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Review of impact of trading conduct enforcement action on spot prices - addendum

Prepared for the Market Development Advisory Group

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1 Purpose

This paper is an addendum to a report[1] prepared by Concept in August 2019 for the Market Development Advisory Group (MDAG). This addendum responds to technical concerns raised by Haast Energy Trading (Haast) [2] of analysis in Concept's August 2019 report. Haast stated that "once corrected for modelling issues, the Concept Report does not support the hypothesis that there has been no structural shift [in prices] from May 2017."

1.1 August 2019 report

Concept's August 2019 report examined:

1. Whether a trading conduct enforcement action by the Electricity Authority in May 2017[3] 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.

To examine these issues, Concept undertook a statistical analysis of electricity market data for the period January 2012 to 30 June 2019. Concept concluded:

> "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."[4]

1.2 Critique of Concept's August 2019 report raised by Haast

Haast raised two concerns about Concept's August 2019 report in its letter to MDAG:

1. **Scope of report** - Concept's report was too narrowly focussed on reviewing the impact of the Authority's trading conduct enforcement action on spot prices. Haast considered that Concept should have examined the broader question of whether prices had shifted at any time in a way that could not be explained by market fundamentals. Haast considered this question important because an unexplained price movement could indicate inadequate competition.[5]
2. **Statistical analysis** – Haast considered that Concept's modelling inappropriately included gas prices as an explanatory variable for electricity prices. Haast removed gas prices as an explanatory variable and replaced it with gas production. Haast said this indicated "a statistically significant price increase of $22.6 since May 2017" which was not explained by market fundamentals.

On the first concern, the scope of Concept's report was set by the terms of reference provided by MDAG. Any questions about the scope of Concept's report should therefore be addressed by MDAG.

[1] See www.ea.govt.nz/dmsdocument/25623-review-of-impact-of-trading-conduct-enforcement-action-on-spot-prices-concept-consulting

[2] Letter to Chair of MDAG from Haast Energy Trading dated 2 December 2019.

[3] 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 .

[4] Ibid at footnote 1

[5] Haast's letter of 2 December 2019, summary section on page 1.

For completeness, we also note that Concept's report cannot be construed as implying "there isn't a problem with changes in market conduct and behaviour".[6] As stated in our report:

> "This report makes no assessment of whether generator behaviour or market outcomes are consistent with those expected in a workably competitive market."[7]

1.3 Structure of this paper

The balance of this addendum is set out as follows:

- Chapter 2 briefly recaps the methodology and data used in Concept's August 2019 report.
- Chapter 3 addresses the technical critique made by Haast.
- Chapter 4 sets out Concept's conclusions.

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

1.4 Acknowledgement

We have corresponded with Haast to better understand their views and analysis. We appreciate their involvement in this review process, and acknowledge that there are differing views on some issues.

[6] Final paragraph on page 2 of Haast letter.

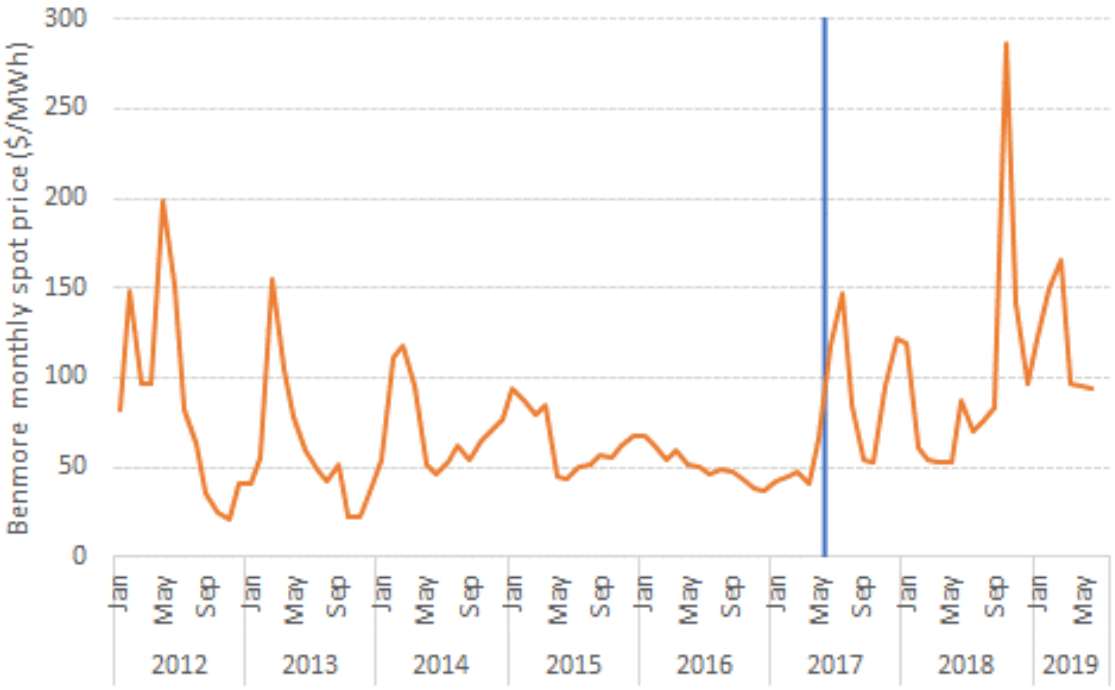
[7] Concept report of August 2019, page 1 of executive summary.

2 Recap on statistical analysis in Concept's August 2019 report

To understand Haast's statistical critique, it is useful to briefly recap Concept's August 2019 analysis.[8] Figure 1 shows monthly average spot prices at Benmore. Prices after May 2017 (shown by the blue line) were clearly higher on average than prices before that date.

