www.concept.co.nz

Review of impact of trading conduct enforcement action on spot prices

Prepared for the Market Development Advisory Group

August 2019

About Concept

Concept Consulting Group Ltd (Concept) specialises in providing analysis and advice on energy-related issues. Since its formation in 1999, the firm's personnel have advised clients in New Zealand, Australia, the wider Asia-Pacific region. Clients have included energy users, regulators, energy suppliers, governments, and international agencies.

Concept has undertaken a wide range of assignments, providing advice on market design and development issues, forecasting services, technical evaluations, regulatory analysis, and expert evidence.

Further information about Concept can be found at www.concept.co.nz.

Disclaimer

This report has been prepared by Concept based entirely on our analysis of public information sources and the Genie data room.

Except as expressly provided for in our engagement terms, Concept and its staff shall not, and do not, accept any liability for errors or omissions in this report or for any consequences of reliance on its content, conclusions or any material, correspondence of any form or discussions, arising out of or associated with its preparation.

The analysis and opinions set out in this report reflect Concept's best professional judgement at the time of writing. Concept shall not be liable for, and expressly excludes in advance any liability to update the analysis or information contained in this report after the date of the report, whether or not it has an effect on the findings and conclusions contained in the report.

This report remains subject to any other qualifications or limitations set out in the engagement terms.

Contents

1 Executive summary

The Market Development Advisory Group (MDAG) asked Concept to examine:

1. Did a trading conduct enforcement action by the Electricity Authority in May 2017[1] cause a structural increase in electricity spot prices since May 2017.
2. To what extent can changes in spot prices since May 2017 be explained by other factors, such as demand, fuel costs or hydrology.

We understand the MDAG's request was triggered by an article published in July 2019[2] which suggested the Authority's trading conduct enforcement action may have had "the unintended consequence of [causing] ongoing higher prices".

For completeness, we note this report makes no assessment of whether generator behaviour or market outcomes are consistent with those expected in a workably competitive market.

Quantitative analysis of prices

We interpret "structural shift" to mean a sustained change in the price formation process, such that for a given set of system conditions, the resulting prices will differ before and after the change event. (We also refer to this as a structural break).

We applied the conventional statistical tests to identify whether there was a structural shift in spot prices following the Authority's enforcement letter. The results of the analysis do not support the view that a structural shift occurred in May 2017. Nor does the statistical analysis indicate any structural shift in spot prices occurred within 12 months after that date.

Rather, the statistical analysis strongly indicates the increase in spot prices observed since May 2017 is best explained by physical (i.e. non-behavioural) factors – especially changes in hydro storage and gas prices over the period.

Physical factors over the 2012-2019 period

The examination of physical factors before and after May 2017 indicates:

- There was an appreciable tightening of the supply-demand balance between 2012 and 2019, driven mainly by plant retirements. This tightening is evidenced by Transpower's Annual Security Assessments and was equivalent to a net reduction of around 1,500 GWh in supply capability during winter (assuming mean hydrology and fully fuelled thermal generators[3]).
- Actual hydrology was generally dryer in the two years after May 2017 than the preceding two years. This accentuated the tightening in supply over the period due to plant retirements.
- Gas supply issues emerged in early 2018 which further tightened the electricity supply-demand balance. In particular, gas supply restrictions at Pohokura were equivalent to a loss of up to 3,000 GWh of supply capability during 2018. Furthermore, it was often unclear how long the Pohokura restrictions would last, exacerbating concerns over thermal supply.

[1] This was a letter from the Authority to Meridian Energy Ltd, dated 8 May 2017. See https://www.ea.govt.nz/dmsdocument/22116-8-may-2017-letter-from-chair-to-meridian-energy-re-trading-conduct-on-2-june-2016 .

[2] Matt Rowe, 'The lakes are near full, the gas fields are back operating, so why are New Zealand's electricity prices still so stubbornly high?', *Energy News,* 2 July 2019

[3] The exception was Whirinaki, which has its output limited by fuel supply.

- Gas and coal spot prices rose more than 80% between mid-2016 and 2018-19, significantly increasing the estimated marginal cost of running thermal plant.

Based on a qualitative assessment of these factors, it is not surprising that average spot prices for the period May 2017 – June 2019 were appreciably higher than in the two years before May 2017.

Analysis of offer data

Although the article suggested a structural shift in *prices,* it also discussed changes in *offers.* For this reason, we have also considered changes in offers over the period of interest. We focussed on two key questions when assessing offer data.

1. Did *offers* undergo a structural shift in May 2017? and
2. If so, would such a shift explain the observed material increase in average spot *prices*?

To answer these questions, we considered three key aspects of generator offers:

- The volume offered below 500 $/MWh (as this was explicitly raised in the article)
- The volume offered below 100 $/MWh (as this materially affects average spot prices)
- The level of supply responsiveness in the offer curve (again because this may affect spot prices).

The results for each aspect of the assessment are described in the body of the report. In summary, the analysis did not find any aspects of offers that underwent a structural shift in May 2017, and which would materially increase prices.

Conclusions

Based on the evidence, we conclude the enforcement action by the Authority in May 2017 did not cause a structural shift in electricity spot prices or generator offers.

Rather, the evidence strongly indicates the increase in spot prices observed since May 2017 is explained by physical factors – especially changes in hydro storage and gas prices over the period.

2 Introduction

2.1 Scope

The Market Development Advisory Group (MDAG) has asked Concept to examine:

1. Whether a trading conduct enforcement action by the Electricity Authority in May 2017[4] caused a structural increase in electricity spot prices since May 2017.
2. The extent to which changes in spot prices since May 2017 can be explained by other factors, such as demand, fuel costs or hydrology.

We understand the MDAG's request was triggered by an article published in July 2019[5] which suggested the Authority's trading conduct enforcement action may have had "the unintended consequence of [causing] ongoing higher prices". The article noted a more sophisticated analysis is probably required to fully test the hypothesis.

The article also mentioned changes to offers, so we have also examined whether there was a change in offer structure in May 2017.

The MDAG is currently reviewing the trading conduct rules. We understand this report will be an input into the MDAG's review.

2.2 Structure of report

This report is set out as follows:

- Section 3 describes the statistical tests and data used to determine whether there was a structural shift in spot prices. It then presents the findings of this quantitative assessment.
- Section 4 discusses spot prices and physical conditions in the electricity system, before and after the May 2017. In presents a qualitative assessment of whether the observed spot prices are better explained by physical conditions, or a response to the enforcement letter of May 2017.
- Section 5 describes the offers of South Island generators before and after May 2017, and assesses whether changes over the period are consistent with physical conditions.
- Section 6 presents the overall findings of this report.
- Statistical details of the analysis are shown in Appendix A.

For completeness, we note this report focuses on the matters in section 2.1. It makes no assessment of whether generator behaviour or market outcomes are consistent with those expected in a workably competitive market.

All of the analysis in this report is based on public information sources.

[4] This was a letter from the Authority to Meridian Energy Ltd, dated 8 May 2017. See https://www.ea.govt.nz/dmsdocument/22116-8-may-2017-letter-from-chair-to-meridian-energy-re-trading-conduct-on-2-june-2016 .

[5] Matt Rowe, 'The lakes are near full, the gas fields are back operating, so why are New Zealand's electricity prices still so stubbornly high?', *Energy News,* 2 July 2019

3 Was there a structural shift in spot prices in May 2017?

Before examining the potential causes of any spot price changes, we begin by assessing whether any 'structural shift' in prices occurred in May 2017.

3.1 Definition of structural shift

We interpret "structural shift" to mean a sustained change in the price formation process, such that for a given set of system conditions, the resulting prices will differ before and after the structural break event. This definition is consistent with the typical use of the term in economics which distinguishes between structural and cyclical changes.

In addition, we believe this definition is consistent with the use of the term in the opinion article. That article posits a change in "offer behaviour" as the trigger for higher prices from May 2017, and suggests prices since then have been "seemingly independent" of factors that have historically driven prices.[6]

3.2 Analysis focuses on spot prices at Benmore

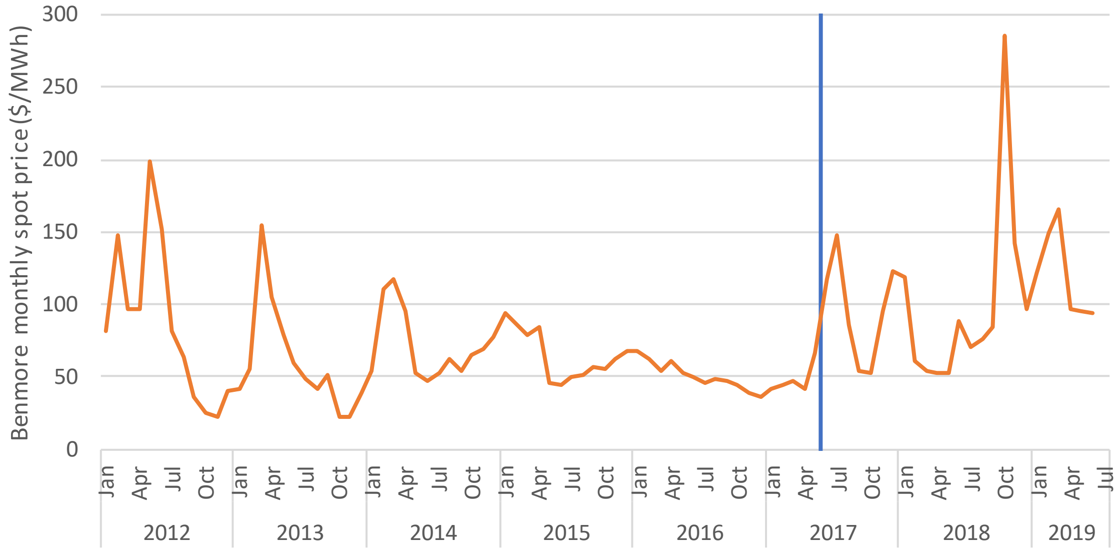
We examined monthly average spot prices at Benmore since 2012. We focussed on monthly average prices because spot prices change every half-hour – and it is difficult to identify any sustained movement at that level of granularity. By contrast, a persistent change should be visible in monthly average spot prices. Benmore prices were examined because the posited change was said to be due to a change in South Island generator offers.

To identify whether any structural change has occurred it is critical to examine prices over an extended period to capture varying market conditions. Unless this is done, it is impossible to know whether any observed change in prices is structural in nature – or merely a transitory phenomenon which has been observed previously. The last time (prior to 2017) that New Zealand experienced sustained dry conditions was in 2012. For this reason, we examined prices over the period January 2012 to 30 June 2019.

Figure 1 shows monthly average spot prices at Benmore. The vertical blue indicates May 2017, the month when the Authority wrote to Meridian. Prior to that date, monthly average spot prices were typically less than 100 $/MWh. Subsequent to that date, monthly average spot prices were frequently above 100 $/MWh. On its face, this indicates that spot prices (on average) did shift upward after May 2017. However, it provides no information on whether the shift was structural or cyclical in nature.

[6] Ibid.

Figure 1 - Monthly average Benmore spot prices



3.3 Was there a structural shift in spot prices?

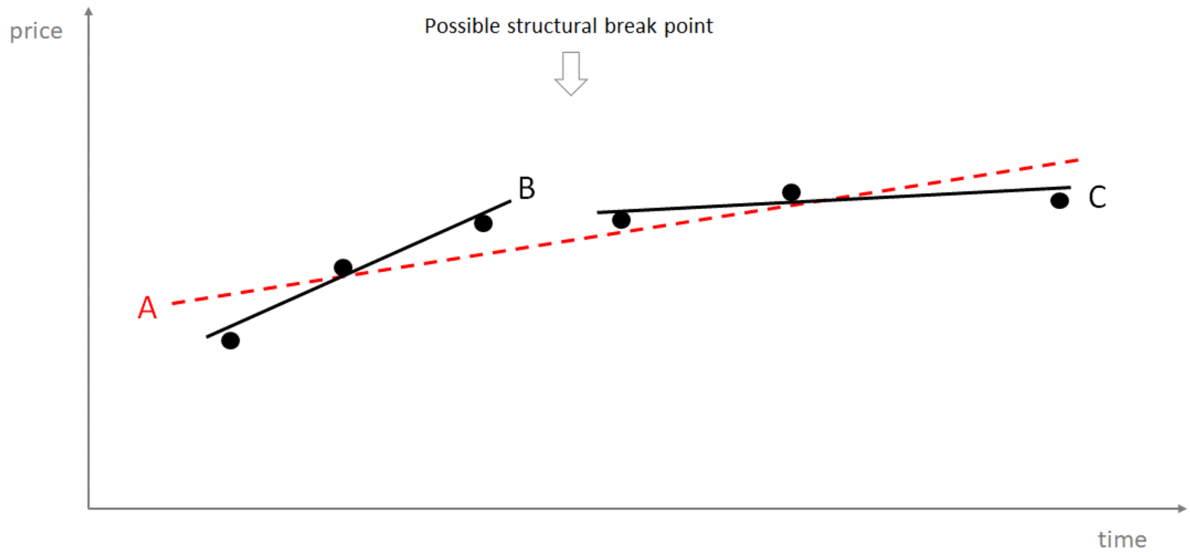
To determine whether there was a structural change in spot prices after May 2017, we performed the typical statistical test (a Chow test) to identify whether a structural break has occurred in a data series.

3.3.1 How does a Chow test work?

The logic behind the Chow test is illustrated in Figure 2. The dots represent the observed data (in this case prices over time). Statistical analysis is performed to estimate the best-fit regression equation for the entire data set (i.e. assuming there is no structural shift). This is shown by line A.

The whole dataset is then separated into two groups at the posited break point. A separate best-fit regression equation is estimated for each subset. These are shown by lines B and C.

Figure 2 – Illustrative example of Chow test



The Chow test assesses whether using two separate lines significantly reduces the error between the actual points and the modelled fit, as compared to a single line. If this is the case, we conclude there was a structural break at the posited point, and vice versa.

Another way of thinking about the Chow test is that it identifies whether the pattern in the data is better explained by one equation (because there is no break) or two equations (because a break occurred).

3.3.2 Chow test indicates no structural break in May 2017

Applying the Chow test in a 'naïve' form would indicate a break in May 2017.[7] However, this form of the test only considers whether prices before and after May 2017 are statistically different. It takes no account of any external cyclical factors that could potentially explain the change.

For that reason, we repeated the statistical analysis by adding two physical variables often cited as having an influence on spot prices. These are:

- New Zealand hydro storage – we used the deviation between actual storage and historical average storage as a measure of how 'wet' or 'dry' conditions are. This variable was added because hydro generation typically accounts for around 59 per cent of New Zealand electricity supply.
- Monthly average spot prices for gas – we used monthly gas prices reported by emsTradepoint as a measure of thermal fuel costs.[8] This variable was added because gas-fired generation is typically utilised more heavily when hydro storage is low, and vice versa.

After adding these two variables and repeating the structural break test, there was no statistically significant change in spot prices in May 2017.[9]

The analysis was also repeated by adding other physical variables – namely the system generation margin (measured by the Winter Energy Margin published by Transpower) and coal prices (given that coal is sometimes the marginal thermal fuel rather than gas). The results of these tests showed an even lower likelihood of any structural break in pricing having occurred in May 2017.[10]

3.3.3 Chow test indicates no structural break within twelve months after May 2017

Although the opinion article posited a "clear change in offer behaviour in May-17", it is plausible that generators took time to digest the contents of the Authority's letter, and reacted some months after May 2017.

For this reason, we performed analysis to search for possible break points in the following 12 months. This analysis did not identify any date in that period which showed a statistically significant break in spot prices.[11]

3.3.4 Alternative test for structural break

An alternative approach was also used to test for a structural break. This involved the estimation of a best-fit regression equation with the following explanatory variables: hydro storage; gas prices; and a dummy variable to represent all observations after May 2017.

