers (all retailers), and median offers for Tier 2 retailers.

**Figure 3. Correlation coefficient between wholesale prices and retail electricity prices (all retailers, by retailer tiers, and offer percentile), January 2019 to March 2021**




## 5. Results

We estimate equation [1] and [2] for the 10th, 50th and 90th percentile offers, for each of the retailer tiers (full estimation results for both symmetric and asymmetric models are presented in Appendix Table 9, and model diagnostics are reported in Table 10, Table 11 and Table 12). Overall, the models provide an exceptional fit of the data. In general, the null hypothesis that there is no omitted nonlinear terms cannot be rejected across the symmetric and asymmetric ARDL models for all price percentiles and across all retailer tiers. We are therefore confident of the linear functional form fitted to the data. There is little evidence that the residuals of any of the estimated models suffer from non-normality,[7] heteroscedasticity, serial correlation or non-stationarity.

Non-nested model selection test results are, however, mixed (see Table 10, Table 11 and Table 12). This highlights the inherent differences in how different retail prices made by different retailers can move in response to wholesale prices. Notwithstanding this, the symmetric and asymmetric models produce estimated coefficients generally very similar in magnitude and direction across all price percentiles and retailer tiers. This suggests our final model specifications are robust to sensitivity analysis.

[7] Despite some model residuals failing the normality test, a visual inspection of the residuals do appear approximately normally distributed. We anticipate that the small number of observations may account for the residuals failing to meet the normality test in some instances.

Having assessed the non-nested model selection tests, model diagnostics and having applied a sanity check to the estimated results, we determine the most appropriate ARDL model for each price percentile and retailer tier. The final ARDL estimation results for each of the retailer tiers at the 10th, 50th and 90th percentile retail prices are presented in Table 2, Table 3 and Table 4, respectively. Importantly, the estimated coefficients are plausible with respect to movements in retail prices observed following the introduction of the VDO (Figure 1).

*Cheapest segment of the market (10th percentile offers)*

For Tier 3 retailer 10th percentile offers, we find a statistically significant relationship between (symmetric) wholesale and retail prices after a four month lag ($W_{t-4}$) (Table 3), and we cannot reject $H_0: W_{t-4} = 1$ (Table 13). We therefore find Tier 3 retailers pass-through wholesale prices to their cheapest offers completely and symmetrically, and the pass-through takes around 4 months to occur.

For Tier 1 retailers cheapest offers, we find a statistically significant relationship between (symmetric) contemporaneous WECs ($W_t$) and retail prices (Table 2). However, the estimated coefficient on contemporaneous WECs is statistically different to one (we reject $H_0: W_t = 1$ , see Table 13) and there is no evidence of asymmetry (based on the non-nested model selection tests, see Table 10). For Tier 2 retailers cheapest offers, we find a statistically significant relationship between asymmetric contemporaneous WECs ($W_t^+$ and $W_t^-$) and retail prices (Table 2). The estimated coefficients on contemporaneous asymmetric WECs are statistically different to one (we reject $H_0: W_t^+ = 1\ and\ H_0: W_t^- = 1$, see Table 13) and these estimated coefficients are not statistically different (we cannot reject $H_0: W_t^+ = W_t^-$, see Table 14). We estimate Tier 1 and 2 retailers pass-through around 40 and 30% of wholesale price movements in the 10th percentile offers, respectively, and the pass-through is instantaneous and symmetric (Table 2).

The estimated coefficients on the VDO dummy variable are statistically significant for all 10th percentile offers across all retailer tiers (Table 2). We estimate the introduction of the VDO increased the cheapest offers by Tier 3 retailers more than their counterparts (around 2.3 cents per kWh for Tier 3, compared to 1.3 cents per kWh for Tier 1).

**Table 2. ARDL estimation results, 10th percentile offers**

| Table 2a | | Table 2b | | Table 2c | |
|---|---|---|---|---|---|
| Tier 1 ARDL estimation results – 50th percentile offers<br>Symmetric ARDL (1,0) | | Tier 2 ARDL estimation results – 50th percentile offers<br>Asymmetric ARDL (2,1,0) | | Tier 3 ARDL estimation results – 50th percentile offers<br>Symmetric ARDL (1,4) | |
| Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) |
| $R_{\theta,t-1}$ | 0.35**<br>(0.147) | $R_{\theta,t-1}$ | 0.38**<br>(0.174) | $R_{\theta,t-1}$ | 0.34<br>(0.211) |
| $W_t$ | 0.42***<br>(0.091) | $R_{\theta,t-2}$ | 0.34**<br>(0.150) | $W_t$ | -0.96<br>(1.157) |
| VDO | 1.34***<br>(0.395) | $W_t^+$ | 0.29**<br>(0.121) | $W_{t-1}$ | 0.78<br>(1.436) |
| C | 10.19***<br>(2.632) | $W_{t-1}^+$ | 0.07*<br>(0.037) | $W_{t-2}$ | -1.28<br>(1.026) |
| | | $W_t^-$ | 0.31**<br>(0.137) | $W_{t-3}$ | -0.52<br>(1.196) |
| | | VDO | 1.39***<br>(0.474) | $W_{t-4}$ | 3.09**<br>(1.104) |
| | | C | 2.31<br>(2.072) | VDO | 2.27**<br>(0.921) |
| | | | | C | 0.93<br>(2.625) |

Notes: An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

*Middle of the market (50th percentile offers)*

For Tier 3 retailers, the estimated coefficient on the one month lagged (symmetric) WEC variable ($W_{t-1}$) is positive and statistically significant (Table 3), and we cannot reject $H_0 = W_{t-1}$ (see Table 13). We conclude Tier 3 retailers take around 1 month to fully pass-through wholesale prices to their median offers.