The central question addressed by Concept's analysis was whether the upward shift in prices after May 2017 was a 'structural break'[9] which could have been triggered by the Authority's enforcement action, or whether it could be satisfactorily explained by physical factors.

Figure 1 - Monthly average Benmore spot prices



Source: Reproduced from data in Concept report, August 2019

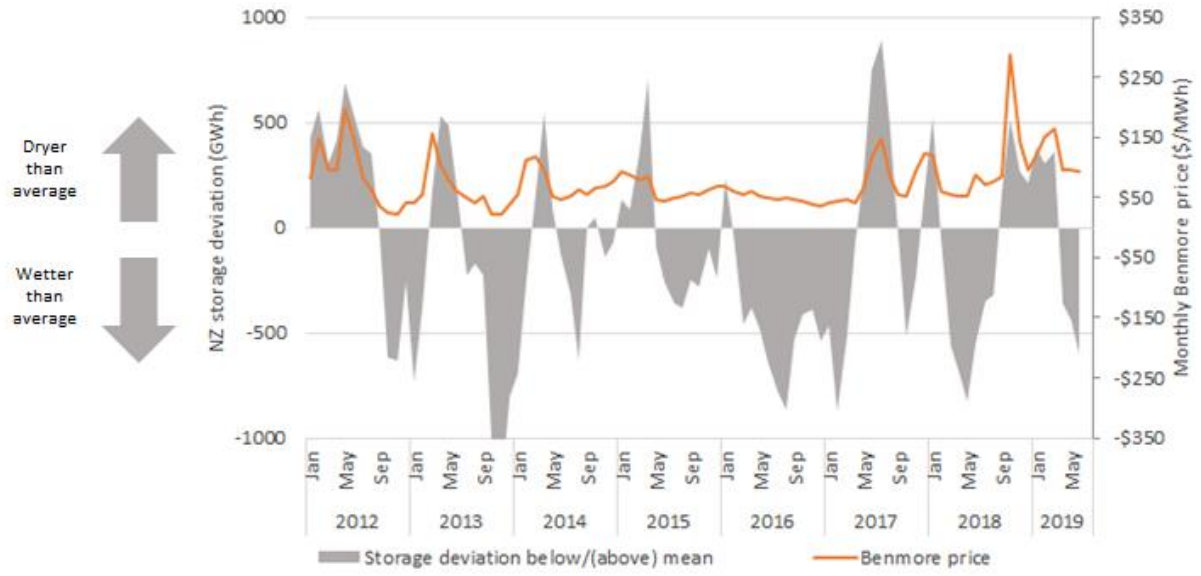
In essence, Concept's analysis occurred in the following steps:

1. Identify any physical factors which had significant[10] ability to explain the movements in Benmore prices observed over the period 2012-2019.
2. After controlling for the factors identified in step (1), determine whether the residual component of Benmore prices was significantly different before and after May 2017. Any significant difference would indicate a likely structural break in prices around that date.

In step 1, Concept identified relative hydro storage[11] and gas prices as being significant explanatory factors.[12] As shown in Figure 2, spot prices at Benmore have tended to be higher when hydro storage in New Zealand was below average, and vice versa.

[8] This section provides a very short summary. Readers should refer to the original report for a full description.
[9] This was defined in the August 2019 report as "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".
[10] In this section, significant means from a statistical perspective.
[11] Relative hydro storage refers to the deviation from the long-term average storage level at that time of the year.
[12] The report also identified changes in electricity demand and coal prices as relevant explanatory factors, but noted that they had limited incremental explanatory value compared to hydro storage and gas prices.

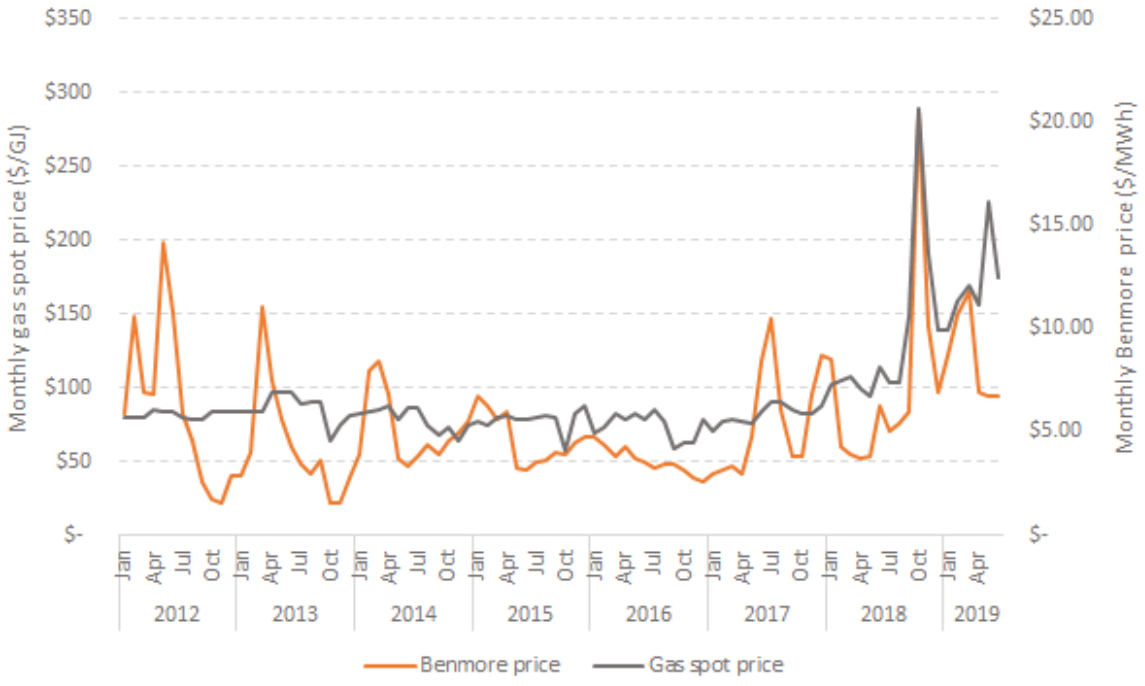
Figure 2 – Hydro storage relative to seasonal average and monthly average Benmore price



Source: Reproduced from data in Concept report, August 2019

As shown in Figure 3 gas spot prices have tended to be correlated with electricity prices, especially since early 2018.