The analysis showed that only the coefficients for gas prices and hydro storage were statistically significant at the 5% confidence level.[12] The coefficient on the dummy variable was well short of the

---

[7] The Chow test found a p-value of less than 0.01%. There is no definitive p-value for a significant result, but a threshold of 5% is typical. In simple terms, a p-value of less than 5% indicates a significant result.

[8] This data commenced in October 2013. For the period prior to this we used estimates of gas prices derived from company reports.

[9] The Chow test found a p-value of 28%.

[10] The Chow test found a p-value of 60%.

[11] See Figure 17

[12] See summary data on page 33

significance threshold at the 5% confidence level.[13] This is further evidence in support of the hypothesis that no structural break occurred in prices at May 2017.

3.4 Quantitative analysis does not identify any structural shift in spot prices

In summary, the statistical analysis does not support the view that a structural shift occurred in May 2017. Nor does the statistical analysis indicate any structural shift in spot prices occurred within 12 months after that date.

Rather, the statistical analysis strongly indicates the increase in spot prices observed since May 2017 is best explained by physical (i.e. non-behavioural) factors – especially changes in hydro storage and gas prices over the period.

Given that the statistical analysis points to the significance of physical factors as the likely explanation for the observed change in average monthly spot prices after May 2017, we examine these in more detail in the next chapter.

[13] The t-value was 0.15 and the p-value was 88%.

4 What physical changes occurred between 2012 and 2019?

This chapter discusses physical factors that may have affected electricity supply and demand from 2012 to mid-2019.

Some of these factors (for example hydro storage and demand) were discussed in the opinion article. However, others were not explicitly considered, such as thermal fuel costs and availability, and the overall balance between system demand and supply. This was an important omission, because there were material changes occurring over the period pre- and post-May 2017.

We discuss each of the factors individually below, and then draw the overall picture together in section 4.7.

4.1 Generation plant

There has been a sizeable net reduction in the generation fleet since 2012. The gas-fired Otahuhu B and Southdown plants were retired in 2015. Two of the dual gas- and coal-fired Huntly Rankine units (number 3 and 4) were also announced as being "retired", although they were subsequently brought back into standby status at various points.[14]

To assess the theoretical generation available from these units, we tracked the peak offered generation from Huntly Rankine units 1-4 in each month to determine whether units were ready for generation.[15] Based on this measure:

- Four Huntly Rankine units were available up to and including 2012
- Three Huntly Rankine units were available up to and including 2014

Two Huntly Rankine units have been available since. The combined nameplate capacity of two Huntly units, Otahuhu B and Southdown represents a 1042MW reduction in capacity between 2012 and 2016.

Partially offsetting this reduction, there have been four sizeable generation units commissioned:

- Te Mihi geothermal in 2013,
- Nga Awa Purua geothermal in 2013,
- Ngatamariki geothermal in 2013,
- McKee gas-fired plant in 2012.

The combined nameplate capacity of these four stations is 438MW.[16]

In energy terms, using a 70% capacity factor for thermal units[17] and a 95% capacity factor for geothermal units, there has been a reduction of about 1,500 GWh of winter generation[18] available over the period. This is a sizeable volume of generation, relative to system winter demand (around 19,900 GWh) or total hydro storage capacity (around 4,000 GWh).

We note that some further new generation projects have recently been committed for construction, but these will not commence operation until 2020 or later.

---

[14] For example, the third Huntly unit was retired prior to 2014, but was then offered during 2014.

[15] It is possible that units were on "standby" and additional capacity would have been available if required for energy purposes.

[16] Te Mihi was a net increase of 114MW when combined with reduced output from Wairakei.

[17] Roughly the capacity factor for combined TCC and e3p output during winter 2017.

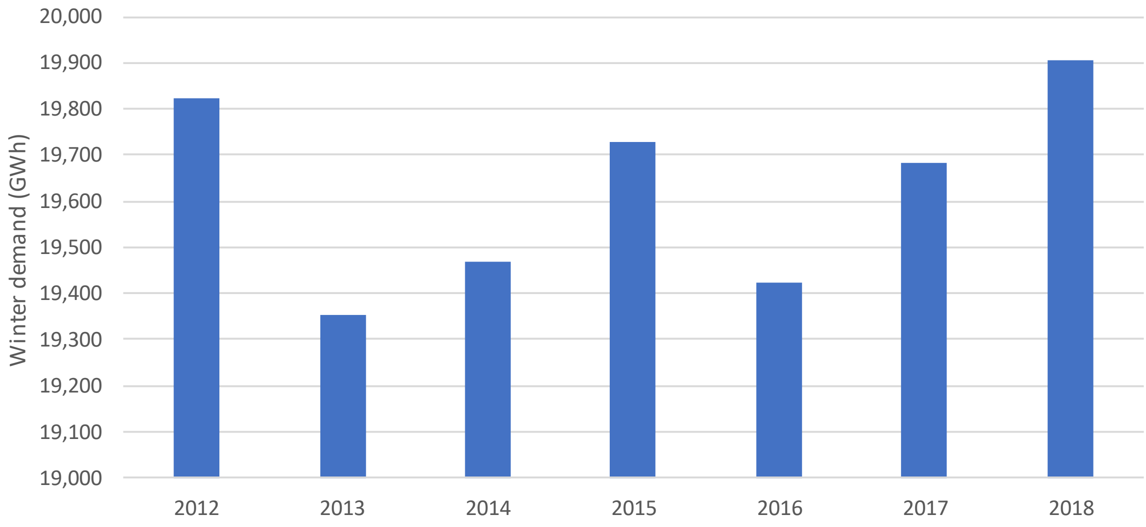
[18] Defined as April to September, consistent with the WEM – see below.

4.2 Electricity demand

Electricity demand in New Zealand is highly seasonal and is also affected by short-term weather variations. These factors can make it difficult to identify trends from looking at daily or monthly demand.

For this reason, we have examined demand during the important winter period.[19]

Figure 3 - New Zealand winter grid demand



Since 2016, demand has been trending upward, and winter 2018 was around 500 GWh/year higher than 2016.[20] Although this increase is relatively modest compared to overall winter energy demand, it occurred at a time when generation capability was falling (as discussed above). These factors indicate that it is important to consider the net margin between supply and demand over the period.

4.3 Margin between supply and demand

Transpower publishes an Annual Security Assessment (ASA) in which it calculates the expected margin between generation and demand for coming years. In that document, Transpower produces a Winter Energy Margin (the WEM) and a Winter Capacity Margin (the WCM). The WEM measures the buffer available to address any extended *energy* shock, such as a drought or loss of gas for thermal generation. The WCM measures the buffer available to address any short-term *capacity* shock, such as exceptionally high demand due to winter storms or a temporary outage at a large power station or transmission circuit.

Higher spot prices have been observed since May 2017 in both peak and off-peak periods,[21] suggesting *energy* availability rather than capacity availability is the relevant issue to examine. Accordingly, we have reviewed the WEM measure over the period 2012 to 2019.[22]

When Transpower publishes the WEM, it expresses the estimated supply buffer as a percentage of winter energy demand and shows it relative to an 'optimal level' of 15%.[23] This optimal margin

[19] This measure is still affected by weather (e.g. cold or mild winters) but less than short-term demand.
[20] Transpower's forecast for winter 2019 continues this trend, and is 400 GWh higher than its 2018 forecast.
[21] Mean off-peak price in 2018 was 37% higher than the 2012-2016 average. Mean peak price was 55% higher.
[22] Transpower produces a new ASA each year and each contains projections for the current and subsequent calendar years. The methodology for calculating the WEM was revised periodically, so each year is not exactly comparable the next. However, we do not believe there has been any bias in WEM methodologies, so comparing annual forecasts should give a reasonable representation of the trend in WEM over time.

recognises that some positive WEM supply buffer is required to address contingencies. Figure 4 shows the difference between Transpower's estimated WEM and the assessed 15% optimal level, with the difference expressed in energy volume (GWh rather than percentage) terms. [24]

Figure 4 – Winter Energy Margin relative to optimal level

Figure 4 shows a downward trend in the WEM between 2012 and 2019.[25] Indeed, over the period in question there was an appreciable tightening of supply margins, with a net reduction of around 2,000 GWh in the winter supply margin. This is consistent with a small increase in demand and estimated loss of about 1,500 GWh of grid connected generation.

To put this into context, a reduced winter energy margin means New Zealand is more susceptible to droughts, because there is less supply buffer available to counteract the loss of hydro generation. Furthermore, a tightening of 2,000 GWh is a sizeable change. It is equivalent to approximately half of total hydro storage.

4.4 Hydrology

The WEM is a forward-looking indicator of the expected energy generation buffer in the system "on average". Importantly, it assumes average hydro generation levels and that thermal stations will not be fuel constrained.[26] In practice, one or both of these assumptions may not hold. The WEM therefore sets the "starting point" for the supply demand balance, but actual hydrology needs to be considered to obtain a fuller picture.

[23] The optimal WEM is intended to reflect the point at which the cost of building new generation is equal to the expected cost of any shortage. The optimal WEM will therefore have some level of energy shortages in extreme dry winters.

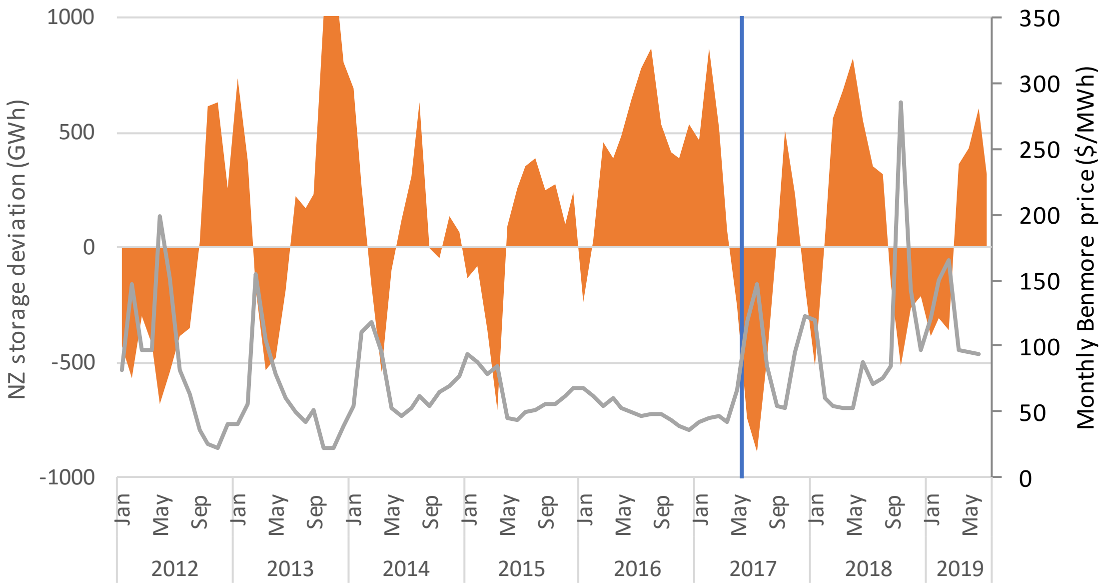
[24] The WEM is calculated for the months between April and September.

[25] There was a step increase in the margin for 2018. This reflects numerous changes, including a decrease in forecast demand, inclusion of generation from Ngawha (it was previously not included) and a reduction in assumptions of frequency keeping and instantaneous reserve required. These changes are mostly methodological, suggesting that the apparent increase in margin was not a physical change.

[26] Aside from Whirinaki.

To assess the effect of hydrological influences, we examined the deviations between actual and average hydro storage levels for each month.[27] The results for the period 2012-2019 are shown in orange in Figure 5. An upward deviation indicates 'wet' conditions and a downward deviation shows 'dry' conditions. The grey line shows the monthly average Benmore spot price (shown on the right-hand axis) for comparison.

Figure 5 - New Zealand storage relative to seasonal average and average Benmore price



Key observations from the chart are:

- In the period 2012-2014 storage fluctuated above and below average levels, and spot prices typically moved in the opposite direction to storage
- In the period 2015-2016 storage was generally above average levels, and monthly average spot prices were relatively flat around 50 $/MWh
- In the period 2017-2019 storage fluctuated above and below average levels. Spot prices typically moved in the opposite direction to storage, but there were exceptions (as discussed further in section 4.7).

The letter from the Authority to Meridian was sent in May 2017, and this coincided with a marked change in hydrology. At that time, New Zealand was heading into a very dry period, in contrast to the almost uniformly 'wet' conditions experienced in 2015 and 2016.

Indeed, storage in mid-2017 dropped below the 1% hydro risk curve.[28] Hydro storage then recovered through the spring of 2017 and was above average for most of the time until mid-2018, when it again fell below average levels for many months. Storage through the early part of 2019 recovered to be above average.

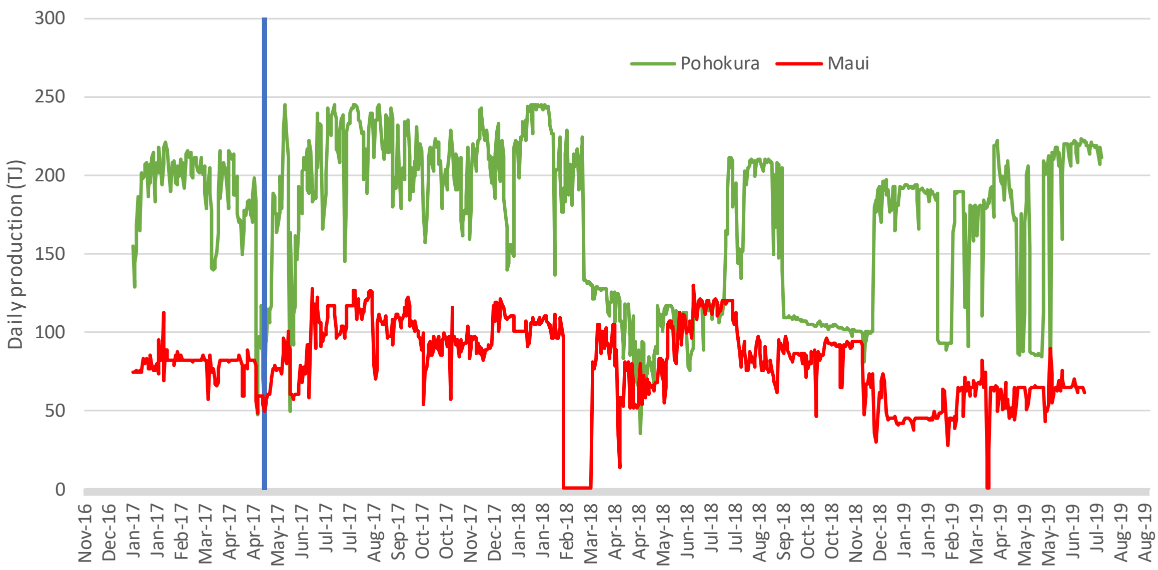
[27] Hydrological conditions are multi-faceted, with starting lake levels, and the timing and size of hydro inflows all being relevant. Hydro storage levels tend to reflect the impact of inflow levels over preceding months. The deviation from average storage for the time of the year provides a useful summary measure of hydro conditions in the recent period.

[28] Hydro risk curves are regularly published by Transpower and show the assessed likelihood of public conservation measures being required to manage a supply contingency such as a drought.

4.5 Thermal fuel availability

New Zealand experienced unprecedented interruptions to gas supply in the past 18 months. In February 2018 there was a temporary shutdown of all Maui production, reducing gas supply by about 100 TJ/day (sufficient to run a large thermal unit). Before Maui returned to operation, bubbles were discovered near an offshore pipeline used to bring Pohokura gas to shore. This was followed shortly after by the shutdown of all offshore Pohokura production until August 2018, reducing gas supply by about 100 TJ/day.