For Tier 1 retailers, the estimated coefficient on the contemporaneous asymmetric WEC variables ($W_t^+$ and $W_t^-$) are positive and statistically different (Table 3). The estimate coefficients are not statistically different to each other (we cannot reject $H_0: W_t^+ = W_t^-$, see Table 14). However, both estimated coefficients are statistically different to one (we reject $H_0: W_t^+ = 1 \; and \; H_0: W_t^- = 1$ , see Table 13) and we estimate Tier 1 retailers only pass-through around 40% of wholesale prices to median offers. We find the pass-through of WEC to Tier 1 median offers is incomplete, immediate and symmetric.

For Tier 2 retailers, the estimated coefficients on the contemporaneous asymmetric WEC variables ($W_t^+$ and $W_t^-$) are positive, but only statistically significant at 10% level of significance (Table 3). On the basis of these results, it might be concluded that Tier 2 retailers' pass-through WECs to median offers instantaneously. However, none of the estimated coefficients on any of the WEC variables satisfy the normal threshold of statistical significance at 5% level of significance, whereas the VDO is highly significant (discussed further below). These results are further confirmed with the symmetric model results (Table 9). As we also observe in Figure 1, median offers by Tier 2 retailers are mostly impacted by the VDO as opposed to movements in WECs. Taken together, these results indicate median offers by Tier 2 retailers have been predominantly influenced by the VDO and WECs have had little if any influence.

The estimated coefficients on the VDO dummy variables are statistically significant for 50th percentile offers made by Tier 1 and Tier 2 retailers (Table 3). However, the estimated impact of the VDO on median offers across retailer tiers is quite different. In response to the VDO, we estimate median offers for Tier 1 retailers decreased by almost 1 cent per kWh, whereas Tier 2 retailers decreased median offers by 3 cents per kWh (Tier 3 retailers did not change their median offers in response to the VDO).

**Table 3. ARDL estimation results, 50th percentile offers**

| Table 3a | | Table 3b | | Table 3c | |
|---|---|---|---|---|---|
| Tier 1 ARDL estimation results – 50th percentile offers Asymmetric ARDL (1,0,0,) | | Tier 2 ARDL estimation results – 50th percentile offers Asymmetric ARDL (4,3,2) | | Tier 3 ARDL estimation results – 50th percentile offers Symmetric ARDL (4,1) | |
| Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) |
| $R_{\theta,t-1}$ | 0.51*** (0.141) | $R_{\theta,t-1}$ | 0.29* (0.137) | $R_{\theta,t-1}$ | 1.01*** (0.210) |
| $W_t^+$ | 0.38*** (0.108) | $R_{\theta,t-2}$ | 0.03 (0.137) | $R_{\theta,t-2}$ | -0.24 (0.335) |
| $W_t^-$ | 0.77 (0.902) | $R_{\theta,t-3}$ | -0.32** (0.141) | $R_{\theta,t-3}$ | -0.16 (0.365) |
| VDO | -0.92** (0.332) | $R_{\theta,t-4}$ | 0.34 ** (0.117) | $R_{\theta,t-4}$ | 0.60** (0.232) |
| C | 9.35*** (3.054) | $W_t^+$ | 1.39* (0.726) | $W_t$ | -0.56 (0.522) |
| | | $W_{t-1}^+$ | 0.44 (0.649) | $W_{t-1}$ | 1.13** (0.506) |
| | | $W_{t-2}^+$ | -1.35* (0.653) | VDO | 0.36 (0.546) |
| | | $W_{t-3}^+$ | -0.13* (0.060) | C | -10.75 (6.262) |
| | | $W_t^-$ | 1.45* (0.736) | | |
| | | $W_{t-1}^-$ | 0.47 (0.661) | | |
| | | $W_{t-2}^-$ | -1.35* (0.655) | | |
| | | VDO | 3.25*** (0.689) | | |
| | | C | 10.41*** (2.861) | | |

$R_{\theta,t-1}R_{\theta,t-1}R_{\theta,t-1}W_t^{+}R_{\theta,t-2}R_{\theta,t-2}W_t^{-}R_{\theta,t-3}R_{\theta,t-3}R_{\theta,t-4}R_{\theta,t-4}W_t^{+}W_tW_{t-1}^{+}W_{t-1}W_{t-2}^{+}W_{t-3}^{+}W_t^{-}W_{t-1}^{-}W_{t-2}^{-}$

Notes: An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

*Top end of the market (90th percentile offers)*

For Tier 2 retailers most expensive offers, the estimated coefficient on the contemporaneous asymmetric WEC variables ($W_t^+$ and $W_t^-$) are positive and statistically significant (Table 4). The estimated coefficients are statistically equal (we cannot reject $H_0: W_t^+ = W_t^-$, see Table 14) but are not statistically different to one (we cannot reject $H_0: W_t^+ = 1, or\ H_0: W_t^- = 1$, see Table 13). We conclude that Tier 2 retailer's pass-through WECs completely, symmetrically and immediately.

For Tier 1 retailers most expensive offers, the estimated coefficient on the asymmetric WECs variables are statistically significant for contemporaneous WEC increases ($W_t^+$) (Table 4). For WEC decreases, the estimated coefficients are statistically significant up to a 2 month lag ($W_t^-, W_{t-1}^-, W_{t-2}^-$) (Table 4). The estimated coefficients at time $t$ are statistically different to one (we reject $H_0: W_t^+ = 1 \ and \ H_0: W_t^- = 1$, see Table 13) but are not statistically different to each other (we cannot reject $H_0: W_t^+ = W_t^-$, see Table 14). We conclude that Tier 1 retailers incompletely pass-through wholesale prices to their most expensive offers, and that falling wholesale prices take around 2 months longer to pass-through compared to rising wholesale prices.

For Tier 3 retailers most expensive offers, the estimated coefficient on the WEC variable ($W_t$) is not statistically significant (Table 4). Tier 3 retailers therefore exhibit no pass-through to their most expensive offers.