Figure 3 – Gas spot price and monthly average Benmore price



Source: Reproduced from data in Concept report, August 2019

In step 2, Concept analysed the residual component of Benmore prices (after controlling for hydro storage and gas prices). The analysis found no statistically significant evidence of a structural break in prices from May 2017 (or for other breakpoints up to 12 months later).

2.1 Datasets differ between Concept and Haast analysis

Before discussing the Concept and Haast analysis in more detail, it is useful to note some differences in datasets. Concept's August 2019 report analysed *monthly data* from January 2012 until June 2019. In this addendum, for any analysis of monthly data, we have added data through to September 2019.

Haast also used *monthly data* for some analysis, but this was supplemented by analysis of *daily data* at times. Our understanding is that for its analysis of daily data, Haast used January 2015 as the starting date.[13] We understand the reason for doing this was changes to the HVDC, but we are not aware exactly what changes these were. We do not consider changes to the HVDC to be crucial to analysis of *prices*.[14]

Concept's initial monthly analysis used data ending July 2019. Haast's analysis of daily data was undertaken later, so was able to use more recent data and ends in November 2019.

Given that Haast analysed daily data in some cases, we have also undertaken some analysis of daily data in this addendum. We have not adopted January 2015 as the start date (for the reason noted above). We have instead used October 2013, as this is the date that daily gas prices first became available.[15]

Figure 4: Time periods and data used by Concept and Haast

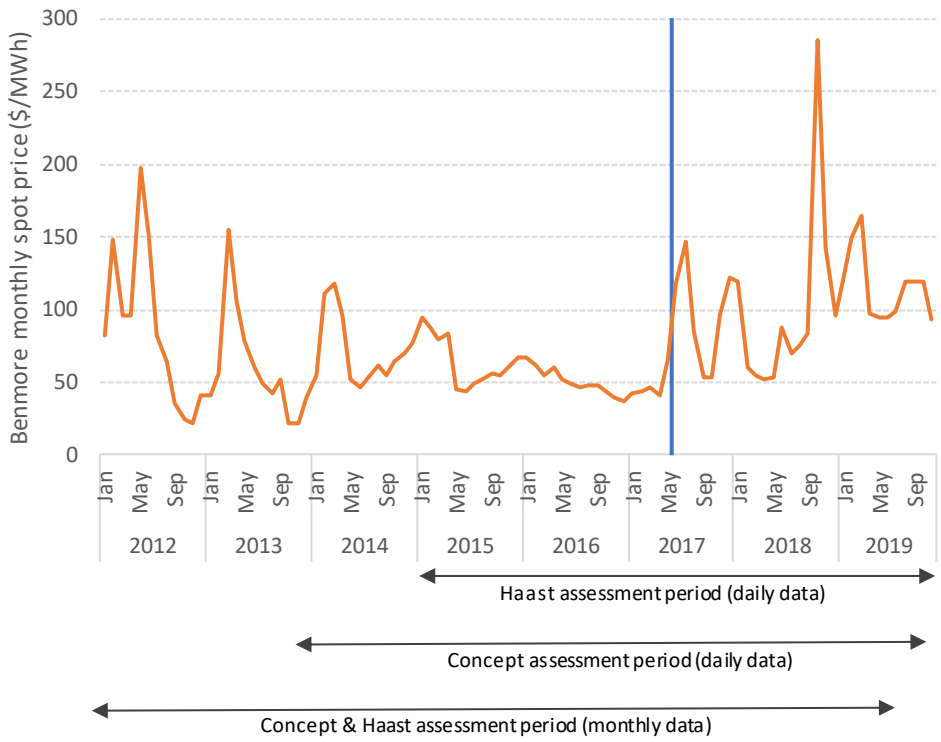


Figure 4 summarises the time periods used by Concept and Haast. As will be apparent from the chart, the apparent behaviour of Benmore prices will differ depending on the start date used for

[13] Based on telephone conference with Haast, 12 December 2019.
[14] We are more receptive to the viewpoint that the HVDC can have material effects on South Island *offers*.
[15] Concept's daily data series finishes in October 2019 (i.e. one month earlier than Haast). Initially we did not know the data range that Haast used but expected it to be October 2019 given when it was released. Later, we learnt their end date was November 2019. We do not expect the one-month difference to materially affect the results of our analysis.

analysis. For this reason, we expect the differences between time periods will account for some of the differing results from the respective analyses.

3 Haast's critique of August 2019 report

3.1 Haast's central critique: use of gas prices as an explanatory variable

Haast's central criticism is that it believes Concept should not have included gas prices as an explanatory variable for Benmore prices. Haast acknowledges that controlling for external factors is common in the type of analysis performed by Concept, but states "it is not appropriate if the factors are affected by the variable under assessment".[16]

Haast says it conducted a Granger test which indicated "electricity price affects gas price suggesting gas prices should have been omitted from Concept's analysis, or replaced with an independent variable that captured the gas market dynamics but was not significantly determined by the electricity price".[17]

Omitting gas prices would have the effect of increasing the component of Benmore prices that is not explained by physical factors. Haast says that when it omitted gas prices from the analysis, it found an unexplained Benmore price increase of $30/MWh since May 2017, and this increase was statistically significant. Haast also replaced gas prices with gas production and found an unexplained price increase of $22.6/MWh since May 2017.