Figure 6: Pohokura and Maui gas production



In previous years, disruptions to Pohokura gas supply have been met by increase in production at Maui, but this did not happen in 2018. Instead, most of the decrease in supply was accommodated by a reduction in demand at Methanex. Even with lower Methanex demand there was still a net reduction in gas available for other purposes, such as electricity production.

After a brief period of normal production in August and September 2018, Pohokura offshore production again ceased from October to December 2018 due to a different technical problem. These two long interruptions reduced Pohokura output by around 20PJ in 2018. Had this “missing” gas been used to fuel a CCGT, it would have produced about 3,000 GWh of electricity.

In 2019, Pohokura has continued to experience periods of reduced production. We are unaware of the cause of these disruptions but note that production appears to have returned to normal in the past two months. It is unclear whether production will continue as normal, or if further disruptions will occur.[29]

The Ahuroa storage facility helps manage disruptions to gas supply, such as seen from Pohokura in 2018. However, we estimate that Ahuroa had a very low amount of gas stored during this period.

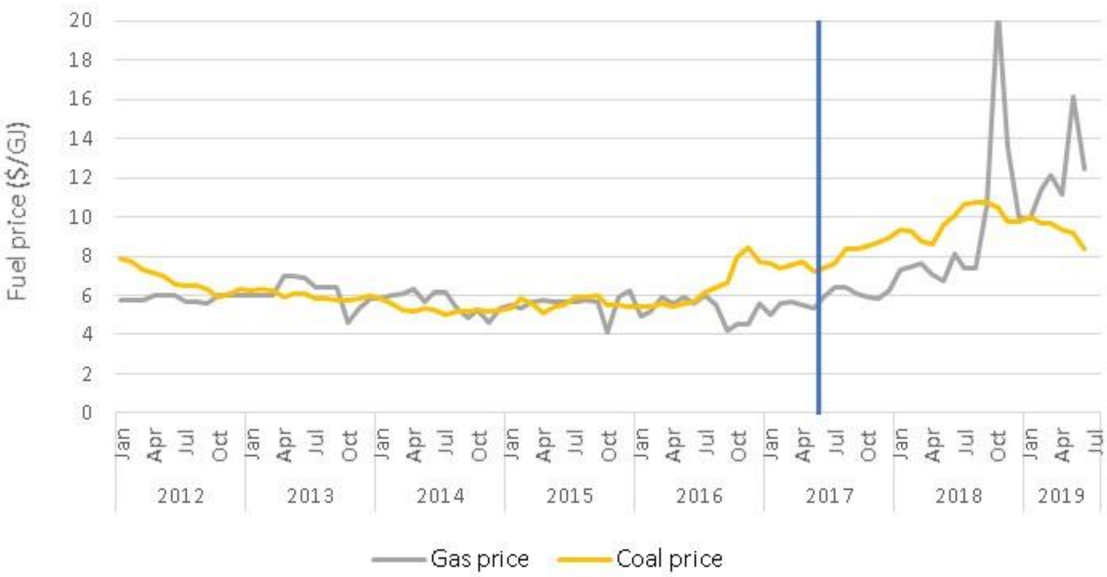
4.6 Thermal fuel costs

Putting thermal fuel availability to one side, there is also the issue of how much it costs to purchase such fuel. This is relevant to electricity spot prices, as thermal generators are unlikely to offer their plant if spot revenues do not cover the expected running costs including fuel.

[29] Pohokura recently announced a two-week planned shutdown in March 2020 for routine maintenance.

To examine thermal generator fuel costs, we collated information on spot prices for gas and coal over the period 2012-2019. It is important to note that generators are unlikely to purchase the bulk of their fuel requirements at spot prices. Rather, they will typically pre-contract for most of their needs. Nonetheless, spot prices are relevant because they provide an indicator of the fuel cost at the margin, which in turn would be expected to influence thermal generator offers.

Figure 7 - Thermal fuel prices[30]



We understand the marginal source of coal is often additional imports. Figure 8 shows there was an increase of more than 80% in coal spot prices between mid-2016 and mid-2018, driven by changes in the international coal market.[31] From mid-2018, coal spot prices eased somewhat, but they still remained well above pre-2016 levels. The rise in spot gas prices was even more dramatic – with prices rising by over 100% between mid-2017 and 2019.

Figure 8 shows the estimated short run marginal cost for running a Rankine unit on either coal or gas.[32] It also shows the Huntly Rankine “GWAP” or generation weighted average price. This is the average spot price realized by Huntly Rankine units when they were operating.[33]

---

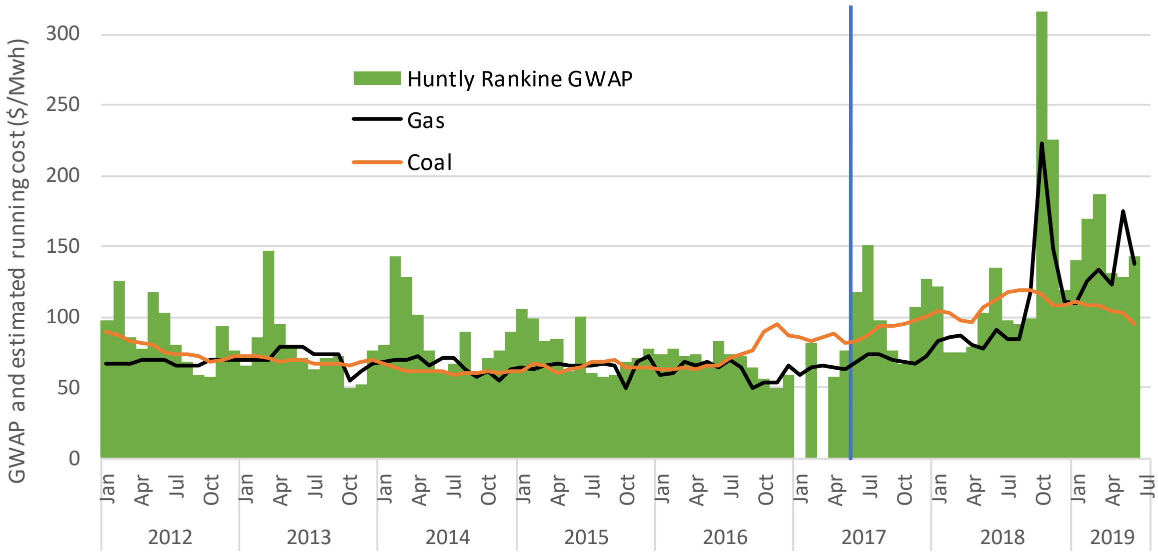
[30] Gas price data is monthly average price on emsTradePoint where data in available. Earlier period data is based on company disclosures from TAG Oil. The monthly coal price is based on prices for Newcastle coal, adjusted for estimated delivery costs to Huntly. An allowance for carbon costs has also been included for both fuels.

[31] In particular, there was a marked increase in prices for premium coal used for power generation.

[32] A heat rate of 10.5 GJ/MWh and a variable operating and maintenance cost of 7.75 $/MWh is assumed.

[33] Months when a Rankine unit did not operate do not have a GWAP.

Figure 8 - Cost and offers of Huntly Rankine units during peak periods



In most months, the Rankine GWAP is slightly above our estimate of its short-run marginal cost. In some months it appears that the Rankine units do not receive sufficient spot market revenue to cover their operating costs. However, estimated operating costs based on a current marginal fuel cost may not reflect Huntly's actual fuel cost because of stockpiled fuel supply or long term fuel supply contracts. Similarly, we expect that some of the revenue received from Huntly Rankine units will be from long term electricity supply contracts not directly linked to the spot market.

In recent years, both the cost of fuel and the Rankine GWAP have increased. We do not see any significant change in the relationship between the two variables. That is, Huntly still appears to be earning slightly above its running cost in most months but was occasionally under-recovering.

To the extent that a Huntly Rankine unit set the spot price, it appears that any increase in spot price could be mostly explained by an increase in the marginal fuel cost.

4.7 Assessment of physical factors over the 2012-2019 period

The examination of physical factors before and after May 2017 indicates:

- There was an appreciable tightening of the supply-demand balance between 2012 and 2019, driven mainly by plant retirements. This tightening is evidenced by Transpower's Annual Security Assessments and was equivalent to a net reduction of around 2,000 GWh in supply capability during winter (assuming mean hydrology and fully fuelled thermal generators).[34]
- Actual hydrology was generally dryer in two years after May 2017 than the preceding two years. This accentuated the tightening in supply over the period due to plant retirements.
- Gas supply issues emerged in early 2018 which further tightened the electricity supply-demand balance. In particular, gas supply restrictions at Pohokura were equivalent to a loss of up to 3,000 GWh of supply capability during 2018. Furthermore, it was often unclear how long the Pohokura restrictions would last, exacerbating concerns over thermal supply.
- Gas and coal spot prices rose more than 80% between mid-2016 and 2018-19, significantly increasing the estimated marginal cost of running thermal plant.

[34] The exception was Whirinaki, which has its output limited by fuel supply.

From a qualitative viewpoint, given the magnitude and direction of these changes, it is not surprising that average spot prices for the period May 2017 – June 2019 were appreciably higher than in the two years before May 2017.

5 South Island generator offers

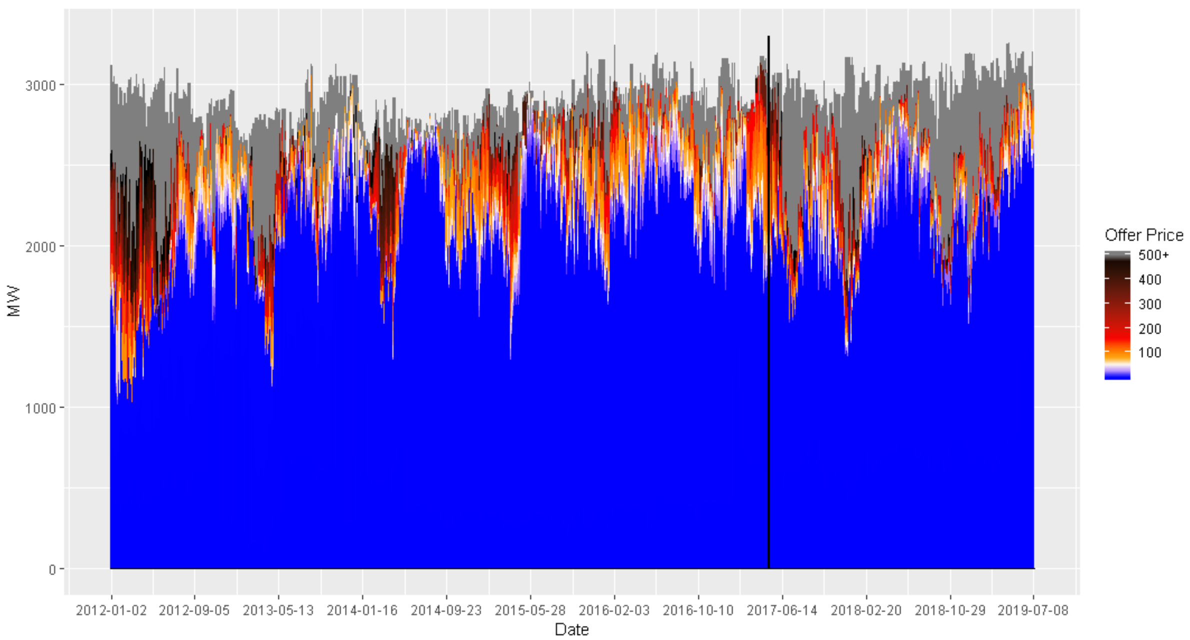
This chapter examines South Island generator *offers* over the period 2012 to 2019. We examine offer data because it was cited[35] as the main evidence in support of the view that the Authority's letter to Meridian triggered the observed increase in spot *prices* after 2017.

5.1 South Island generators

We examined offer data for generators in the South Island since 2012. While we consider offers for each major generator,[36] because prices are determined by the interplay of all supply and demand, we believe it is more informative to focus on the offers of all major South Island generators as a group.

Figure 9 and Figure 10 show price and quantity data for these generators' offers. The vertical axis indicates offer volumes, and the price of different offer tranches is indicated by differing colours in the key. Offers for generation in peak demand periods (defined as trading period 36) are shown in Figure 9.[37] Figure 10 shows the corresponding offers for off-peak periods (trading period 3).

Figure 9 - Total South Island offers in peak periods

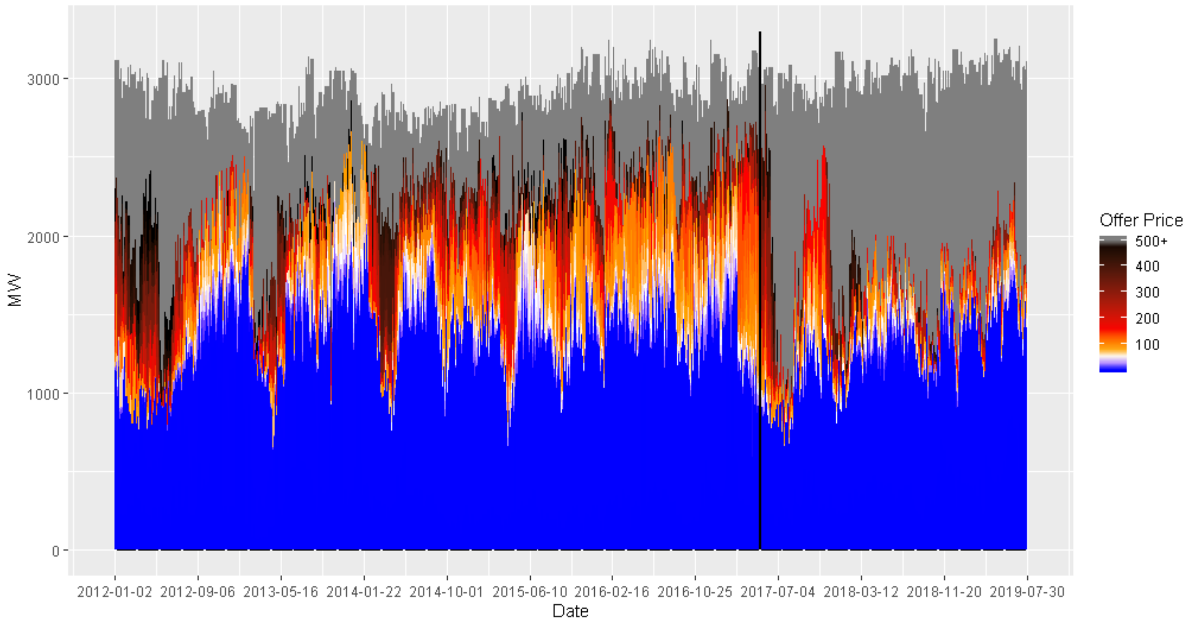


[35] Matt Rowe, 'The lakes are near full, the gas fields are back operating, so why are New Zealand's electricity prices still so stubbornly high?', *Energy News,* 2 July 2019.

[36] Contact Energy (Clutha scheme), Genesis Energy (Tekapo stations), Meridian Energy (Waitaki and Manapouri schemes).

[37] We examined other trading periods during peak and off-peak periods, and the results are very similar.

Figure 10 - Total South Island offers in off-peak periods



These figures can be hard to interpret. They present a large amount of information at once, because offers are multi-faceted. To try to quantify any changes to offers, we examined different "metrics" that seek to summarize key aspects of the offer curve.

In this section we focus on two key metrics:

- Quantity of offers below a defined offer price threshold
  - We considered alternative thresholds of 500 and 100 $/MWh
- Responsiveness of offers – which measures how much additional generation volume will be dispatched for a given increase in the clearing price.

5.2 Quantity of generation offered below 500 $/MWh

The article stated there was a change in offer behaviour in May 2017 with "a significant increase in the proportion of MWs offered in higher price bands, across both the Clutha and Waitaki schemes".[38] As evidence, the article referred to an apparent change in the volume of generation offered in excess of 500 $/MWh since May 2017.