The estimated coefficients on the VDO dummy variables are negative and statistically significant across all retailer tiers 90th percentile offers. We estimate the VDO reduced the most expensive offers of Tier 1 retailers the most (almost 7 cents per kWh), followed by Tier 3 (around 4 cents per kWh) and Tier 2 (just over 1 cent per kWh) retailers.

**Table 4. ARDL estimation results, 90th percentile offers**

| Table 4a | | Table 4b | | Table 4c | |
|---|---|---|---|---|---|
| Tier 1 ARDL estimation results – 90th percentile offers<br>Asymmetric ARDL (1,0,2) | | Tier 2 ARDL estimation results – 90th percentile offers<br>Asymmetric ARDL (3,0,2) | | Tier 3 ARDL estimation results – 90th percentile offers<br>Symmetric ARDL (1,0) | |
| Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) | Variable | Estimated coefficient (std. error) |
| $R_{\theta,t-1}$ | 0.03<br>(0.119) | $R_{\theta,t-1}$ | 0.15<br>(0.206) | $R_{\theta,t-1}$ | 0.53***<br>(0.103) |
| $W_t^+$ | 0.26*<br>(0.139) | $R_{\theta,t-2}$ | 0.05<br>(0.204) | $W_t$ | 0.29<br>(0.173) |
| $W_t^-$ | 0.45**<br>(0.165) | $R_{\theta,t-3}$ | -0.46*<br>(0.228) | VDO | -4.27***<br>(1.036) |
| $W_{t-1}^-$ | 0.14***<br>(0.047) | $W_t^+$ | 0.82***<br>(0.181) | C | 15.49***<br>(3.535) |
| $W_{t-2}^-$ | 0.13**<br>(0.045) | $W_t^-$ | 0.78***<br>(0.189) | | |
| VDO | -6.73***<br>(0.903) | $W_{t-1}^-$ | 0.06*<br>(0.031) | | |
| C | 28.56***<br>(4.009) | $W_{t-2}^-$ | 0.06<br>(0.034) | | |
| | | VDO | -1.43***<br>(0.375) | | |
| | | C | 31.04***<br>(7.809) | | |

Notes: An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

We summarise the aforementioned results in relation to our five testable hypotheses as follows:

*H1: Pass-through is dynamic*

Table 5 summarises how many months it takes for wholesale prices to pass-through to the various offers and retailer tiers. Retailer generally pass-through wholesale prices quickly, ranging from immediately to up to 4 months later. We find some important differences in the dynamics of the pass-through across retailers and offers. First, pass-through is quickest for the 10$^{th}$ percentile offers and longest for the 90$^{th}$ percentile offers. Second, Tier 1 retailers (vertically integrated incumbent firms) and Tier 2 retailers pass-through wholesale prices faster than Tier 3 retailers. Third, Tier 1 and 2 retailers take around one month longer to pass-through wholesale price declines to their most expensive offers, compared to wholesale price increases. Interestingly, we estimate that Tier 2 retailers take one month longer to pass-through wholesale price increases in their cheapest offers.

**Table 5. Summary of duration for wholesale prices to pass-through to retail prices**

| | All retailers | Tier 1 | Tier 2 | Tier 3 |
|---|---|---|---|---|
| 10$^{th}$ percentile offers | 1 | 0 | 0 – 1 (+)<br>0 (-) | 4 |
| 50$^{th}$ percentile offers | 1 | 0 | 0 | 1 |
| 90$^{th}$ percentile offers | 3 | 0 (+)<br>0 – 2 (-) | 0 (+)<br>0 – 1 (-) | No pass-through |

*H2: Pass-through is complete*

We find Tier 1 (incumbent firms) do not fully pass-through wholesale prices across any of their offers. Tier 2 retailers, however, pass through wholesale prices to all but their cheapest offers. The smallest retailers, Tier 3, exhibit complete pass-through to their retail prices (excluding their most expensive offers, however, these attract almost no customers).

*H3: Pass-through is symmetric*

We find no evidence that wholesale prices pass-through asymmetrically to retail prices. However, there is some evidence of asymmetry in the time taken for wholesale prices increases and decreases to pass-through for some retailers and offers. In particular, Tier 1 and 2 retailers take slightly longer to pass-through wholesale price declines compared to increases to their most expensive offers. On the other hand, Tier 2 retailers take slightly longer to pass-through wholesale price increases to their cheapest offers.

*H4: Pass-through varies across retailers and offers*

As demonstrated by the results discussed to this point, the magnitude and rate of wholesale price pass-through varies markedly across different offers in the market, and across different offers made by different retailers when classified by tier. Most notably, incumbent firms (Tier 1) do not fully pass-through wholesale prices, whereas new entrants (Tier 3) do. There are also small differences in the time taken to pass-through movements in wholesale prices.

*H5: The VDO impacted retail electricity prices*

The results find that the VDO had a statistically significant impact on all retail prices made by all retailers, with the exception of 50th percentile offers by Tier 3 retailers (Table 6). However, there are important differences in whether the VDO increased or decreased retail prices. For instance, the VDO increased the 10th percentile offers for Tier 3 retailers by around 1 cent per kWh whereas it reduced the 90th percentile offers by almost 3 cents per kWh.

There are other noticeable differences in terms of the magnitude of the pricing response to the VDO across retailer tiers. For instance, Tier 3 retailers increased cheapest offers by almost twice that of Tier 1 and 2 retailers. On the other hand, the median offer of Tier 3 retailers was not influenced by the VDO whatsoever.