We do not agree with Haast's conclusion that gas prices should be omitted as an explanatory variable. This is because:

- Granger tests do not prove causation, and therefore are not sufficient by themselves[18] to justify excluding gas prices as an explanatory variable from the analysis.
- In any case, Haast's analysis did not identify Granger-causation between *monthly* electricity and gas prices (the level of data granularity used in Concept's August 2019 analysis). Rather, Haast found Granger- causation in daily data for a different and shorter time period – neither of which were used in Concept's report.
- Concept's subsequent analysis of gas usage and gas prices in this addendum indicates that gas prices primarily lead to changes in gas usage, rather than the other way around. This suggest that the direction of causation (at least in the review period) is the opposite of that posited by Haast (i.e. gas prices affect electricity prices).
- If gas prices are nonetheless excluded, other previously excluded explanatory variables become more statistically significant – such as coal prices. If the analysis is rerun with coal prices instead of gas prices, there is no evidence of a structural break in Benmore prices at May 2017.
- Applying Haast's overall reasoning about the selection of explanatory variable on a consistent basis would also invalidate use of hydro storage. This would be counter to Concept's (and Haast's) understanding of how the New Zealand electricity market functions, and illustrates the risks of using Granger tests alone as a screening criterion.

3.2 Granger tests do not prove causation

We agree that if electricity prices wholly *caused* gas prices, then the latter should be omitted as an explanatory variable. However, causation has not been established.

[16] Haast letter, page 2.
[17] Ibid.
[18] There is no single statistical test that can 'prove' causation. It requires a "real-world" understanding of the relationship between variables. We address this question further in section 3.4.

Haast's exclusion is based on the application of a Granger test. "Granger cause" is a technical term that means the past history of one variable has useful predictive information about a second variable, over and above what is available from the past history of the second variable.

A positive Granger test does not prove causation – rather it simply shows that one variable is useful in forecasting another - and the name is controversial for this reason. To illustrate the absence of provable causation, it is trivial to construct a data series with three variables such that two variables satisfy a test for Granger causality, but are actually both caused by the third.[19]

Accordingly, a Granger test can provide part of an initial screening process to determine which explanatory variables should be used in a model. However, it does not provide an unequivocal answer about which variables to include and exclude. Researchers need to consider relative merits of including and excluding each variable.

3.3 Data used in Concept's August 2019 report does not show Granger-causality

Haast performed Granger tests on electricity and gas prices. Using *daily* data, Haast found that electricity prices Granger-cause gas prices.

We sought to replicate Haast's analysis. An important input to Granger tests is the "lag" between past observations and the predicted variable. Haast presented results for a lag of 6 days, but we understand that they tested a range of different possible lags and found similar results. We tested all lags from one to ten days because it is possible that effects might not happen instantaneously.

The results of our analysis on *daily* data are consistent with Haast's results. We found Granger causality for lags from 1-10 days.

We extended Haast's analysis to look at relationships in the reverse direction, and found almost identical results. That is: daily gas prices Granger-cause daily electricity prices and daily electricity prices Granger-cause daily gas prices.[20]

Haast stated the presence of Granger-causality in price data meant it was inappropriate for Concept to include gas prices in its analysis as an explanatory variable. However, this was based on Haast's analysis of daily price data whereas Concept's analysis used *monthly* price data. Applying the test to monthly data does not indicate Granger-causation in either direction.[21] We understand that Haast tested the raw monthly data and did not find that electricity prices Granger-cause gas prices.[22]

We do not agree with Haast's approach of rejecting analysis of monthly data on the basis of Granger tests applied to daily data.

Instead, the more relevant issue is whether the analysis *in totality* should be based on monthly or daily data – acknowledging that with the latter, there are more apparent grounds for concern about potential causation running between gas and electricity prices (in both directions).

Haast's reason for rejecting monthly data for the application of Granger tests was because the sample size for monthly data was "too small". We disagree with this assessment, as the monthly data series included 90 months, which is far in excess of the sample size required to perform a regression with two independent variables. Furthermore, although daily data has more observations, it provides little or no additional information about whether long term structural changes had occurred (which was the focus of the overall analysis). In our view, the monthly data series holds more information, because it permitted analysis of prices under a wider range of hydro

[19] "Simulation evidence on Granger causality in presence of a confounding variable" - http://www.usc.es/economet/reviews/ijaeqs526.pdf

[20] See Appendix A a).

[21] See Appendix A b)

[22] Based on discussions with Haast.

storage conditions. We note that Haast's approach excluded the data before 2015 when there were sustained periods with low hydro storage.

3.4 Further analysis of gas price and electricity price relationship

We believe it is common ground that electricity prices are affected by the difficulty of sourcing gas from the gas market. We refer to this as 'gas stress'. Gas stress is hard to measure directly, as it is the result of a combination of supply, demand and other factors. Concept used EMS Tradepoint's volume weighted average price (VWAP) as the measure of gas stress in the August 2019 report, but is open to using an alternative measure if a better one were available.