In our view, the volume of offers above 500 $/MWh is not a reliable indicator of how offers will affect spot prices (the focus of the article). This is because such offers may not alter dispatch patterns if they simply reflect re-pricing of generation which is very seldom dispatched.[39] A more useful metric is the quantity of generation offered *below* 500 $/MWh.

The quantity of generation below a given price determines how much hydro generation is available and therefore how much other generation (such as from thermal plant) is required to meet the rest of demand. It might be intuitive to expect "offers above 500 $/MWh" to simply be the complement

[38] Ibid at footnote 35.

[39] We note that altering the price of offers above 500 $/MWh could change spot prices during inter-island transmission constraints and hence alter spot prices. However, unless such events are relatively frequent, this would be unlikely to trigger a 'structural shift' in average spot prices.

of "offers below 500 $/MWh". However, this is not necessarily the case because hydro generators do not always offer their full nameplate capacity.[40]

This can be seen in Figure 9 and Figure 10 by the unshaded area above the "grey" offers. On inspection, this unshaded area appears to have decreased since 2014 and 2015. One likely reason for this is the change to the HVDC transmission charge regime, meaning that generators are no longer penalized for generating larger quantities during peak periods.[41]

Figure 11 – South Island generation offered below 500 $/MWh during peak periods

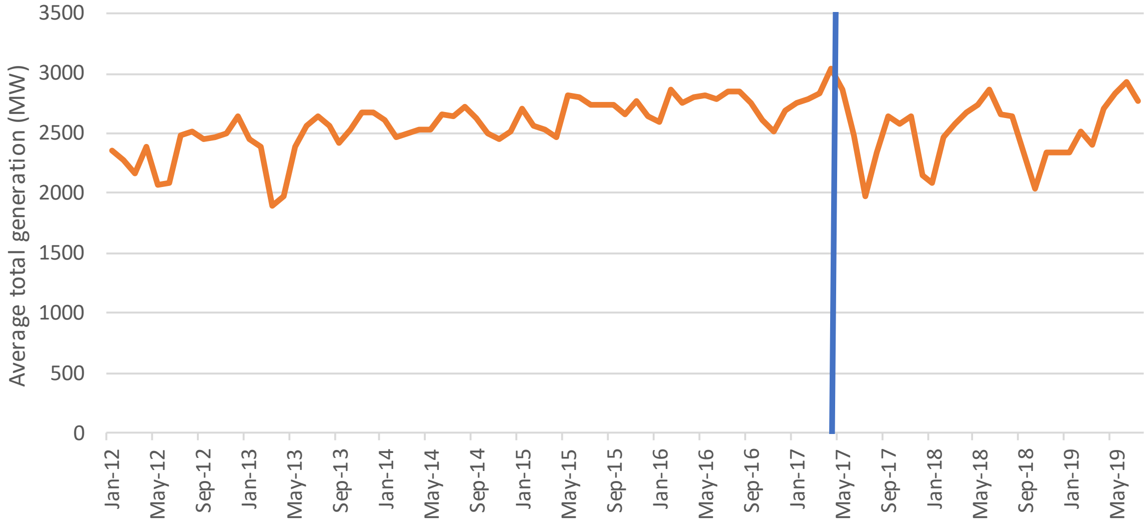


Figure 11 shows the average quantity of offers available below 500 $/MWh during peak periods. Values were lower for many months after May 2017, as compared to the preceding three years. However, the lowest value for the entire period occurred in May 2013, and June 2019 was the second highest month since 2012. The change in offer volume is therefore not clear-cut.

We used a Chow test to investigate whether there was evidence of a structural break in this metric in May 2017. Our fitted model accounted for the effect of storage levels, the change to HVDC transmission charging methodology, gas price and seasonality. The model found evidence of a structural break for peak offers in May 2017.[42]

To investigate this change further, we considered offers by different generators separately. This analysis showed a clear change to offered quantity below 500 $/MWh by Contact Energy for the Clutha Scheme in May 2017.[43] However, the test showed no statistically significant change to Meridian's generation offer volumes on the Waitaki scheme at that date.[44,45]

---

[40] In effect, any unoffered generation is offered at "infinity", and could be considered as priced above 500 $/MWh.

[41] "The methodology to allocate the HVDC costs to South Island (SI) generators was changed from 2015. This change involved transitioning from the peak-based metric (HAMI) to an average-based metric (SIMI) from the 2017/18 pricing year (PY)." –https://www.transpower.co.nz/resources/market-impact-assessment-changes-hvdc-cost-allocation

[42] The F-statistic was 2.4 and the p-value was 3.6%.

[43] The F-statistic was 4.8 and the p-value was 0.03%.

[44] The F-statistic was 0.88 and the p-value was 51%.

[45] We have not reported results for Genesis Energy's Tekapo generation because the plant was affected by maintenance outages for part of the period, making it difficult to interpret the results.

5.2.1 Quantity of generation offered below 500 $/MWh in off-peak periods

We repeated the above Chow test analysis for off-peak periods. Again, we found evidence that for South Island generators the quantity of offers below 500 $/MWh changed in May 2017.[46] The separate Chow tests of Meridian's and Contact's offer volumes below 500 $/MWh also indicated a structural break from May 2017.[47]

5.3 Relationship between generation offers above 500 $/MWh and spot prices

The preceding section indicates the quantity of *offers* below 500 $/MWh changed in May 2017 in a way that is not fully explained by physical factors. However, as noted in section 3, we found no evidence of a structural shift in *spot prices* at that date. These two findings might seem contradictory, but this is not so. The two findings are compatible because offers above 500 $/MWh were very rarely cleared, and so they have little direct effect on spot prices.

Figure 12 - Cleared South Island peak offers

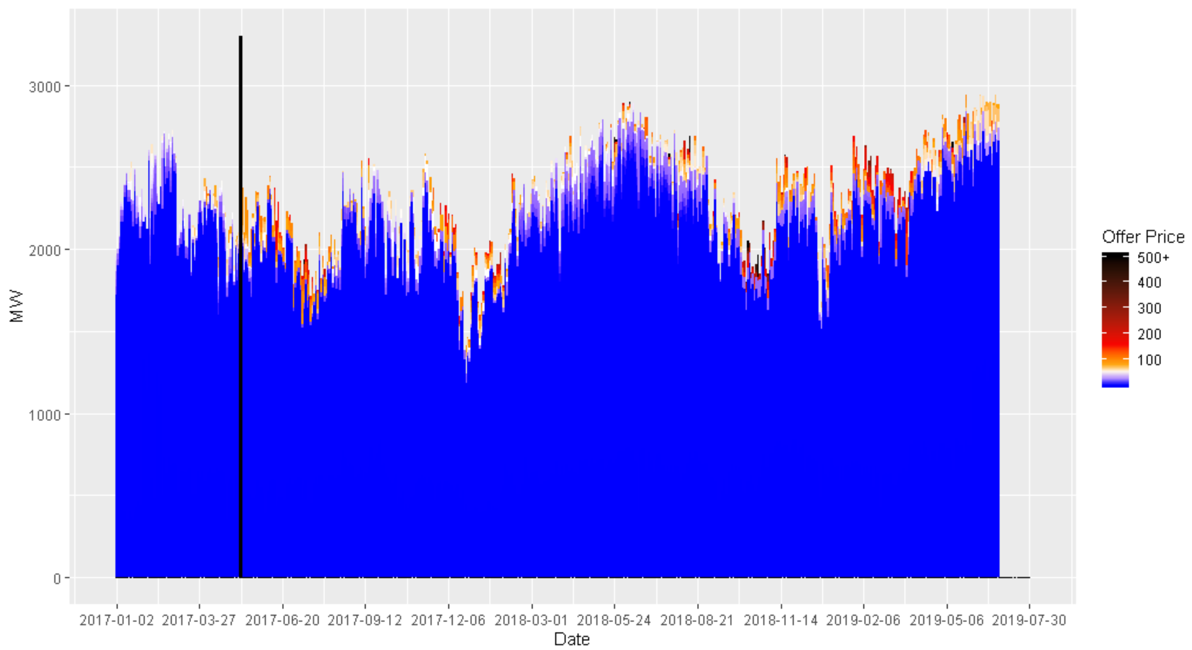


Figure 12 shows offers that were cleared for South Island generation during peak periods (only 2017 onwards is shown for greater detail).[48] The higher priced "black" offers (500 $/MWh or more) are only cleared very occasionally – in less than 1% of trading periods – and therefore hardly show up on the chart. In the vast majority of periods, even in recent dry conditions, prices cleared below this level.

To further assess this issue, we estimated the effect of reducing all 'high priced' offers after May 2017 to 500 $/MWh by capping spot prices at this level. This would have reduced the average spot price at Benmore since May 2017 by 1.06 $/MWh or by about 1%. However, that would almost certainly overstate the effect of 'reverting' to offer structures observed pre-2017 for dry conditions, because those structures had generation tranches offered above 500 $/MWh. If we instead capped spot prices at 900 $/MWh,[49] the average spot price at Benmore would have reduced by 0.8

[46] An F-statistic of 11.6 and a p-value of less than 0.01%.

[47] An F-statistic of 5.3 and a p-value of 0.01% for Meridian. An F-statistic of 13.2 and a p-value of less than 0.01% for Contact.

[48] Dispatched offers are estimated based on observed spot prices. Actual dispatch may have differed slightly.

[49] Significant quantities of generation were offered at about 900 $/MWh pre-2017.

c/MWh.[50] This is well short of the actual increase in spot prices, which is the focus of the opinion article.

5.4 Quantity of generation offered below 100 $/MWh

In its conclusion, the article[51] states that changes to hydro offers can affect the dispatch of thermal plant and we agree. However, we do not believe the relevant offer price threshold to measure the switching between hydro and thermal is 500 $/MWh. The short run marginal cost (SRMC) for a thermal plant is almost always much lower than this, implying that if such offers are dispatched then thermal plant will already be running.[52] A more relevant offer price threshold to test this effect is one comparable to the SRMC of a thermal plant, as reductions in hydro generation volumes offered below this price will likely cause more thermal plant to run.

From inspection of Figure 8, 100 $/MWh appears to be a reasonable estimate of the price level at which discretionary (i.e. not baseload) thermal plant is operating. Put another way, when South Island generators reduce the volume offered below 100 $/MWh, this will likely cause an increase in discretionary thermal generation (and average spot prices), and vice versa.

Figure 13 - Generation offered below 100 $/MWh during peak periods

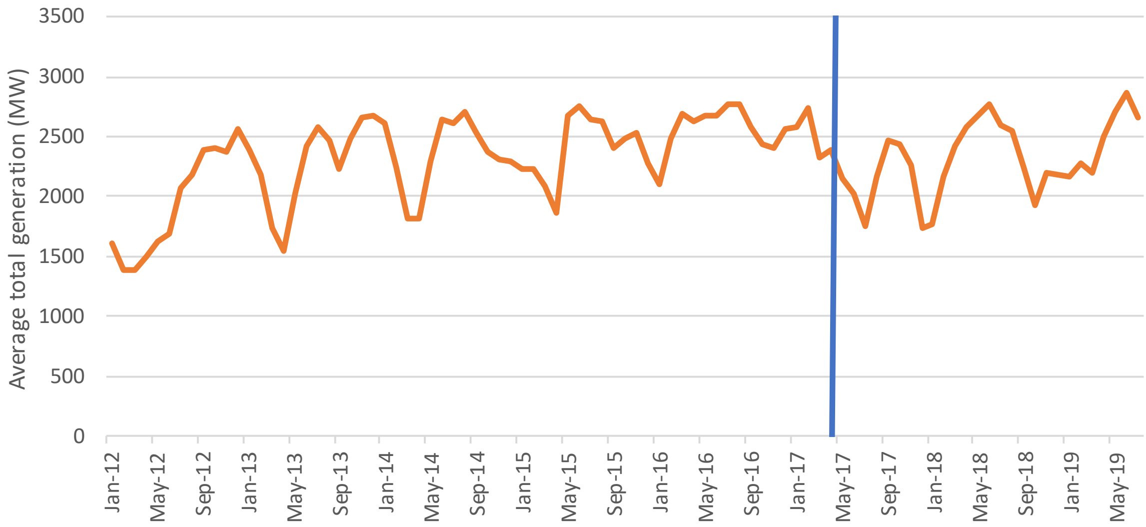


Figure 13 shows the quantity of South Island generation offered for less than 100 $/MWh in peak periods. The quantity dropped after May 2017, but not below levels seen in 2012 and 2013. The highest average value for a month occurred in May 2019.

A Chow test was performed on this data to examine whether a structural shift occurred in May 2017. The explanatory variables used in this analysis were gas prices, relative storage, changes to the HVDC charge regime and seasonality. The Chow test analysis did not find any statistical evidence of a structural break in May 2017.[53]

[50] Of course, as discussed in section 5.5, the narrowing of the 'in-market' offer band did contribute to higher spot prices, as thermal generation substituted for hydro generation. However, that pattern of behavior was apparent throughout the period under review when the system was stressed by low hydro storage.
[51] Ibid at footnote 35.
[52] We do not consider the effect of any transmission constraints.
[53] The F-statistic was 0.45 and the p-value was 81%.

For off-peak offers, there was evidence that the quantity of offers below 100 $/MWh was different before and after May 2017.[54] However, the Chow test suggests the breakpoint actually occurred in February 2017, before the letter to Meridian was sent or published.[55]

In summary, the tests for changes to offered quantities below 100 $/MWh resulted in either no evidence for a structural break in May 2017, or evidence that the break was more likely to have occurred some months before the letter was sent by the Authority. Neither result supports the view that the letter caused a change to the part of offer structures which materially affects spot prices.

5.5 Structure of offers priced near market-clearing spot price

In addition to the analysis discussed above, we examined the structure of offers near the market clearing price. We define these as offers above 50 $/MWh and below 500 $/MWh (i.e. offers other than those shaded blue or grey in Figure 9 and Figure 10). We call these ‘in-market’ offers.

There has been a noticeable reduction in the quantity of these in-market offers at times. A narrowing of offer volumes in this band will reduce supply ‘responsiveness’ from the relevant generators during normal operation. Put another way, when this offer band is relatively narrow, differences between expected and actual system conditions within a half-hour trading period will have more effect on the market clearing spot price, and vice versa.

Figure 9 and Figure 10 show tighter responsiveness after May 2017. However, this type of tightening has sometimes occurred in the past. For example, in winter 2012 and autumn 2013 (both of which were dry), there were periods with smaller volumes offered in this price band. The changes are particularly apparent for the off-peak offers (Figure 10). This raises the question of what can explain the fluctuations in supply responsiveness.