**Table 6. Summary results, t-test whether estimated coefficient on VDO Dummy variable is statistically significant**

| | **All retailers** | **Tier 1** | **Tier 2** | **Tier 3** |
|---|---|---|---|---|
| 10th percentile offers | 1.07** (0.370) | 1.34*** (0.395) | 1.39*** (0.474) | 2.27** (0.921) |
| 50th percentile offers | 0.07 (0.537) | -0.92** (0.332) | 3.25*** (0.689) | 0.36 (0.546) |
| 90th percentile offers | -2.70*** (0.614) | -6.73*** (0.903) | -1.43*** (0.375) | -4.27*** (1.036) |

Notes: An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

## 6. Discussion

Segmenting the market of offers by retailer tier and by percentile has delivered a rich understanding of the way that wholesale prices pass-through into retail offers. The main results can be summarised as follows:

1. At the cheap end of the market (measured using the 10th percentile cheapest offers) only the Tier 3 retailers fully pass-through wholesale price movements in their offers, with a four month

lag. Tier 1 and Tier 2 retailers pass through 40% and 30%, respectively, albeit with no lag. A possible explanation for the four month lag is the Tier 3 retailers' response to the obligation – under the VDO regulations – to notify customers of savings that are available if they were supplied on the retailer's cheapest available offer. In particular, noting the finding in Mountain and Burns (2020) that Tier 3 retailers typically increase prices to their customers more quickly than Tier 2 and Tier 1 (i.e. relative to Tier 2 they penalise loyalty) Tier 3 retailers may have responded to the VDO by seeking to reduce the risk that existing customers would switch to their cheaper tariffs by lagging the pass-through of declining wholesale prices in their offers to new customers. This can be seen in the narrowing gap (see Figure 1.B) between the average Tier 3 10$^{th}$ percentile offer compared to the average Tier 1 and Tier 2 10$^{th}$ percentile offers since the introduction of the VDO. It also notable that our finding for Tier 1 and 2 retailers (who together serve 89% of the Victorian retail market) is broadly consistent with findings on the Texas retail electricity market by Brown et al. (2020).

2. In the middle of the market (measured using the 50$^{th}$ percentile offers and segmented by retail tier), Tier 1 retailers again passed through around 40% of the wholesale price changes. Tier 2 retailers fully pass-through with no lag. Tier 3 retailers' median offers remained consistently higher than those of Tier 1 or Tier 2's median offers. However, Tier 3 retailers once again fully pass through wholesale prices and with only a one month lag. The full pass-through in this segment of the market for Tier 2 retailers is consistent with the suggestion in Mountain and Burns (2020) that Tier 2 retailers compete mainly in this segment of the market. This is also seen in the evidence that Tier 2 retailers generally having the most competitively priced median offers (see Table 1 and Figure 1).
3. At the top of the market (measured using the 90$^{th}$ percentile offers), the VDO is more likely to influence prices than wholesale price changes (recalling that the VDO applies strictly to customers that had not previously switched retailer and whose prices were typically much higher than those of customers who had switched). This can be seen in the much lower standard errors for the VDO coefficient estimate in the 90$^{th}$ percentile model than for the 10$^{th}$ and 50$^{th}$ percentile models across all retailer tiers. Although Tier 3 retailers had no customers on standing offers (and so unlike Tier 1 retailers they were not directly affected by the VDO) before the introduction of the VDO, they nonetheless had a marketing incentive to also offer high priced offers in order to present a high stated percentage discount in their cheapest offers and hence improved the perceived attractiveness of those cheaper offers. The VDO eliminated this incentive since it required that the stated discounts in retailers' offers had to be expressed with reference to the VDO.
4. With respect to the overall impact of the VDO, the models find that average 10$^{th}$ percentile offers rose for all three tiers, but the increase was the largest for Tier 3 retailers and the least

for Tier 1 retailers. Effectively the gap between Tier 3 and Tier 1 retailers' narrowed as Tier 3 raised the price of their cheapest offers more than Tier 1 retailers. This is consistent with the pattern of prices in Figure 1.B. For the 50$^{th}$ percentile offers, the VDO had no effect for Tier 3 retailers' prices, slightly reduced Tier 1 retailers' prices and increased meaningfully Tier 2 prices. This is consistent with the pattern of prices in Figure 1.C. At the upper end of the market (90$^{th}$ percentile), the VDO brought prices down in all three tiers but more so for Tier 1 (some of whose customers were directly affected by the VDO).

The reliability of wholesale pass-through estimates depend on appropriate estimates of wholesale and retail prices. In the Victorian situation, the analysis is complicated further by the introduction of a default offer in the early stages of our study. The VDO directly affected only a small number of customers of the Tier 1 retailers, while it is likely to have indirectly affected the offers of all retailers. Similarly, changes to the regulations on the presentation of discounts and savings available on best offers is also likely to have affected retailers' offers. Our analysis delivers results that align plausibly with the observed offers, and with our prior understanding of prices and Available Savings, segmented by retailer tier in Mountain and Burns (2020). Our finding of complete pass-through for Tier 3 retailers at the bottom end of the market (albeit lagged by four months) is consistent with the proposition that the new entrant (Tier 3) retailers compete mainly on price. In addition, the finding of incomplete pass through for Tier 2 and Tier 3 at the 10$^{th}$ percentile end of the market is consistent with the conclusion in Mountain and Burns (2020) that retailers in these tiers compete less vigorously on price and their prices are more stable than those of Tier 3 retailers.

Does this analysis lend itself to a general conclusion on wholesale price pass-through in the Victoria's retail electricity market? Since Tier 1 and 2 retailers supply 89% of the market, and most of the circa 660,000 switchers each year will be between customers that were supplied by a Tier 1 or Tier 2 retailer that switched to an offer from another Tier 1 or 2 retailer, it might be concluded that the Victorian retail electricity market is, generally, characterised by incomplete pass-through over the period of this study.