3.4.1 Gas production is not a robust indicator of gas market conditions

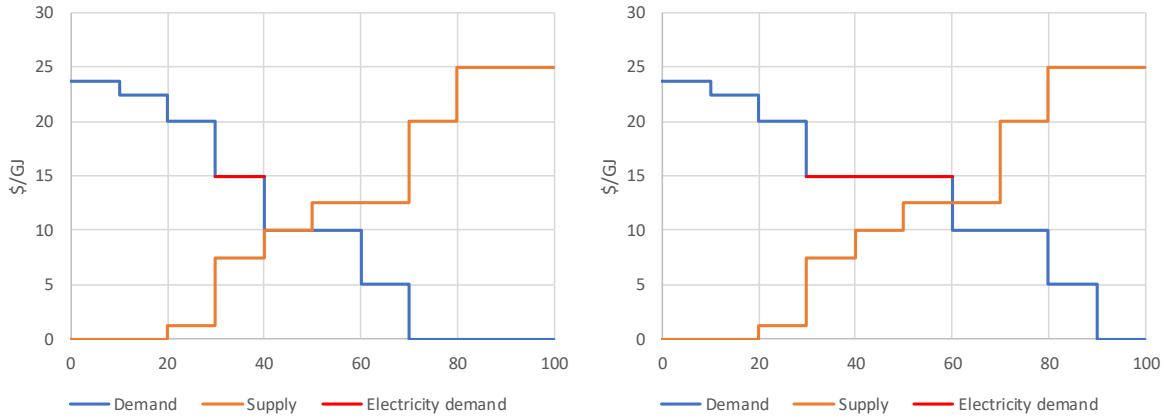
Haast suggested using gas production data as an alternative way to measure 'gas stress', given its view that gas prices should be excluded.

Haast found that gas production does not explain much of the variation in electricity prices. We do not find this result surprising, because we do not believe gas production is a good measure of gas stress. Primarily, this is because gas production is only one half of the supply and demand relationship that determines outcomes in the gas market. Reduced gas production could stress the market (such as during the unexpected Pohokura outages in 2018). But it may indicate the opposite at other times (such when gas production decreases over summer and over weekends). Using gas production as the measure of gas stress would suggest that the system is under gas stress every summer and every weekend. We do not believe this is an accurate reflection of market dynamics.

3.4.2 Gas prices seem to drive thermal generation – rather than vice versa

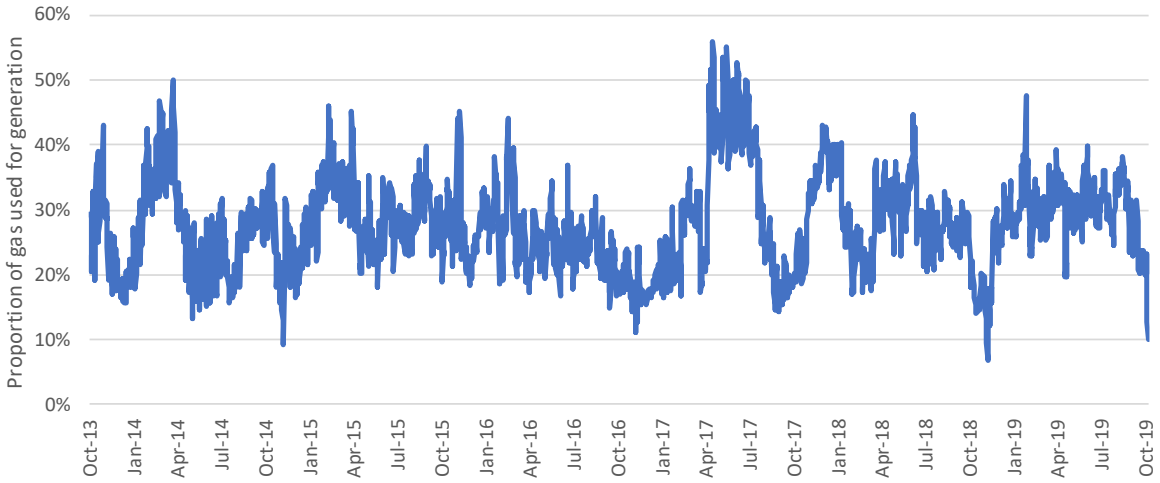
Haast's exclusion of gas prices seems to rest on a view that electricity prices largely drive gas prices. To test this hypothesis, it is useful to consider the stylised gas supply and demand curves in Figure 5. The red highlighted step shows the portion of gas that is demanded to generate electricity.

Figure 5 - Stylised gas supply and demand curves



The left-hand figure has 10 units of "electricity demand" resulting in a clearing gas price of 10 $/GJ. The right-hand figure has 30 units of "electricity demand" resulting in a clearing gas price of 12.50 $/GJ. The *gas price* has increased due to a rise in the electricity sector's *demand for gas* (which if Haast's hypothesis is correct, was itself triggered by a preceding rise in the *electricity price*).