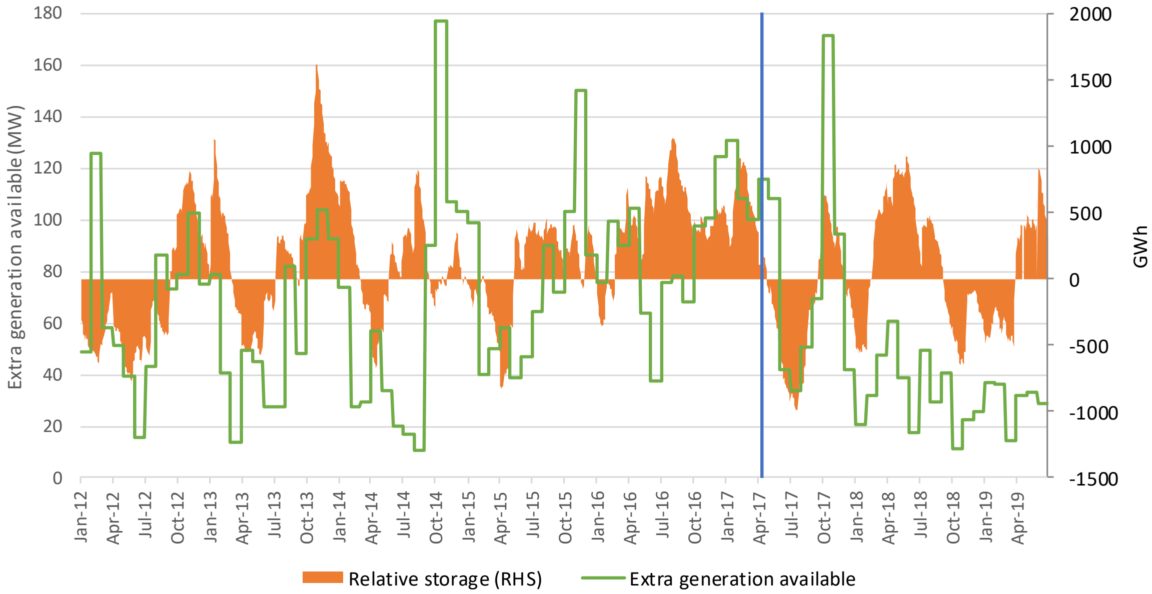
5.5.1 Supply responsiveness

To further examine the changes in supply “responsiveness”, we looked at the amount of generation that would have been cleared if spot prices had increased by 20 $/MWh. In effect, this provides a measure of how steep the supply curve is above the market-clearing price. This information is shown in Figure 14.

[54] The F-statistic was 2.5 and the p-value was 3.4%.

[55] Off-peak offered quantity dropped dramatically in February, despite above average storage levels and a normally benign time of year. A Chow test for February 2017 returned an F-statistic of 3.6 and a p-value of 0.3%.

Figure 14 - Extra generation available during peak periods with a 20 $/MWh increase in spot price



Looking over the entire period, the supply responsiveness measure fluctuates significantly, and is normally lower in autumn/winter and higher in spring/summer. Putting seasonal factors to one side, the supply responsiveness measure also appears to have reduced after late 2017.

Focussing on the period from May 2017 when the Authority wrote to Meridian, we observe:

- The supply responsiveness measure dropped in winter 2017 and recovered in the following spring/summer. This was consistent with the 'normal' seasonal pattern observed in previous years.
- The supply responsiveness measure declined in autumn/winter 2018 – again following the 'normal' seasonal pattern observed in previous years.
- The supply responsive measure did not increase in the 2018 spring/2019 summer – unlike the pattern observed in previous years. Instead, the measure remained more like that typically observed during autumn/winter conditions.

This raises the question of what happened from late 2018 – and why the 'normal' supply responsiveness did not re-emerge in 2018 spring. Was it a reaction (albeit delayed) to the Authority's May 2017 letter, or were physical factors the more likely cause?

We address this question using both quantitative and qualitative approaches.

5.5.2 Qualitative assessment of changes in supply responsiveness

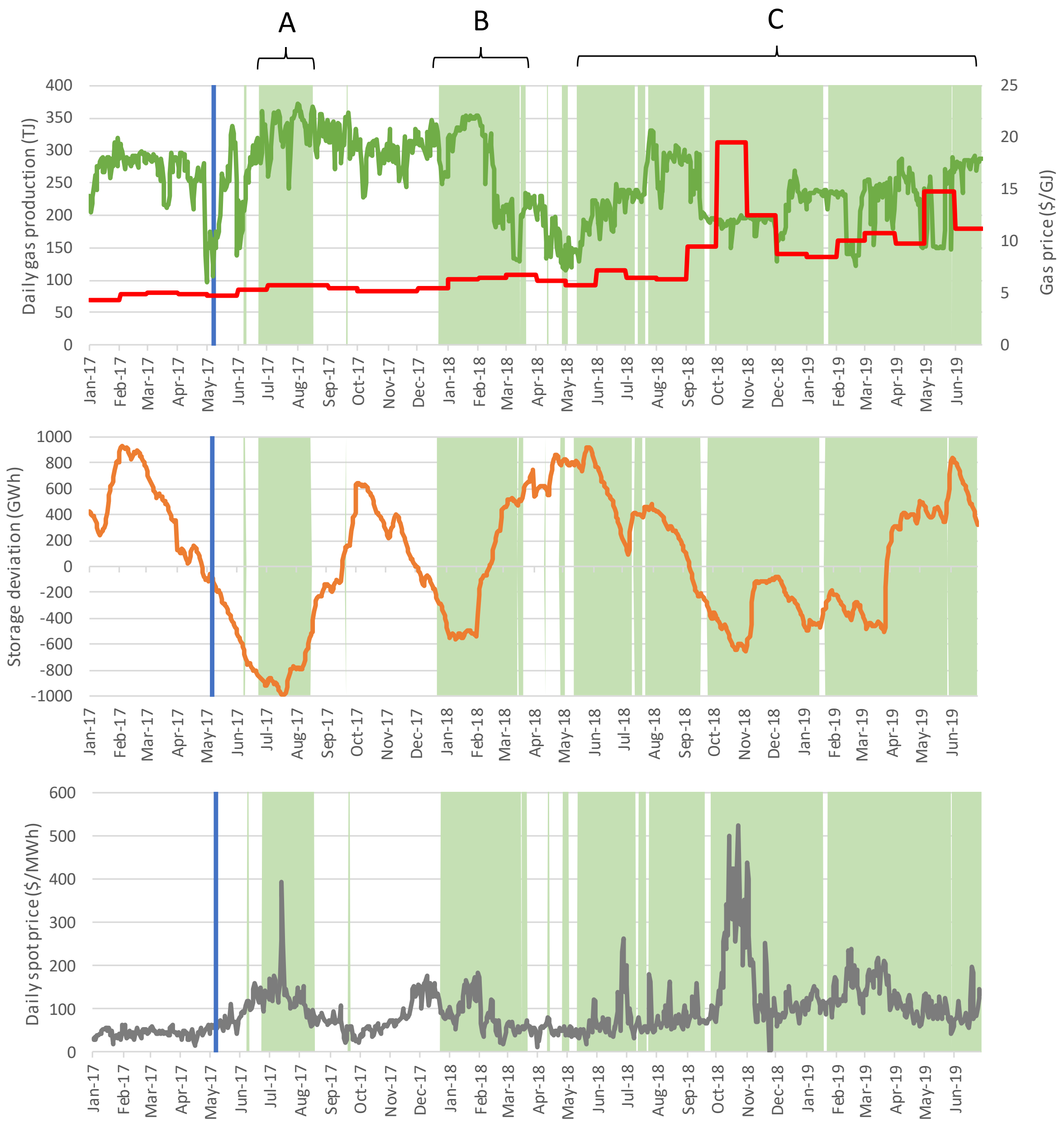
Our qualitative approach compares the supply responsiveness with information on storage and gas market conditions. This information is shown in Figure 15. Periods when tight supply responsiveness was observed in South Island generator offers are shaded light green.[56] Also shown on the chart is output from the Pohokura and Maui gas fields (in darker green),[57] the monthly average gas spot price (in red and on right hand axis), and deviations from average hydro storage levels (orange). The

[56] Defined as points from Figure 14 at which less than 50MW of extra generation in available with a price increase of 20 $/MWh. Measure is a 2-week rolling average of weekday peak periods.

[57] Estimated by injections to the Maui pipeline. We have not included other fields because their fluctuations over this period were significantly smaller.

chart also shows the average daily Benmore spot price (in dark grey) and the date when the Electricity Authority wrote to Meridian (blue vertical line).

Figure 15 – Generator offer responsiveness and physical system conditions



The periods of reduced responsiveness are labelled A, B and C. The key observations are:

- Period A – hydro storage was well below average for all of this period. It was also winter, and responsiveness was observed to decline in previous winter periods.
- Period B – hydro storage was below average for the first half of this period but recovered to end above average. However, from the middle of the period gas supply was significantly impaired by a planned complete shutdown at Maui followed by an unplanned partial shutdown at Pohokura.[58]

[58] See Figure 6 for more detail.

- Period C – hydro storage fluctuated, being below, close to, and above average at times. However, gas supply was uncertain and/or significantly restricted through much of this period, and monthly average gas spot prices were significantly higher through the entire period. Such factors effectively created conditions akin to a "dry" period, even though hydro storage as such was above average at times.

In summary, Period A was not especially unusual, given that responsiveness normally reduces in winter (especially in dry winters). Conversely, Periods B and C were somewhat unusual because responsiveness did not increase in the spring/summer period. Physical factors (such as hydro storage and gas prices) may explain that change, but it is hard to tell and for this reason we undertook statistical analysis to examine the issue in more detail.

5.5.3 Quantitative assessment of changes in supply responsiveness

Our quantitative approach used a Chow test to determine if there was a "structural break" in the level of supply responsiveness.

The regression model used gas prices, changes to the HVDC charge regime, and seasonality, all of which had statistically significant explanatory power.[59] Interestingly, the analysis indicated that hydro storage did not have significant explanatory power, if these other variables were included.

Using the standard form of the Chow test, there was a statistically significant change in responsiveness before and after May 2017. However, as noted in the preceding section, the qualitative assessment suggested that if there was a change, it more likely occurred in late 2017 when supply responsiveness did not lift in spring/summer.

For this reason, the alternative Chow test was also used to identify all potential structural break points. The Chow test F-statistic was highest in November 2017, suggesting that this was the month when the change occurred. This result is consistent with the qualitative analysis.[60]

5.6 Overall assessment of offer data

There is no doubt that generator offers changed many times over the period 2012-2019, so the examination needs to focus on more particular questions to provide useful information. In our view the key questions are:

1. Did *offers* undergo a structural shift in May 2017? and
2. If so, would such a shift explain the observed material increase in average spot *prices*?

To answer these questions, we considered three key aspects of generator offers:

- The volume offered below 500 $/MWh (as this was explicitly raised in the article)
- The volume offered below 100 $/MWh (as this materially affects average spot prices)
- The level of supply responsiveness in the offer curve (again because this may affect spot prices).

The results for each aspect of the assessment are summarised in Table 1.

[59] See summary output on page 49
[60] See Figure 30

Table 1: Summary of analysis of offer data[61]

Specific aspect of generator offers	Was there statistically significant evidence of a structural shift in May 2017?	Would a change materially raise spot prices?
Volume offered in the price bands below 500 $/MWh	**Yes** Contact's offers appear to have changed for peak and off-peak periods, and Meridian's for off-peak periods.	**No** Changes in the volume offered below 500 $/MWh can simply result in higher offer prices for volumes which are seldom cleared - and the data indicates this was the case
Volume offered in the price bands below 100 $/MWh	**No** While generator offers for off-peak periods show a change, evidence indicates it occurred in February 2017 (before the Authority issued its letter)	**Yes** Changes in the volume offered below 100 $/MWh are very likely to affect the level of thermal generation and spot prices
Supply responsiveness	**No** While responsiveness shows a change, the evidence indicates it was in November 2017, not May 2017.	**Yes** Reduced responsiveness likely to increase frequency of price spikes

In summary, the analysis did not find any aspects of offers that underwent a structural shift in May or June 2017, and which would materially increase prices.

[61] See Appendix A starting page34.

6 Conclusions

Our conclusions in relation to the questions posed by the MDAG are set out below.

1. **Did a trading conduct enforcement action by the Electricity Authority in May 2017 cause a structural increase in electricity spot prices since May 2017**

The statistical evidence does not support the view that a structural shift in spot prices occurred in May 2017. Nor does the statistical analysis indicate any structural shift in spot prices occurred within 12 months after that date. We therefore conclude that the enforcement action by the Authority in May 2017 did not cause a structural increase in electricity spot prices.

2. **To what extent can changes in spot prices since May 2017 be explained by other factors, such as demand, fuel costs or hydrology.**

The statistical evidence strongly indicates the increase in spot prices observed since May 2017 is explained by physical factors – especially changes in hydro storage and gas prices over the period. Other factors such as changes in demand or coal prices have some explanatory value, but are much less important than hydro storage and gas prices.

We also considered changes to offers, as this was cited[62] as the main evidence in support of the view that the Authority's letter to Meridian triggered the observed increase in spot *prices* after 2017. The analysis did not find any aspects of offers that underwent a structural shift in May 2017, and which would materially increase prices.

[62] Matt Rowe, 'The lakes are near full, the gas fields are back operating, so why are New Zealand's electricity prices still so stubbornly high?', *Energy News,* 2 July 2019.

concept

Appendix A. Results of statistical tests

This appendix presents more details about the statistical tests described in the body of the paper.

All Chow tests were performed on monthly average data. We investigated daily models that also considered demand, but these models generally had less explanatory power compared to monthly ones (i.e. lower R^2 values). This was likely to be because daily data contains more short-term 'noise', and this acts to obscure the relationships apparent in the monthly average data.

Standard Chow test identifies whether break occurred in May 2017

The Chow test compares the residuals from a single regression line to the residuals from two separate regression lines. If using two lines reduces the residuals sufficiently, the Chow test indicates there was a structural break in the data series.

The standard Chow test identifies whether a break has occurred at a single hypothesised point. To test for changes in May 2017 (the date hypothesised in the article), we performed the standard Chow test to identify whether there was a structural break at this month.

Alternative form of Chow test identifies whether break occurred at any date

We also used an alternative method that performs Chow tests at each intermediary point[63] in the time series. This produces a plot showing the F-statistics for each month and the corresponding p-value required for the result to be statistically significant (i.e. whether there is statistical support for a break occurring at that date).

The p-value shown on these plots is a higher value than when testing for a single break point. This is because testing multiple points is a different task than testing a single point with an a priori basis to suspect it. To conceptualize why this is the case, consider a set of 20 independent tests. With a 5% threshold test, we could be expected to meet the threshold for one positive result just by random chance. The Chow tests on sequential points in a time series aren't independent, but a similar concept holds.

The plots shown in this appendix show the results from testing every point in the series. The black line showing the F-statistic for each month and the red-line indicates the (more stringent) value required to produce a significant p-value. The vertical blue line indicates the timing of the Authority's letter. It is possible that a Chow test on the single month of May 2017 could be significant, but not show up as significant when looking at the entire time period.

A key step in conducting Chow tests is determining the regression equation to model. We initially use a naïve model to test for a change to prices, but reject that model as not being relevant because it ignores all external explanatory variables, such as hydro storage conditions. For subsequent analysis, we use fuller models that account for changes in explanatory variables.

To determine the variables that should be included in each of the fuller models, we performed a regression considering the following potential variables:

- The cost to operate a Huntly Rankine unit on gas[64] [`gas`]
- The cost to operate a Huntly Rankine unit on coal [`coal`]
- National storage levels relative to the historical average storage at that time of the year [`rStor`]

[63] That is, for all points not near either end of the time series.
[64] Huntly Rankine units often operate as the marginal plant.

- The Winter Energy Margin as defined in the Annual Security Assessments issued by Transpower [WEM]
- Changes to the HVDC charging regime [HAMI]
- Seasonality (modelled by including a sine and cosine term repeating every year). [cosMth and sinMth]

We did not include a "time" variable (other than seasonality). We are not aware of any reason to expect the modelled variables to change systematically over time. For offer quantities, the nameplate capacity of generators in the South Island has not changed significantly. Furthermore, a time variable would be correlated with changes to the HVDC charging regime, which would introduce collinearity issues to the analysis. For prices, we do not observe any systematic trend change in prices over time.

Variables without statistically significant explanatory power were excluded from each regression model. We also confirmed the results of the model building process produced explanatory variables that "made sense" from our understanding of their interaction with the dependent variable. For example, HAMI showed up as a significant variable for analysis on offer quantities, but not for prices. This isn't surprising because the HAMI change directly affects the incentives on generators when offering generation, whereas its effects on price are less direct.