What do these results mean for conclusions on the competitiveness of the Victorian retail electricity market? Much of the literature in other countries tends to the view that the rate of wholesale price pass-through (and the symmetry of pass-through) is an indicator of the competitiveness of the market. Hartley et al. (2019) suggest electricity reform (including retail unbundling) sought to ensure that prices more accurately reflected marginal costs. Von Der Fehr and Hansen (2010) distinguish "active" consumers (high pass-through) from inactive consumers' (low pass-through) and that low pass-through suggests retailers exploit the passivity of some customers. Mirza and Bergland (2012) similarly distinguish dominant retailers who pass through wholesale prices at around half the rate of their new entrant counterparts and characterise the former as exercising market power. Mulder and Willems (2019) suggest that low search and switch costs and barriers, as well as engaged consumers, are essential for effective pass-through of wholesale to retail prices (and thus market efficiency). Following this strand of thought, the Victorian market might be consistent with the characterisation abroad of dominant retailers exploiting disengaged consumers with low rates of pass-through, and new entrant retailers catering for active customers and quickly passing-through wholesale price changes.

An alternative perspective – see for example Littlechild (2002) – recognises that consumers have diverse preferences and so the relatively lower rate of pass-through amongst the Tier 1 and 2 retailers reflects some consumers' preferences for stable prices and hence, necessarily, lower rates of wholesale price pass-through. This is consistent also with the observed lower volatility of 10$^{th}$ and 50$^{th}$ percentile prices amongst the Tier 1 and 2 retailers compared to the Tier 3 retailers (see Table 1). From this perspective, the observed pass-through rates amongst different cohorts of retailers reflects a market effectively catering to consumers' diverse preferences.

Finally, vertical integration might contribute to the explanation of the lower rate of pass through amongst the Tier 1 and 2 retailers, compared to the Tier 3 retailers. We noted earlier that Tier 1 retailers are highly vertically integrated, Tier 2 integrated to some degree and Tier 3 usually not integrated at all. Vertically integrated generator/retailers may manage their margins across their total business and so rising (falling) wholesale prices increase (decrease) generation profits and create room for a more gradual rise (fall) in retail prices if the objective is to achieve greater stability in total business profitability. Ofgem (2011) argues on these lines to explain their observation of asymmetry (rising wholesale prices are passed through more quickly than falling wholesale prices). While we do not observe asymmetry, the argument applies as a possible explanation of the different rates of pass-through between amongst the three retailer tiers.

*Limitations and further work*

We stress that market offers and the prices that existing customers pay can, and typically do, deviate from the offers that retailers make to new customers. This study therefore cannot conclude on the extent of wholesale price pass-through in the prices that customers actually paid. As noted earlier, retailers have been preventing from increasing prices more than once per year to existing customers, but this was only introduced towards the end of our study period and thus is unlikely to affect the results of this study. On the other hand, regulations were introduced near the beginning of our study period that required retailers to tell customers how much they could save if they switched to their retailer's cheapest offer. We suggest this is likely to have linked the prices paid by existing customers somewhat to the offers that retailers made to new customers and may mean that the offers that retailers make to new customers may also reflect, to some degree, the prices that they charge their existing customers. In this sense, our conclusions from the analysis of offers to new customers may also be valid to existing customers.

The measurement of the relationship between wholesale and retail prices is greatly affected by the estimation of each. There are several plausible ways to define and measure prices in the wholesale and retail markets and different approaches to the estimation of wholesale prices are likely to lead to different conclusions. Further work remains to be done assess different approaches.

It is also important to acknowledge limitations of this study arising from the study duration. While our data allows a sophisticated characterisation of the retail market, there are just 27 monthly observations in our sample. It would be valuable to extend this study over longer periods (both prior to and after the introduction of the VDO) to assess how these conclusions may change, and to further refine estimates of the impact of the VDO.

Finally, the electricity market in Victoria is likely to change considerably in the coming decade. Whereas one in six households currently have rooftop solar photovoltaics, Government policy seeks to ensure that around one in two eligible homes will have rooftop solar by 2030.[8] In addition, Government policy is seeking that one in two new vehicles purchased in Victoria are electric by this time and that there is a significant expansion in distributed (behind the meter) batteries.[9] These policies are likely to have a big impact consumers' relationship with the retail electricity market. It will be valuable to understand the relationship between wholesale and retail markets, not just for customers on single rate offers, but also for those that are able to move electric vehicle charging demands to different times of the day, and for those who are able to choose whether to sell their rooftop photovoltaics production back to their retailers, or increase the amount of self-supply by shifting demand or installing and charging behind the meter batteries.

## 7. Conclusions

Part of the rationale for choice in retail electricity markets is that this would cater for consumers' diverse preferences. Are market outcomes consistent with this rationale? Our analysis in Victoria suggests that wholesale price changes are being passed through in retail offers quickly and symmetrically. However, it is only the new entrant small retailers (that together sell to 11% of households) that are passing wholesale price changes through completely, and only in their low price offers. The large incumbent

[8] https://www.solar.vic.gov.au/solar-panel-rebate
[9] https://www.solar.vic.gov.au/zero-emissions-vehicle-subsidy

(first tier) and established (second tier) retailers are passing through less than half of the wholesale price variation in their retail offers. In this sense, retailers in these tiers provide some level of insulation from wholesale price volatility. In comparable studies in other countries, this is often characterized as evidence of inadequate competition and exploitation of customer apathy. Alternatively, it may reflect the preference some customers have for stable prices even if they are higher.

Our analysis also finds that after adjusting for wholesale price changes, the regulated default offer increased the prices that retailers' offered in their cheapest offers, but reduced prices in their more expensive offers.

Pass-through studies such as ours depend on appropriate measures of both wholesale and retail prices. Neither are known with certainty and so it is valuable to extend analyses such as these over longer periods.

Finally, the Victorian retail electricity market is likely to change significantly over the coming decade considering government policy that one in two households should have rooftop solar, that a significant number will have batteries and that half of all cars sold should be electric. These changes can be expected to have a big impact on retail markets. It would be valuable to assess what affect these changes will have on wholesale market pass-through.