Figure 6 - Proportion of gas used for generation

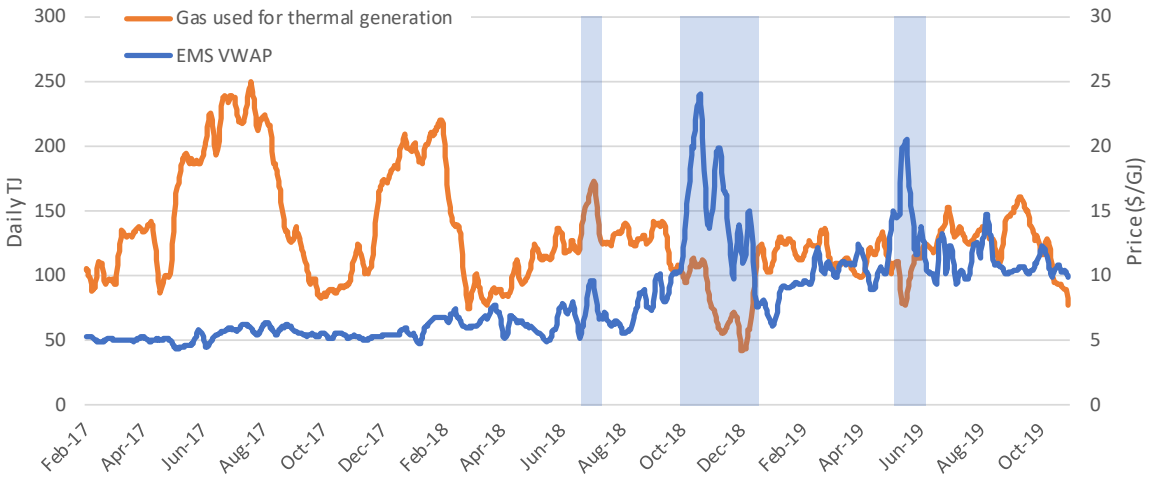


To help explore this further, Figure 6 shows the proportion of gas used for generation over time.[23,24] This fluctuated from day to day and varied from less than 10% to more than 50%. Thus thermal generation made up a significant portion of the gas demand at times, and its likely there is a relationship between generation demand for gas and gas prices.

The direction of the relationship is not clear from the above, but if using more gas for generation causes gas prices to increase, then this would support Haast's claims that gas prices should be excluded as an explanatory variable. If, instead, gas prices had a negative causative effect on the quantity of gas used for generation, this would be evidence for the reverse, i.e. gas can be validly included as an explanatory variable.

Before jumping to analytical tests, it's useful to simply look at the data.

Figure 7 – Weekly average gas price and gas used for thermal generation



[23] We did not include gas used for cogeneration, because this consumption primarily varies depending on factors other than gas prices and supply availability.

[24] Estimated from data on gas supplied to Huntly power station and assumed heat rate for other thermal plant.

Figure 7 shows how the two variables have tracked in recent years.[25] From inspection, gas prices did not change much in 2017. Around July 2018 (highlighted),[26] both gas prices and gas used for thermal generation increased. This relative movement implies that gas prices were responding to changes in the electricity market.

In late 2018 (highlighted), the opposite occurs: gas prices increase dramatically followed by a decrease in gas used for generation. A similar, although less pronounced, effect can be seen during the gas price spike in June 2019 (highlighted). These "counter-directional" movements appear to be much larger in magnitude than instances of "same-directional" movements.

To investigate this further, Concept performed Granger tests[27] on these two variables, using both monthly and daily data.[28] We found that both monthly and daily gas prices were not Granger-caused by the quantity of gas used for thermal generation. On the other hand, we found weak evidence that the quantity of gas used for thermal generation was Granger-caused by monthly gas prices. We also found a strong positive relationship in the daily data for lags of one and two days,[29] and a weak relationship for lags of three and four days.[30],[31] Both daily and monthly data show a weak negative correlation[32] between the two variables since 2017.

The results of these tests, as well as an inspection of the data support Concept's view that gas prices primarily cause changes to the operation of thermal generation, rather than the other way around. This provides further support to the view that it is reasonable to use gas prices as an explanatory variable to model electricity prices.

3.5 What if gas prices are completely excluded?

If we accept, for the sake of argument, that gas prices cannot be included as an explanatory variable and that there are no other useful measures of stress in the gas market, are there other variables that might explain high electricity prices?[33]

Another variable that intuitively makes sense is the coal price – since coal and gas can be used to produce electricity in Huntly Rankine units, making them substitute fuels at the margin. Furthermore, causation should not be a concern as international coal prices are not significantly affected by the New Zealand electricity market.[34]

In our August 2019 report, we tested monthly coal prices (based on the estimated cost of importing coal) as an explanatory variable, and found only weak explanatory power *if gas prices were already included*.

[25] Data from prior to 2017 is not shown as gas price was relatively stable during this period.
[26] Although the price spike does not look large in light of prices that came later, when it occurred daily gas prices were significantly higher than they had been in the previous two years.
[27] Bearing in mind that Granger tests do not prove causation, and are merely informative.
[28] We tested both the full series (from October 2013) and also the series starting January 2017. Results for both were similar.
[29] A p-value of less than 1%
[30] A p-value of between 5 and 10%.
[31] See Appendix A
[32] Correlation coefficients of -29% and -34% respectively.
[33] We assume that hydro storage is valid to include. However, as we note later, we find it would be excluded if we adopt Haast's criteria on a consistent basis.
[34] We merely note that coal exports to New Zealand comprised about 0.1% of Australia's exports in 2017.

We repeated our analysis from our initial report using coal price *after omitting gas price*s. The Chow test shows no break point in all of 2017. The coefficient of the dummy variable for May 2017 was non-significant, although months after September 2017 showed an unexplained uplift in prices.[35]

In short, substituting coal prices for gas prices would not alter the basic conclusion in the August 2019 report that there was no structural break in May 2017 due to the Authority's letter.

3.6 Consistency of screening for explanatory variables

As part of its analysis, Haast applied a Granger test to relative hydro storage and daily electricity prices. Haast reported that it found no evidence of Granger-causation in this instance, and concluded that relative hydro storage could be validly included as an explanatory variable in the pricing analysis.

Concept sought to replicate Haast's analysis, but found daily storage was Granger-caused by electricity prices. This relationship holds for all lags between one and ten days. When we repeat the calculation using only data from 1 January 2015 onwards[36] the results are little changed, although the strength of the relationship is slightly lower.[37]

We corresponded with Haast to understand the differences between Haast's results and ours. The difference stems from how hydro storage is corrected for seasonality. Concept has used the "20-year average" series from the Electricity Authority's EMI website as the typical seasonal shape. Our relative storage is calculated as actual storage minus the 20 year average. Haast calculated their seasonal shape using a "Seasonal Decomposition Of Time Series By Loess" approach.[38] They used data from 2015 to 2019 for the model.