The exact model is slightly different for each section of the analysis depending on which explanatory variables were statistically significant:

- For price regressions, the model only included gas prices and relative storage.
- For quantities offered below a threshold price, the model included gas prices, relative storage, HAMI and seasonality.
- For "responsiveness", the model included gas prices, HAMI, and seasonality.

General approach to dummy variable testing

We also used an alternative method to look for a structural break. This was to re-run the regression analysis including a dummy variable in the regression model that is 0 for all months up to and including May 2017, and 1 thereafter. We consider it unlikely that any response to the letter would have happened instantaneously, and therefore consider May to better belong in the period before the letter.

If this variable has significant explanatory power, then the test suggests there was a structural break at this point. This test has the advantage of giving an indication of both the "sign" (i.e. an increase or decrease) and the magnitude of any change.

We include the output from the summary() function operating on the regression object in R. This provides extensive information about the regression equations and statistical test results which may be informative for some readers.

Collinearity of explanatory variables

We tested each combination of explanatory variables for collinearity. This is important as we use the coefficient for the dummy variable to draw conclusions about behaviour before and after the letter.[65] If the effect of the dummy variable were similar to another explanatory variable, then we would not be able to say which input explained the change observed. All combinations had variance

[65] This does not mean the letter *caused* any change, simply that there was different behaviour before and after

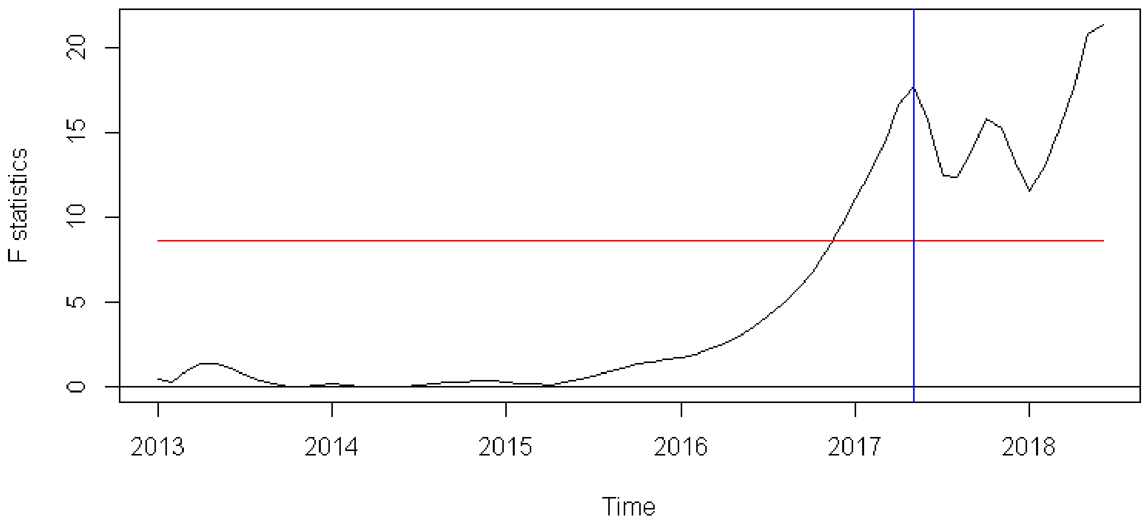
inflation factors (VIFs) of less than 5,[66] indicating there was minimal collinearity between explanatory variables.

However, coal price and the dummy variable are somewhat correlated (coal prices increased in late 2016 to early 2017) and this can result in a VIF of greater than 4 when both are used as explanatory variables. While this is not particularly high, from an abundance of caution we did not include coal price in any of the dummy variable models.

We do not consider it likely that excluding international coal prices will have a significant effect on the analysis. This is because the cost to run a Huntly Rankine unit on coal or gas is similar for much of the time series. The two costs only diverged significantly between late 2016 and mid 2018 when international coal was more expensive than gas. During this period, Huntly Rankine units were primarily operated on gas,[67] and this arguably meant that coal prices can be excluded without greatly reducing the explanatory power of the regression analysis.

Price – naïve application of Chow test (no explanatory variables)

Figure 16 - F-statistics for simple price model



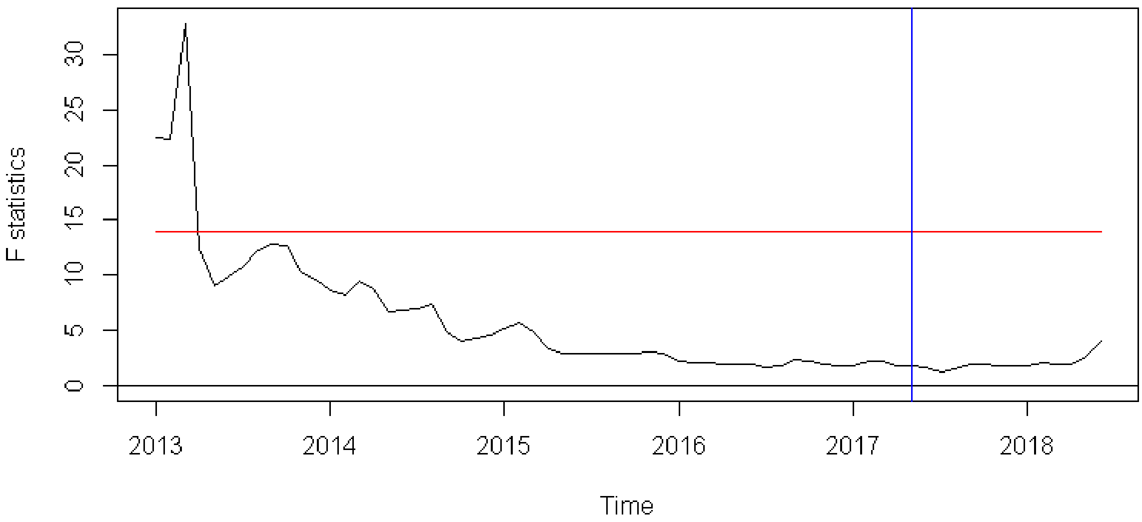
The test indicates a structural shift in 2017.

[66] A common "rule of thumb". Sheather, Simon (2009). A modern approach to regression with R. New York, NY: Springer. ISBN 978-0-387-09607-0.

[67] Estimated based on the quantity of gas delivered via Maui pipeline, Huntly electricity generation and estimated heat rates.

Price – application of Chow test (explanatory variables included)

Figure 17 – F-statistics for sophisticated price model



We do not conclude that there was a structural shift in 2017.

Result of including dummy variable on sophisticated model:

```
Call:
lm(formula = price ~ gas + rStor + DV, data = TS)

Residuals:
   Min      1Q Median      3Q     Max
-43.96 -15.14  -2.39  11.04  85.72

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 26.179524   7.968940   3.285  0.00147 **
gas          8.344934   1.279069   6.524 4.35e-09 ***
rStor       -0.052643   0.005502  -9.567 3.10e-15 ***
DV           1.046265   7.131432   0.147  0.88370
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 23.63 on 87 degrees of freedom
Multiple R-squared:  0.6937,    Adjusted R-squared:  0.6832
F-statistic: 65.69 on 3 and 87 DF,  p-value: < 2.2e-16
```

The coefficient of the dummy variable is 1 $/MWh and is not significant. After correcting for gas price and relative storage, the dummy variable has no explanatory power.

This result is consistent with Figure 17 in finding no evidence that prices changed in May 2017.

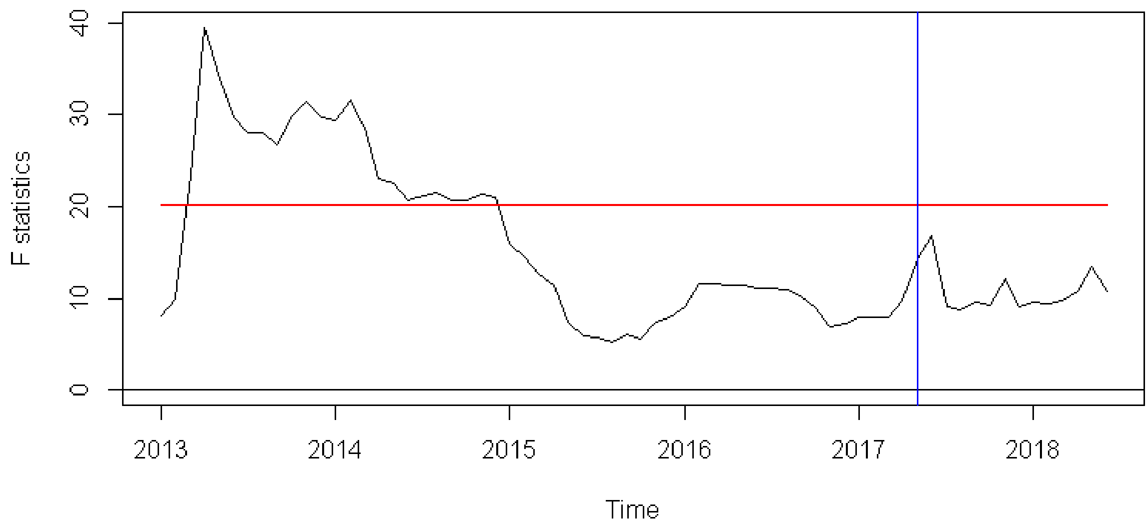
Quantity offered below various offer price thresholds

This analysis involves multiple steps:

- We first consider the total island offers, both for peak and off-peak.
- We then examine individual schemes
- We repeat the analysis for a lower price threshold.

To produce a "like for like" comparison, we have used the same underlying model for all comparisons in this section. This model includes `HAMI`, `gas`, `rStor` and seasonality.

Figure 18 - F-statistics for Quantity offered under 500 $/MWh (peak)



Both May and June 2017 are somewhat elevated but neither month yields statistically significant results. (However, recall the difference between a single point Chow test, and a test across the entire time series. When tested alone, a Chow test for June 2017 has a p-value of 1.6%, a significant result at the 5% level.)

When considered with the results from other months, the result for June 2017 does not particularly stand out. There was stronger evidence of a structural break occurring in 2013 or 2014.

Results from dummy variable modelling:[68]

```
Call:
lm(formula = Q500 ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)
```

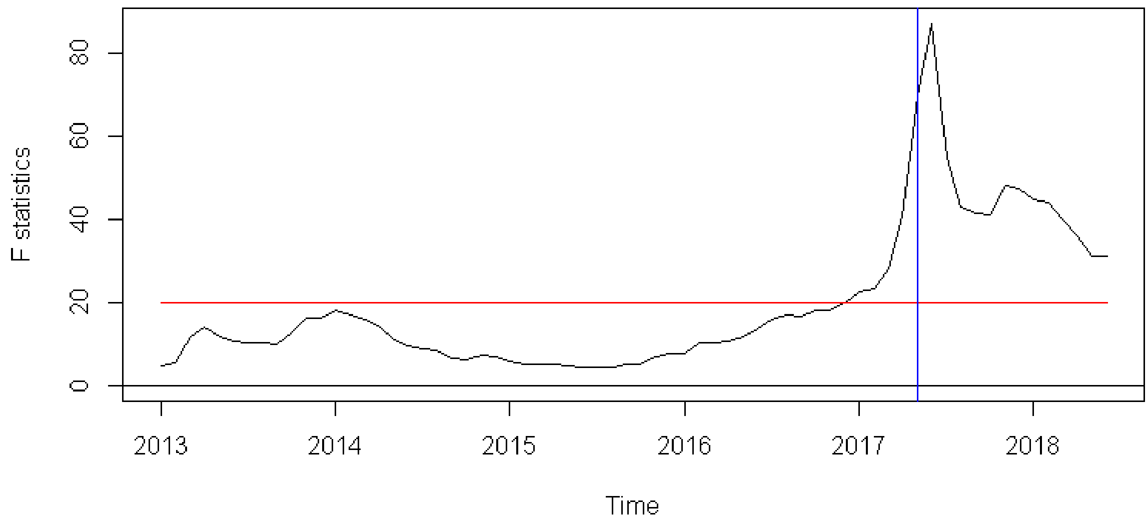
[68] We include the `sinMth` term even though it is not significant because in conjunction with the `cosMth` term it allows seasonality to shift through the year as well as change in amplitude. Without the combination of both these terms we would be exogenously defining the timing of the seasonal peak and we have no basis on which to do this.

```
Residuals:
    Min      1Q  Median      3Q     Max
-535.97  -80.93   12.56  110.97  343.21

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 2671.40760   58.74388  45.476  < 2e-16 ***
gas           -2.10024    8.38605  -0.250  0.80286
rStor          0.29361    0.03831   7.665 2.83e-11 ***
HAMI        -188.36763   42.83704  -4.397 3.19e-05 ***
cosMth       -95.02672   23.01280  -4.129 8.55e-05 ***
sinMth        17.58089   23.62796   0.744  0.45891
DV          -164.39191   57.04651  -2.882  0.00502 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 154.1 on 84 degrees of freedom
Multiple R-squared:  0.5877,    Adjusted R-squared:  0.5582
F-statistic: 19.95 on 6 and 84 DF,  p-value: 2.338e-14
```

The coefficient for the dummy variable is -164, indicating that there has been about 164 MW less generation offered at below 500 $/MWh since May 2017.

We conclude that there was a reduction to peak offer quantities in May 2017. But note that changes to offer structure have happened frequently over the past few years, and such a change is not unusual.

Figure 19 - F-statistics for Quantity offered under 500 $/MWh (off-peak)



The was a clear increase in the F-statistic during mid-2017, around the time of the letter. Both May and June are elevated, with June slightly higher. No other obvious change points are identified in the test.