## Appendix

### Table 7. Network tariff schedules 2019 to 2021

| | | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|---|
| | | Fixed charge $ p/a | Variable rate cents p/kWh | Fixed charge $ p/a | Variable rate cents p/kWh | Fixed charge $ p/a | Variable rate cents p/kWh |
| Ausnet | Flat (NE11) | 115 | 10.0603 block 1<br>13.0609 block 2 | 118 | 11.3645 block 1<br>13.0839 block 2 | 106 | 10.535 block 1<br>12.0737 block 2 |
| | Controlled load (NEE30) | | 3.7201 | | 4.152 | | 3.8612 |
| | AMI | 57.80 | | 51.40 | | 29.80. | |
| United | Flat (LVS1R) | 25.88 | 9.36 | 28.65 | 9.49 | 39.97 | 7.67 |
| | Controlled load (LVDed) | | 1.99 | | 2.23 | | 1.73 |
| | AMI | 57 | | 54.23 | | 24.41 | |
| Citipower | Flat (C1R) | 90.00 | 6.59 | 95.00 | 7.06 | 90.00 | 6.47 |
| | Controlled load (CDS) | | 2.16 | | 2.23 | | 2.09 |
| | AMI | 73.00 | | 71.30 | | 32.9 | |
| Jemena | Flat (A1000/F1000/T1000) | 51.308 | 7.97 | 59.18 | 8.58 | 69.03 | 7.414 |
| | Controlled load (A180) | | 2.568 | | 2.57 | | 2.916 |
| | AMI | 79.84 | | 79.64 | | 66.28 | |
| Powercor | Flat (D1) | 130.00 | 7.22 | 140.00 | 7.98 | 140 | 6.74 |
| | Controlled load (DD1) | | 2.32 | | 2.56 | | 2.14 |
| | AMI | 73.00 | | 67.30 | | 32.75 | |

Source: AER approved 2020 and 2019 Network Tariff Schedules, available at: https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/pricing-proposals-tariffs?f%5B0%5D=field_accc_aer_sector%3A4

### Table 8. Unit root test results

| | | ADF | KPSS | Ng-Perron |
|---|---|---|---|---|
| WECs | | -1.326 | 0.636 ** | -15.393 *** |
| 10th percentile prices | All retailers | -2.332 | 0.397 * | -0.861 |
| | Tier 1 | -1.521 | 0.198 | -2.212 |
| | Tier 2 | -1.999 | 0.343 | -1.772 |
| | Tier 3 | -2.743 * | 0.312 | -7.729 * |
| 50th percentile prices | All retailers | -0.983 | 0.236 | -2.523 |
| | Tier 1 | -0.421 | 0.580 ** | -0.784 |
| | Tier 2 | -2.007 | 0.402 * | -2.724 |
| | Tier 3 | -1.844 | 0.179 | -13.803 *** |
| 90th percentile offers | All retailers | -1.527 | 0.612 ** | -1.108 |
| | Tier 1 | -1.779 | 0.382 * | -2.611 |
| | Tier 2 | -0.920 | 0.696 ** | -2.735 |
| | Tier 3 | -1.712 | 0.646 ** | 0.214 |

Notes: p-values reported. The null hypothesis of the ADF and Ng-Perron test is the residuals are non-stationary. The null hypothesis of the KPSS test is that the residuals are stationary. An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 9. Symmetric (equation 1) and asymmetric (equation 2) model estimation results**