We prefer our approach as it is more straightforward and easier to replicate. Our approach also includes a longer time period when calculating "normal" and we do not consider five years sufficient to capture a range of possible underlying hydro conditions.[39]

If we were to apply Haast's reasoning for omitting monthly gas price data as an explanatory variable and our measure of hydro storage deviation, we would also reject the inclusion of monthly relative hydro storage data as an explanatory variable. This would result in a very limited model – the only 'explanatory' variable would be whether an observation occurred before or after May 2017.

Furthermore, most parties knowledgeable about the New Zealand electricity market would expect hydro storage to be an important explanatory factor for electricity prices. The application of Haast's screening logic would not permit use of hydro storage as an explanatory variable. In our view, this illustrates why the simple application of Haast's screening criteria is not sound.

[35] See Appendix A

[36] We used October 2013 as the start date, which is when daily gas prices first became available. We understand Haast used January 2015 as the start date for its analysis.

[37] See Appendix A

[38] Based on the stl function in R. https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/stl

[39] See Figure 4 for how Benmore prices varied over the five years in question.

4 Conclusion

Haast considered that gas prices were erroneously included as an explanatory variable by Concept in its August 2019 analysis of electricity prices. Haast reported that replacing gas prices with gas production as an explanatory variable indicated a statistically significant price increase of $22.6/MWh since May 2017.

We do not agree with Haast's conclusion that gas prices should be omitted as an explanatory variable. This is because:

- Granger tests do not prove causation, and therefore are not sufficient by themselves to justify excluding gas prices as an explanatory variable from the analysis.
- In any case, Haast's analysis did not identify Granger-causation between *monthly* electricity and gas prices (the level of data granularity used in Concept's August 2019 analysis). Rather, Haast found Granger- causation in daily data for a different and shorter time period – neither of which were used in Concept's report.
- Concept's subsequent analysis of gas usage and gas prices in this addendum indicates that gas prices primarily lead to changes in gas usage, rather than the other way around. This suggests that the primary direction of causation (at least in the review period) is the opposite of that posited by Haast (i.e. gas prices affect electricity prices).
- If gas prices are nonetheless excluded, other previously excluded explanatory variables become more statistically significant – such as coal prices. If the analysis is rerun with coal prices instead of gas prices, there is no evidence of a structural break in Benmore prices at May 2017.
- Applying Haast's overall reasoning about the selection of explanatory variable on a consistent basis would also invalidate use of hydro storage in our view. This would be counter to Concept's (and Haast's) understanding of how the New Zealand electricity market functions, and illustrates the risks of using Granger tests alone as a screening criterion.

Accordingly, we believe the conclusions set out in Concept's August 2019 report continue to apply – i.e. the enforcement action by the Authority in May 2017 did not cause a structural shift in electricity spot prices, and the higher spot prices observed between May 2017 and June 2019 are explained by physical factors – especially changes in hydro storage and gas prices over the period.

Appendix A. Output from analysis

This appendix presents outputs from R for the analysis discussed in the body of the report.

a) Granger causality tests on daily gas price data

Does daily gas price Granger cause average daily Benmore electricity price?

We tested all lags from 1 to 10 days. All produced significant results, with p-value of less than 5%. Output for order 6 is shown below.

```
[[6]]
Granger causality test

Model 1: ben ~ Lags(ben, 1:6) + Lags(gas, 1:6)
Model 2: ben ~ Lags(ben, 1:6)
  Res.Df Df      F    Pr(>F)
1   2180
2   2186 -6 4.8916 5.623e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Does average daily Benmore electricity price Granger cause daily gas price?

We tested all lags from 1 to 10 days. All produced significant results, with p-value of less than 5%. Output for order 6 is shown below.

```
[[6]]
Granger causality test

Model 1: gas ~ Lags(gas, 1:6) + Lags(ben, 1:6)
Model 2: gas ~ Lags(gas, 1:6)
  Res.Df Df      F    Pr(>F)
1   2180
2   2186 -6 5.3191 1.852e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

b) Granger causality tests on monthly data

Does monthly gas price Granger cause average monthly Benmore electricity price?

We only tested a lag of 1 month.

```
Granger causality test

Model 1: price ~ Lags(price, 1:1) + Lags(gas, 1:1)
Model 2: price ~ Lags(price, 1:1)
  Res.Df Df      F Pr(>F)
1     87
2     88 -1 0.7119 0.4011
```

Does average monthly Benmore electricity price Granger cause monthly gas price?

We only tested a lag of 1 month.

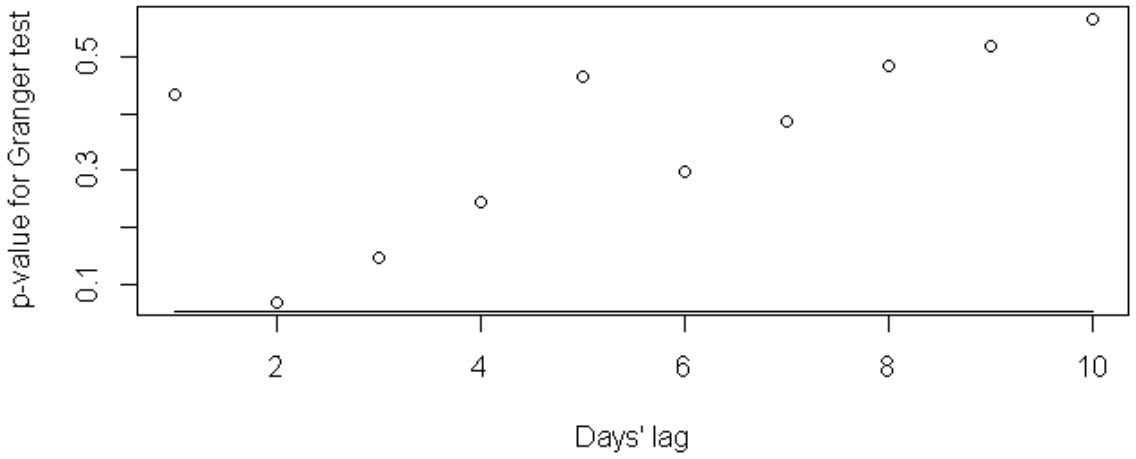
```
Granger causality test

Model 1: gas ~ Lags(gas, 1:1) + Lags(price, 1:1)
Model 2: gas ~ Lags(gas, 1:1)
  Res.Df Df      F Pr(>F)
1     87
2     88 -1 0.4884 0.4865
```

c) Granger causality tests on gas used for generation

Does daily gas used for generation Granger cause daily gas prices?