Results from dummy variable modelling:

```
Call:
lm(formula = Q500O ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
   Min     1Q Median     3Q    Max
-657.9 -112.4    6.3  103.8  549.0

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 2349.88001   75.07502  31.300  < 2e-16 ***
gas           -7.96606   10.71743  -0.743    0.459
rStor          0.26850    0.04896   5.484 4.29e-07 ***
HAMI        -234.87831   54.74598  -4.290 4.75e-05 ***
cosMth        39.47605   29.41049   1.342    0.183
sinMth        36.01527   30.19667   1.193    0.236
DV          -599.99825   72.90578  -8.230 2.10e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

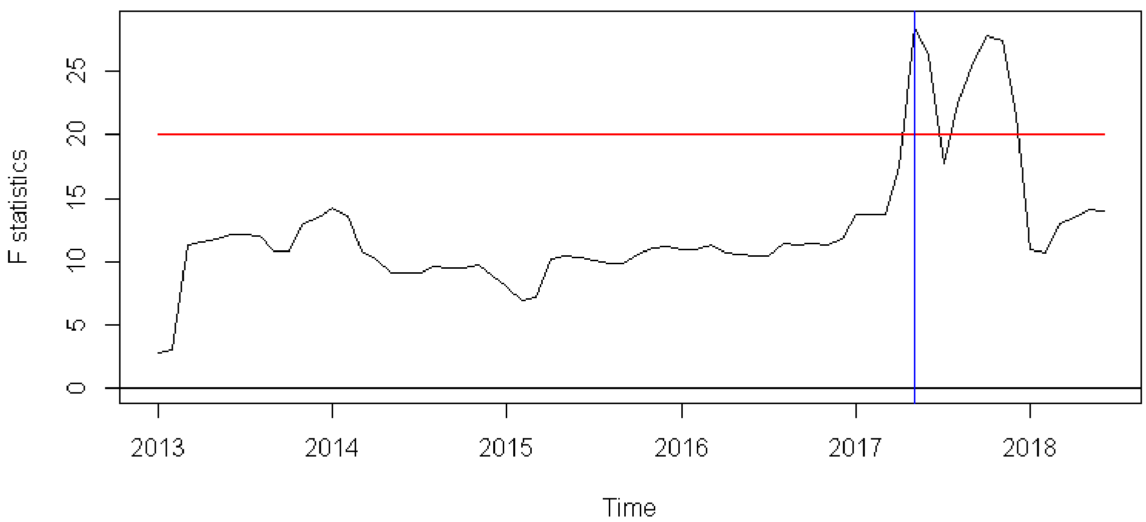
```
Residual standard error: 197 on 84 degrees of freedom
Multiple R-squared:  0.7032,    Adjusted R-squared:  0.682
F-statistic: 33.17 on 6 and 84 DF,  p-value: < 2.2e-16
```

The coefficient for the dummy variable is -600 MW, indicating that there has been about 600 MW less generation offered at below 500 $/MWh since May 2017. This is particularly notable given the average quantity offered is about 2,100MW.

Individual participant behaviour – Contact Clutha

To isolate the cause of the changes, we analysed individual schemes.

Figure 20 - F-statistics for Quantity offered under 500 $/MWh (peak Clutha)



There was a clear increase in May 2017. Note that this is a month earlier than the largest change observed for total South Island offers, suggesting that Contact changed their behaviour in Winter 2017 prior to other generators. We observe that the letter was published on the 8th of May 2017 and so for the average behaviour in May 2017 to have changed as a result of this would require a very fast response time.

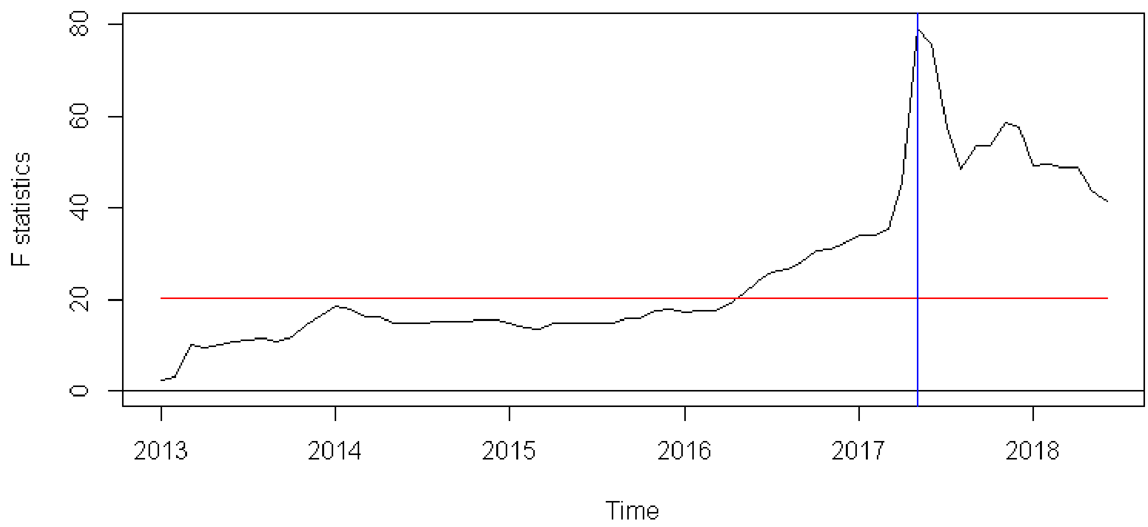
Results from dummy variable modelling:

```
Call:
lm(formula = Q500C ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)


Residuals:
     Min        1Q    Median        3Q       Max
-213.137   -32.432     4.027    36.836   128.091


Coefficients:
```

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 634.58366   21.22083  29.904  < 2e-16 ***
gas           5.88109    3.02941   1.941 0.055571 .
rStor         0.09348    0.01384   6.755 1.75e-09 ***
HAMI        -44.86893   15.47459  -2.900 0.004768 **
cosMth      -25.84880    8.31322  -3.109 0.002560 **
sinMth        1.72784    8.53544   0.202 0.840070
DV          -74.09656   20.60767  -3.596 0.000545 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 55.67 on 84 degrees of freedom
Multiple R-squared:  0.4982,    Adjusted R-squared:  0.4623
F-statistic:  13.9 on 6 and 84 DF,  p-value: 6.53e-11
```

The coefficient for the dummy variable is -74, indicating that there has been about 74 MW less generation offered at below 500 $/MWh since May 2017.

Figure 21 - F-statistics for Quantity offered under 500 $/MWh (off-peak Clutha)



The was a clear increase in the F-statistic during mid-2017. Note that the largest change occurred in May 2017.

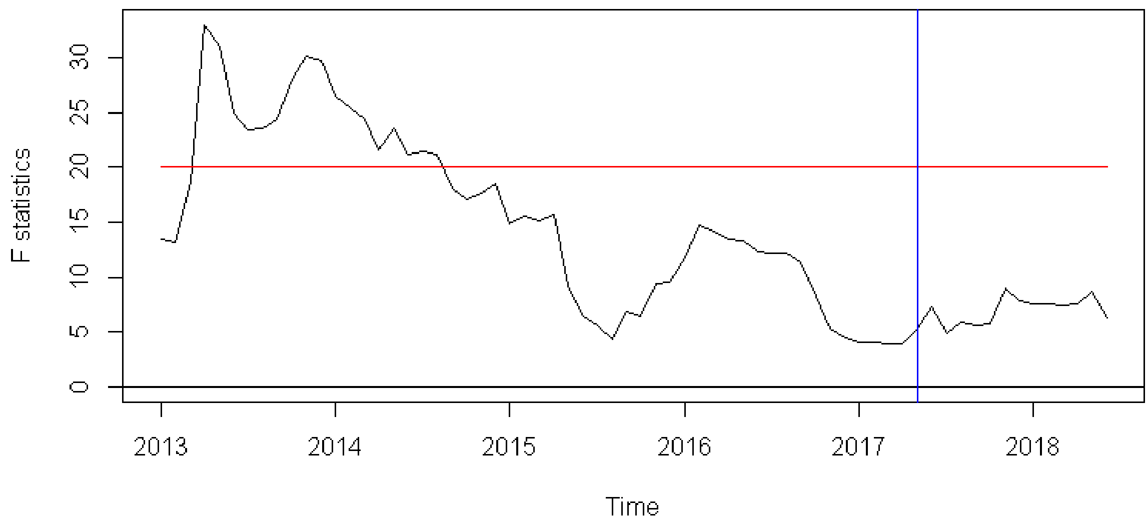
Results from dummy variable modelling:

```
Call:
lm(formula = Q500CO ~ gas + rStor + HAMI + cosMth + sinMth +
    DV, data = TS)
```

```
Residuals:
    Min      1Q  Median      3Q     Max
-419.89  -54.77   13.38   65.03  349.61

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  644.85141   40.53486  15.909  < 2e-16 ***
gas            0.29066    5.78660   0.050    0.960
rStor          0.13197    0.02643   4.992 3.19e-06 ***
HAMI         -41.14004   29.55871  -1.392    0.168
cosMth        -1.27675   15.87945  -0.080    0.936
sinMth         6.72849   16.30393   0.413    0.681
DV          -292.90682   39.36363  -7.441 7.88e-11 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 106.3 on 84 degrees of freedom
Multiple R-squared:  0.6615,    Adjusted R-squared:  0.6373
F-statistic: 27.36 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable is highly significant and has a coefficient of -292 indicating that there has been about 292 MW less generation offered at below 500 $/MWh since May 2017. This is particularly notable given the average quantity offered is about 2,100 MW.

Figure 22 - F-statistics for Quantity offered under 500 $/MWh (peak Meridian)



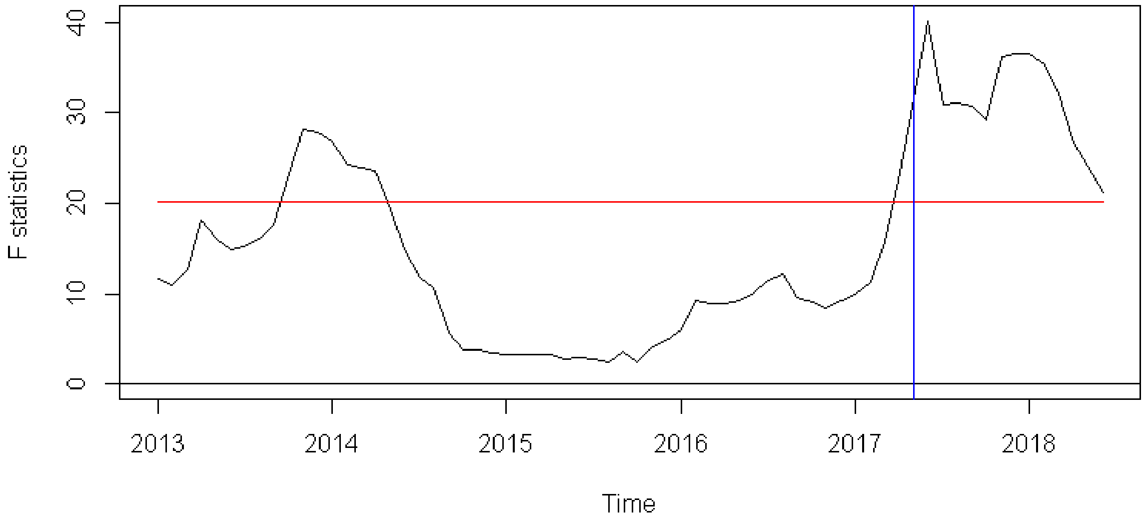
There is a small spike in the F-statistic plot in June 2017. However, this is not significant when tested as a point in the entire series. When tested as a single point, the Chow test returns a p-value of 31%, also a non-significant result.

Results from dummy variable modelling:

```
Call:
lm(formula = Q500M ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
     Min       1Q   Median       3Q      Max
-289.304  -77.256    9.608   90.528  237.640

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1875.99253   44.21825  42.426  < 2e-16 ***
gas           -8.00158    6.31243  -1.268 0.208447
rStor          0.20838    0.02884   7.226 2.09e-10 ***
HAMI        -114.91592   32.24470  -3.564 0.000606 ***
cosMth       -54.06765   17.32241  -3.121 0.002469 **
sinMth        32.72182   17.78546   1.840 0.069329 .
DV           -64.28268   42.94059  -1.497 0.138138
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 116 on 84 degrees of freedom
Multiple R-squared:  0.5345,    Adjusted R-squared:  0.5013
F-statistic: 16.08 on 6 and 84 DF,  p-value: 3.175e-12
```

The dummy variable has a p-value of 14%, so it is not significant at the 5% threshold.

Figure 23 - F-statistics for Quantity offered under 500 $/MWh (off-peak Meridian)



There is a clear change in offer quantity in June 2017.

```
Call:
lm(formula = Q500MO ~ gas + rStor + HAMI + cosMth + sinMth +
    DV, data = TS)

Residuals:
    Min       1Q   Median       3Q      Max
-318.19   -84.80    11.50    86.97   331.67

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1546.67904   50.49593  30.630  < 2e-16 ***
gas           -6.97375    7.20861  -0.967 0.336111
rStor          0.12284    0.03293   3.731 0.000346 ***
HAMI        -148.83548   36.82249  -4.042 0.000117 ***
cosMth        54.79868   19.78168   2.770 0.006895 **
sinMth        33.96029   20.31047   1.672 0.098234 .
DV          -265.19520   49.03688  -5.408 5.88e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 132.5 on 84 degrees of freedom
Multiple R-squared:  0.5577,    Adjusted R-squared:  0.5261
```

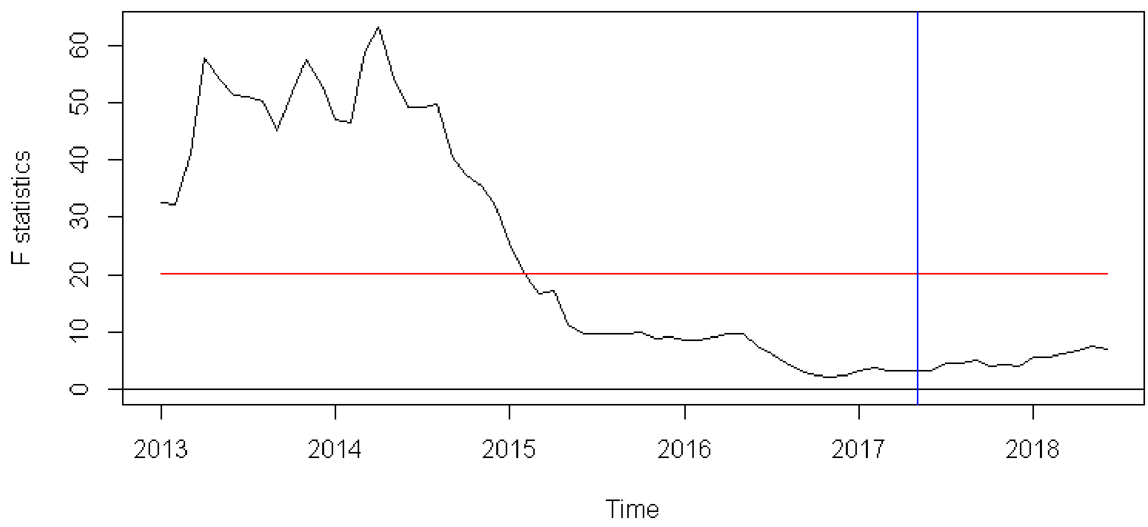
```
F-statistic: 17.65 on 6 and 84 DF,  p-value: 4.043e-13
```

The dummy variable is highly significant and has a coefficient of -265 indicating that there has been about 265 MW less generation offered at below 500 $/MWh since May 2017. This is particularly significant given the average quantity offered is about 2,100 MW.

We conclude that Meridian's offered quantity below 500 $/MWh has changed during off-peak periods but not during peak periods.

Offers less than 100 $/MWh

Figure 24 - F-statistics for Quantity offered under 100 $/MWh (peak)



There is no apparent change in May 2017. The Chow test confirms this, with a p-value of 76% for May 2017.

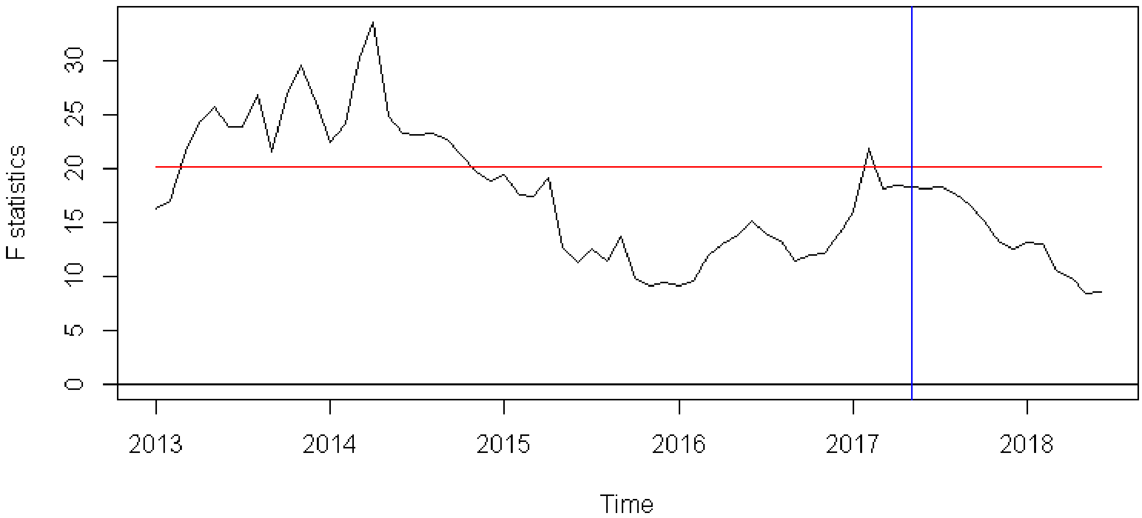
Results of dummy variable modelling:

```
Call:
lm(formula = Q100 ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
    Min       1Q   Median       3Q      Max
-545.16 -121.36   17.35  115.61  384.68

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 2234.65349   71.35473  31.318  < 2e-16 ***
gas           13.43738   10.18633   1.319  0.19070
rStor          0.58851    0.04653  12.648  < 2e-16 ***
```

```
HAMI         -121.99700   52.03308  -2.345  0.02141 *
cosMth       -108.35896   27.95307  -3.876  0.00021 ***
sinMth        -84.23378   28.70030  -2.935  0.00430 **
DV            -67.93630   69.29298  -0.980  0.32969
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 187.2 on 84 degrees of freedom
Multiple R-squared:  0.7367,    Adjusted R-squared:  0.7179
F-statistic: 39.17 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable approach also shows no sign of a break in May 2017.