| | Tier 1 | | | Tier 2 | | | Tier 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Symmetric | 10th | 50th | 90th | 10th | 50th | 90th | 10th | 50th | 90th |
| $R_{\theta,t-1}$ | 0.35** (0.147) | 0.43** (0.160) | 0.14 (0.107) | 0.26 (0.177) | 0.10 (0.098) | 0.20 (0.181) | 0.34 (0.211) | 1.01*** (0.210) | 0.53*** (0.103) |
| $R_{\theta,t-2}$ | | | | 0.33** (0.158) | | | | -0.24 (0.335) | |
| $R_{\theta,t-3}$ | | | | | | | | -0.16 (0.365) | |
| $R_{\theta,t-4}$ | | | | | | | | 0.60** (0.232) | |
| $W_t$ | 0.42*** (0.091) | -0.65 (0.413) | -1.69** (0.636) | -0.22 (0.498) | 0.86 (0.677) | 0.54*** (0.139) | -0.96 (1.157) | -0.56 (0.522) | 0.29 (0.173) |
| $W_{t-1}$ | | 0.74 (0.543) | -0.08 (0.865) | 0.68 (0.524) | -0.53 (0.802) | | 0.78 (1.436) | 1.13** (0.506) | |
| $W_{t-2}$ | | -0.51 (0.550) | 0.17 (0.832) | | -0.57 (0.529) | | -1.28 (1.026) | | |
| $W_{t-3}$ | | 1.03** (0.427) | 2.09*** (0.648) | | -0.66 (0.716) | | -0.52 (1.196) | | |
| $W_{t-4}$ | | | | | 1.42* (0.674) | | 3.09** (1.104) | | |
| VDO | 1.34*** (0.395) | -0.89** (0.393) | -5.59*** (0.802) | 1.58*** (0.499) | 4.82*** (0.584) | -0.92*** (0.318) | 2.27** (0.921) | 0.36 (0.546) | -4.27*** (1.036) |
| C | 10.19*** (2.632) | 9.43** (3.265) | 24.28*** (3.805) | 3.64 (0.2119) | 14.32*** (2.245) | 19.60*** (4.565) | 0.93 (2.625) | -10.75 (6.262) | 15.49*** (3.535) |
| Asymmetric | 10th | 50th | 90th | 10th | 50th | 90th | 10th | 50th | 90th |
| $R_{\theta,t-1}$ | 0.26 (0.251) | 0.51*** (0.141) | 0.03 (0.119) | 0.38** (0.174) | 0.29* (0.137) | 0.15 (0.206) | 0.16 (0.204) | 1.02*** (0.236) | 0.52*** (0.105) |
| $R_{\theta,t-2}$ | -0.03 (0.243) | | | 0.34** (0.150) | 0.03 (0.137) | 0.05 (0.204) | 0.05 (0.215) | -0.24 (0.356) | |
| $R_{\theta,t-3}$ | -0.69** (0.229) | | | | -0.32** (0.141) | -0.46* (0.228) | -0.10 (0.220) | -0.13 (0.392) | |
| $R_{\theta,t-4}$ | 0.78** (0.298) | | | | 0.34 ** (0.117) | | 0.45** (0.158) | 0.55** (0.256) | |
| $W_t^+$ | -1.15 (0.944) | 0.38*** (0.108) | 0.26* (0.139) | 0.29** (0.121) | 1.39* (0.726) | 0.82*** (0.181) | -299* (1.510) | -0.38 (0.618) | 0.28 (0.178) |
| $W_{t-1}^+$ | 4.89** (1.912) | | | 0.07* (0.037) | 0.44 (0.649) | | 0.90 (2.335) | 0.92 (0.615) | |
| $W_{t-2}^+$ | -0.23 (0.545) | | | | -1.35* (0.653) | | -0.54 (1.055) | | |
| $W_{t-3}^+$ | 0.32 (0.856) | | | | -0.13* (0.060) | | 0.23 (1.296) | | |
| $W_{t-4}^+$ | -3.52* (1.496) | | | | | | 3.73* (1.612) | | |
| $W_t^-$ | -0.92 (0.931) | 0.46*** (0.126) | 0.45** (0.165) | 0.31** (0.137) | 1.45* (0.736) | 0.78*** (0.189) | -2.96* (1.461) | -0.36 (0.636) | 0.24 (0.196) |
| $W_{t-1}^-$ | 4.84** (1.913) | | 0.14*** (0.047) | | 0.47 (0.661) | 0.06* (0.031) | 0.69 (2.313) | 0.91 (0.622) | |
| $W_{t-2}^-$ | -0.05 (0.547) | | 0.13** (0.045) | | -1.35* (0.655) | 0.06 (0.034) | -0.69 (1.046) | | |
| $W_{t-3}^-$ | 0.37 (0.837) | | | | | | -0.06 (1.295) | | |
| $W_{t-4}^-$ | -3.26* (1.416) | | | | | | 3.70** (1.505) | | |
| VDO | -0.47 (0.942) | -0.92** (0.332) | -6.73*** (0.903) | 1.39*** (0.474) | 3.25*** (0.689) | -1.43*** (0.375) | 2.88** (1.066) | 0.28 (0.589) | -4.15*** (1.065) |
| C | 10.97* (5.544) | 9.35*** (3.054) | 28.56*** (4.009) | 2.31 (2.072) | 10.41*** (2.861) | 31.04*** (7.809) | -3.16 (4.486) | -10.44 (6.756) | 15.85*** (3.622) |

Notes: An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 10. Model diagnostics, 10th percentile offers**

| | Symmetric | | | | Asymmetric | | | |
|---|---|---|---|---|---|---|---|---|
| | All retailers ARDL (4,2) | Tier 1 ARDL (1,0) | Tier 2 ARDL (2,1) | Tier 3 ARDL (1,4) | All retailers ARDL (4,2,2) | Tier 1 ARDL (4,4,4) | Tier 2 ARDL (2,1,0) | Tier 3 ARDL (4,4,4) |
| Adj. $\bar{R}^2$ | 0.95 | 0.84 | 0.88 | 0.86 | 0.98 | 0.86 | 0.89 | 0.92 |
| RESET test Ho: Non-linear term not significant | 0.592 | 0.036** | 0.570 | 0.189 | 0.928 | 0.624 | 0.652 | 0.155 |
| Normality test Ho: Residuals are normally distributed | 0.027 | 0.765 | 0.922 | 0.476 | 0.371 | 0.148 | 0.570 | 0.847 |
| Homoscedasticity test Ho: Residuals are homoscedastic | 0.505 | 0.359 | 0.427 | 0.151 | 0.385 | 0.973 | 0.534 | 0.940 |
| Serial correlation at lags 1 Ho: no serial correlation | 0.594 | 0.382 | 0.538 | 0.770 | 0.324 | 0.928 | 0.725 | 0.255 |
| Serial correlation at lags 3 | 0.499 | 0.203 | 0.401 | 0.845 | 0.267 | 0.822 | 0.487 | 0.303 |
| Serial correlation at lags 6 | 0.420 | 0.250 | 0.122 | 0.566 | 0.125 | 0.146 | 0.611 | 302 |
| Unit root test residuals Ho: unit root | 0.001*** | 0.007*** | 0.008*** | 0.003*** | 0.001*** | 0.001*** | 0.026** | 0.002*** |
| Non-nested model selection test | | | | | 0.000*** Asymmetric | n.a. Symmetric | 0.039** Asymmetric | 0.000*** Symmetric |

Notes: p-values reported (except for Adj. $\bar{R}^2$). An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 11. Model diagnostics, 50th percentile offers**