Figure 25 - F-statistics for Quantity offered under 100 $/MWh (off-peak)



The F-statistic for May 2017 appears to be nearly significant. A Chow test on the point results in a value of 1%, indicating evidence of a break at the 5% threshold. However, the most significant month in 2017 was February, suggesting that the largest change to offers occurred in this month. The p-value for a Chow test on February 2017 returns a p-value of 0.3%.

Results of dummy variable modelling:

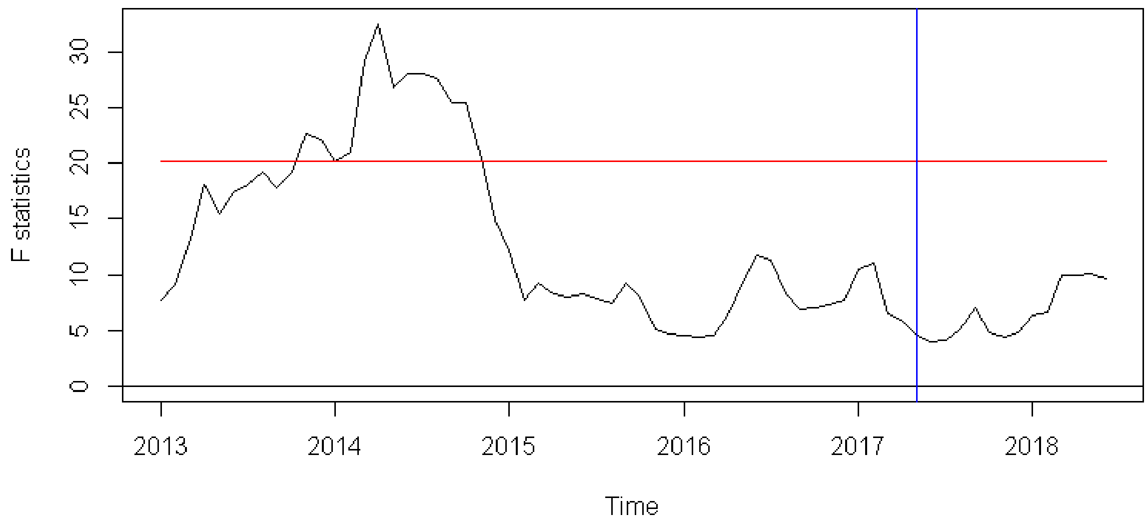
```
Call:
lm(formula = Q100O ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
    Min      1Q  Median      3Q     Max
-401.52 -106.14   -2.19  102.00  418.35
```

```
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1379.07532   69.24606  19.916  < 2e-16 ***
gas           24.53989    9.88530   2.482  0.01504 *
rStor          0.60761    0.04516  13.456  < 2e-16 ***
HAMI          59.55040   50.49540   1.179  0.24160
cosMth        57.95949   27.12700   2.137  0.03554 *
sinMth       -41.62509   27.85215  -1.495  0.13879
DV          -223.90457   67.24523  -3.330  0.00129 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 181.7 on 84 degrees of freedom
Multiple R-squared:  0.7537,    Adjusted R-squared:  0.7361
F-statistic: 42.84 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable test also indicates there was a change in May 2017.

We conclude that offers did change in 2017, but note that the largest change was in February, prior to the publication of the letter. This does not rule out a change in May 2017, which may have been caused by the letter, but it does suggest it wasn't the primary cause of changes to offers in 2017.

Figure 26 - F-statistics for Quantity offered under 100 $/MWh (Clutha peak)



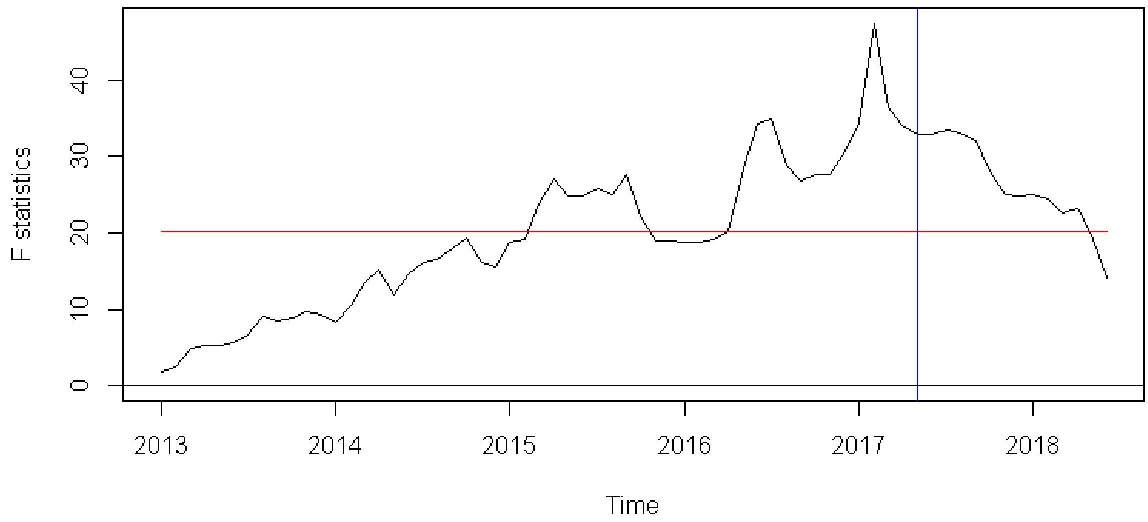
There is no evidence of a structural break in May 2017. The p-value for a Chow test for May 2017 is 60%.

```
Call:
```

```
lm(formula = Q100C ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
     Min       1Q   Median       3Q      Max
-153.530  -45.677   -2.469   45.378  131.448

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 468.00701   24.41930  19.165  < 2e-16 ***
gas          14.51605    3.48601   4.164 7.54e-05 ***
rStor         0.18341    0.01592  11.518  < 2e-16 ***
HAMI        -20.10666   17.80697  -1.129  0.26205
cosMth      -27.75768    9.56621  -2.902  0.00474 **
sinMth      -30.63730    9.82193  -3.119  0.00248 **
DV          -45.69056   23.71372  -1.927  0.05739 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 64.06 on 84 degrees of freedom
Multiple R-squared:  0.698,     Adjusted R-squared:  0.6764
F-statistic: 32.36 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable p-value is 5.7%, nearly significant at the 5% threshold. This is interesting as this result is somewhat different to the Chow test result. This reflects that while the two approaches attempt to answer the same question, the underlying methodology is different, and may sometimes produce slightly different results.

Figure 27 - F-statistics for Quantity offered under 100 $/MWh (Clutha off-peak)



The F statistics indicate there was a structural break for most of 2016 and all of 2017. The peak change occurred in February 2017, consistent with the result for the South Island as a whole.

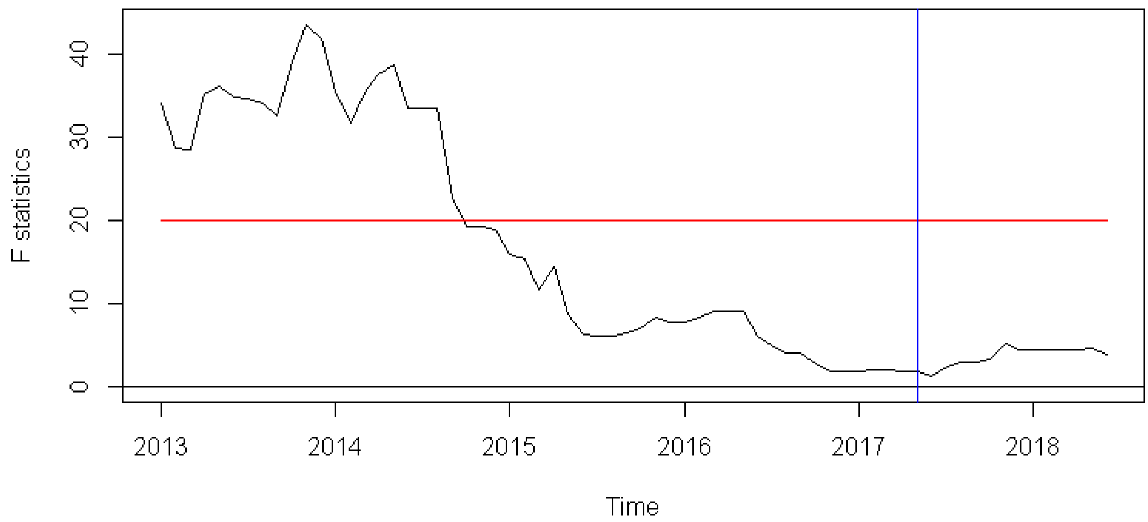
```
Call:
lm(formula = Q100CO ~ gas + rStor + HAMI + cosMth + sinMth +
    DV, data = TS)

Residuals:
    Min       1Q   Median       3Q      Max
-265.57   -79.15   -12.02    77.21   240.34

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  240.12724   45.43441   5.285 9.76e-07 ***
gas           17.10529    6.48604   2.637 0.009956 **
rStor          0.25686    0.02963   8.670 2.74e-13 ***
HAMI          61.26765   33.13154   1.849 0.067943 .
cosMth         3.30319   17.79884   0.186 0.853218
sinMth       -38.93003   18.27463  -2.130 0.036073 *
DV          -168.19686   44.12161  -3.812 0.000262 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 119.2 on 84 degrees of freedom
```

```
Multiple R-squared:  0.6206,    Adjusted R-squared:  0.5935
F-statistic:  22.9 on 6 and 84 DF,  p-value: 7.859e-16
```

The dummy variable test also indicates there was a change in May 2017.

We conclude that offers did change in 2017, but note that the largest change was in February, prior to the publication of the letter. This does not rule out a change in May 2017, which may have been caused by the letter, but it does suggest it wasn't the primary cause of changes to offers in 2017.

Figure 28 - F-statistics for Quantity offered under 100 $/MWh (Meridian peak)



There is no evidence for a change in offers in May 2017.

```
Call:
lm(formula = Q100M ~ gas + rStor + HAMI + cosMth + sinMth + DV,
    data = TS)

Residuals:
    Min      1Q  Median      3Q     Max
-470.35  -86.14   20.75   74.54  272.34

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1633.40193   53.71550  30.408   <2e-16 ***
gas           -1.53805    7.66822  -0.201   0.8415
rStor          0.40083    0.03503  11.443   <2e-16 ***
HAMI         -90.82209   39.17026  -2.319   0.0228 *
cosMth       -64.08918   21.04294  -3.046   0.0031 **
sinMth       -35.82925   21.60545  -1.658   0.1010
```

```
DV           -11.31065   52.16343  -0.217   0.8289
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 140.9 on 84 degrees of freedom
Multiple R-squared:  0.6892,    Adjusted R-squared:  0.667
F-statistic: 31.04 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable test also indicates there was no change in May 2017.

Figure 29 - F-statistics for Quantity offered under 100 $/MWh (Meridian off-peak)

From inspection there was no structural break in May 2017. The p-value for the Chow test is 40%, confirming this.

Dummy variable analysis

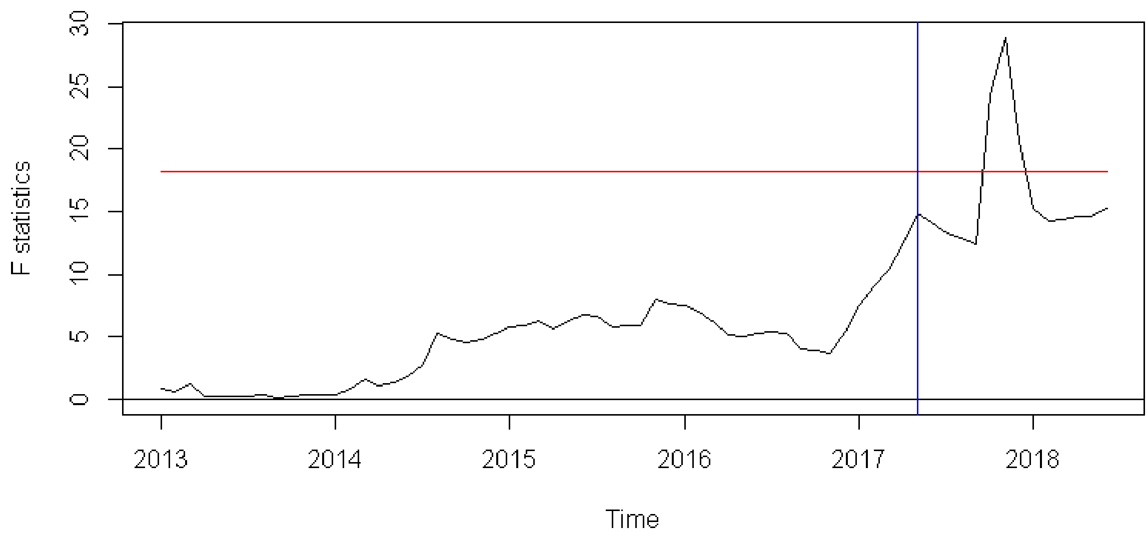
```
Call:
lm(formula = Q100MO ~ gas + rStor + HAMI + cosMth + sinMth +
    DV, data = TS)

Residuals:
    Min      1Q  Median      3Q     Max
-346.87  -75.95   -4.70   89.23  248.72

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1068.23584   43.59863  24.502  < 2e-16 ***
gas            6.14820    6.22397   0.988    0.326
```

```
rStor            0.31169    0.02843  10.963  < 2e-16 ***
HAMI           -13.97460   31.79286  -0.440    0.661
cosMth          70.32458   17.07967   4.117 8.92e-05 ***
sinMth          -9.27310   17.53624  -0.529    0.598
DV             -69.35540   42.33887  -1.638    0.105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 114.4 on 84 degrees of freedom
Multiple R-squared:  0.6818,    Adjusted R-squared:  0.659
F-statistic: 29.99 on 6 and 84 DF,  p-value: < 2.2e-16
```

The dummy variable is non-significant, also indicating there was no break in May 2017.

Responsiveness

Figure 30 – F-statistics for responsiveness of offers.



The Chow test returns a p-value of 1.8% for May 2017. This is a significant result at the 5% threshold. However, there was stronger evidence of a break in November 2018, suggesting this as a more likely timing for the change in behaviour.

```
Call:
lm(formula = R20 ~ gas + HAMI + cosMth + sinMth + DV, data = TS)

Residuals:
    Min      1Q  Median      3Q     Max
-53.405 -19.315  -0.659  13.458  95.285
```

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  116.477      9.721  11.982  < 2e-16 ***
gas           -4.352      1.450  -3.001 0.003531 **
HAMI         -27.364      7.148  -3.828 0.000246 ***
cosMth        19.310      3.975   4.857 5.36e-06 ***
sinMth        -9.093      3.997  -2.275 0.025421 *
DV           -31.892      9.706  -3.286 0.001479 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 26.72 on 85 degrees of freedom
Multiple R-squared:  0.4969,    Adjusted R-squared:  0.4673
F-statistic: 16.79 on 5 and 85 DF,  p-value: 1.651e-11
```

The dummy variable appears significant, consistent with the result of the Chow test. Note the R^2 value of 47%, lower than for most previous models in this appendix. This indicates there is significant variation in responsiveness that is not explained by the model.