| | Symmetric | | | | Asymmetric | | | |
|---|---|---|---|---|---|---|---|---|
| | All retailers ARDL (4,3) | Tier 1 ARDL(1,3) | Tier 2 ARDL (1,4) | Tier 3 ARDL (4,1) * | All retailers ARDL (4,2,3) * | Tier 1 ARDL (1,0,0) * | Tier 2 ARDL (4,3,2) * | Tier 3 ARDL (4,1,1) |
| Adj. $\bar{R}^2$ | 0.90 | 0.84 | 0.91 | 0.90 | 0.93 | 0.85 | 0.91 | 0.89 |
| RESET test Ho: Non-linear term not significant | 0.301 | 0.936 | 0.883 | 0.305 | 0.873 | 0.228 | 0.732 | 0.249 |
| Normality test Ho: Residuals are normally distributed | 0.388 | 0.800 | 0.110 | 0.006*** | 0.393 | 0.553 | 0.491 | 0.009*** |
| Homoscedasticity test Ho: Residuals are homoscedastic | 0.668 | 0.030** | 0.620 | 0.672 | 0.457 | 0.217 | 0.145 | 0.585 |
| Serial correlation at lags 1 Ho: no serial correlation | 0.633 | 0.817 | 0.304 | 0.874 | 0.761 | 0.829 | 0.681 | 0.795 |
| Serial correlation at lags 3 | 0.658 | 0.377 | 0.025** | 0.083* | 0.267 | 0.559 | 0.346 | 0.072* |
| Serial correlation at lags 6 | 0.361 | 0.353 | 0.176 | 0.191 | 0.521 | 0.774 | 0.439 | 0.136 |
| Unit root test residuals Ho: unit root | 0.001*** | 0.003*** | 0.028** | 0.037** | 0.006*** | 0.001*** | 0.008*** | 0.002*** |
| **Non-nested model selection test (based on 5% los)** | | | | | 0.041** Asymmetric | 0.083* Asymmetric | 0.053* Asymmetric | 0.671 Symmetric |

Notes: p-values reported (except for Adj. $\bar{R}^2$). An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 12. Model diagnostics – 90th percentile offers**

| | Symmetric | | | | Asymmetric | | | |
|---|---|---|---|---|---|---|---|---|
| | All retailers ARDL (1,3) | Tier 1 ARDL (1,3) | Tier 2 ARDL (1,0) | Tier 3 ARDL (1,0) | All retailers ARDL (1,3) | Tier 1 ARDL (1,0,2) | Tier 2 ARDL (3,0,2) | Tier 3 ARDL (1,0,0) |
| Adj. $\bar{R}^2$ | 0.93 | 0.89 | 0.79 | 0.95 | 0.94 | 0.90 | 0.86 | 0.95 |
| RESET test Ho: Non-linear term not significant | 0.015** | 0.042** | 0.071* | 0.805 | 0.013** | 0.098* | 0.015** | 0.870 |
| Normality test Ho: Residuals are normally distributed | 0.387 | 0.451 | 0.710 | 0.118 | 0.645 | 0.649 | 0.970 | 0.070* |
| Homoscedasticity test Ho: Residuals are homoscedastic | 0.100* | 0.257 | 0.018** | 0.103 | 0.120 | 0.049** | 0.029** | 0.099* |
| Serial correlation at lags 1 Ho: no serial correlation | 0.064* | 0.105 | 0.395 | 0.404 | 0.151 | 0.047** | 0.368 | 0.348 |
| Serial correlation at lags 3 | 0.096* | 0.091* | 0.125 | 0.615 | 0.121 | 0.126 | 0.283 | 0.586 |
| Serial correlation at lags 6 | 0.043** | 0.027** | 0.072* | 0.322 | 0.061* | 0.077* | 0.213 | 0.342 |
| Unit root test residuals Ho: unit root | 0.081* | 0.037** | 0.005*** | 0.000*** | 0.021** | 0.072* | 0.012** | 0.000*** |
| Non-nested model selection test | | | | | 0.342 Symmetric | n.a. Asymmetric | 0.003*** Asymmetric | 0.469 Symmetric |

Notes: p-values reported (except for Adj. $\bar{R}^2$). An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 13. T-test results for complete pass-through (estimated coefficient on wholesale price variables(s) equal to one)**

| | All | | Tier 1 | | Tier 2 | | Tier 3 | |
|---|---|---|---|---|---|---|---|---|
| 10th percentile offers | $W^+_{t-1}$ | 0.115 | $W_t$ | 0.000*** | $W^+_t$ | 0.000*** | $W_{t-4}$ | 0.073* |
| | $W^-_{t-1}$ | 0.150 | | | $W^+_{t-1}$ | 0.000*** | | |
| | | | | | $W^-_t$ | 0.000*** | | |
| 50th percentile offers | $W^+_{t-1}$ | 0.402 | $W^+_t$ | 0.000*** | $W^+_t$ | 0.597 | $W_{t-1}$ | 0.803 |
| | $W^-_{t-1}$ | 0.367 | $W^-_t$ | 0.000*** | $W^-_t$ | 0.545 | | |
| 90th percentile offers | $W_{t-3}$ | 0.914 | $W^+_t$ | 0.000*** | $W^+_t$ | 0.341 | $W_t$ | 0.000*** |
| | | | $W^-_t$ | 0.003*** | $W^-_t$ | 0.256 | | |
| | | | $W^-_{t-1}$ | 0.000*** | $W^-_{t-1}$ | 0.000*** | | |
| | | | $W^-_{t-2}$ | 0.000*** | | | | |

Notes: P-values reported. An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

**Table 14. t-test results for whether estimated coefficients on asymmetric wholesale price variables are statistically equal**

| | All retailers | | Tier 1 | | Tier 2 | | Tier 3 | |
|---|---|---|---|---|---|---|---|---|
| 10th percentile offers | $W^+_{t-1} = W^-_{t-1}$ | 0.887 | $W^+_{t-1} = W^-_{t-1}$ | 0.997 | $W^+_t = W^-_t$ | 0.836 | $W^+_{t-4} = W^-_{t-4}$ | 0.983 |
| 50th percentile offers | $W^+_{t-1} = W^-_{t-1}$ | 0.938 | $W^+_t = W^-_t$ | 0.446 | $W^+_t = W^-_t$ | 0.932 | $W^+_{t-1} = W^-_{t-1}$ | 0.985 |
| 90th percentile offers | $W^+_t = W^-_t$ | 0.813 | $W^+_t = W^-_t$ | 0.183 | $W^+_t = W^-_t$ | 0.809 | $W^+_t = W^-_t$ | 0.829 |

Note: P-values reported. An ***, **, * denote statistical significant at the 1, 5 and 10% level of significance, respectively.

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