We tested daily data with a lag of 1 to 10 days. Figure 8 shows there is no Granger causality for daily data, for any of the tested lags. The black line indicates a 0.05 p-value threshold, and results for all tests are above this line.

Figure 8 - p-values for daily gas used Granger tests



Does monthly gas used for generation Granger cause monthly gas prices?

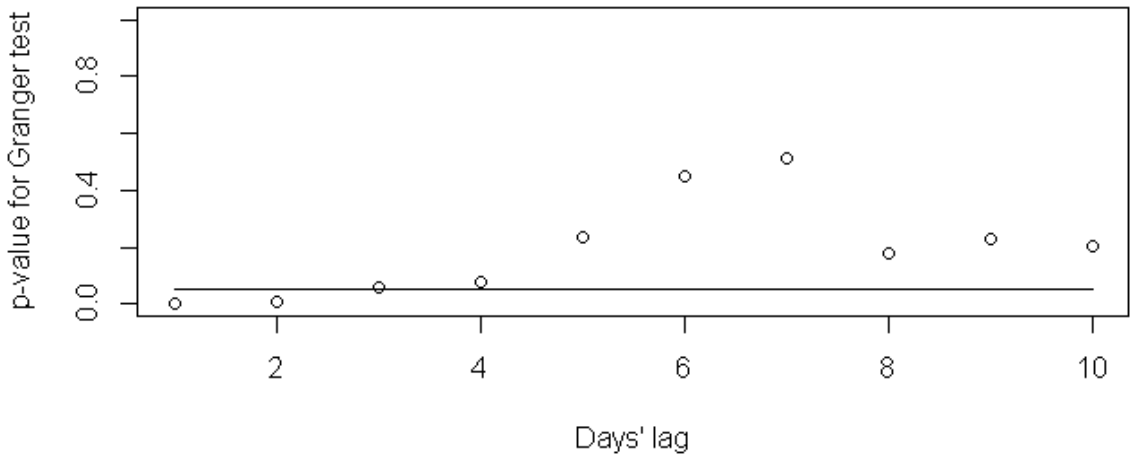
We only tested a lag of 1 month. We found no evidence of a relationship.

```
Granger causality test

Model 1: gas ~ Lags(gas, 1:1) + Lags(gasUsed, 1:1)
Model 2: gas ~ Lags(gas, 1:1)
  Res.Df Df      F Pr(>F)
1     87
2     88 -1 0.0139 0.9063
```

Does daily gas price Granger cause daily gas used for generation?

We tested daily data with a lag of 1 to 10 days. We found a positive result for lags of one and two days.

Figure 9 - p-values for daily gas used Granger tests



Does monthly gas price Granger cause monthly gas used for generation?

We only tested a lag of 1 month. We found no evidence of a relationship.

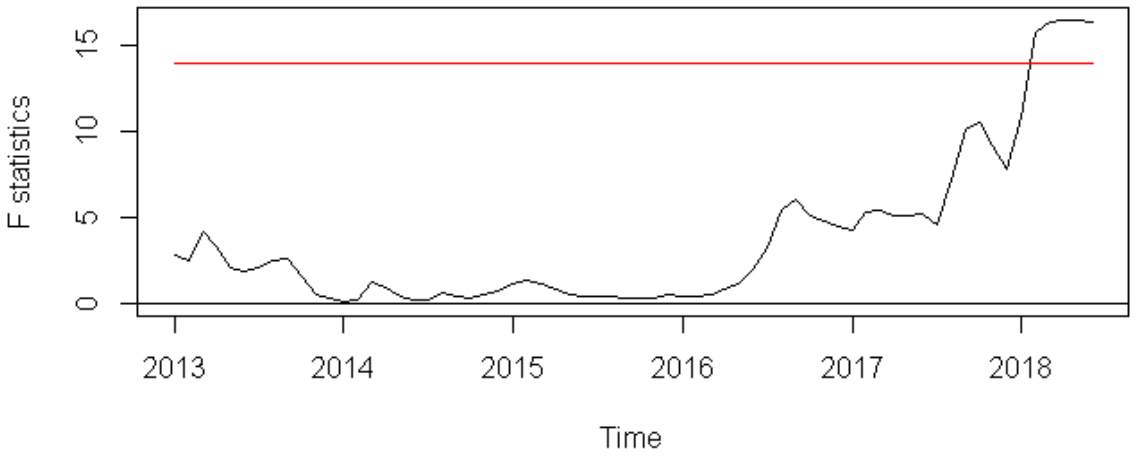
```
Granger causality test

Model 1: gasUsed ~ Lags(gasUsed, 1:1) + Lags(gas, 1:1)
Model 2: gasUsed ~ Lags(gasUsed, 1:1)
  Res.Df Df      F Pr(>F)
1     87
2     88 -1 1.913 0.1702
```

d) Using coal as explanatory variable

Does monthly coal price explain changes in monthly electricity price?

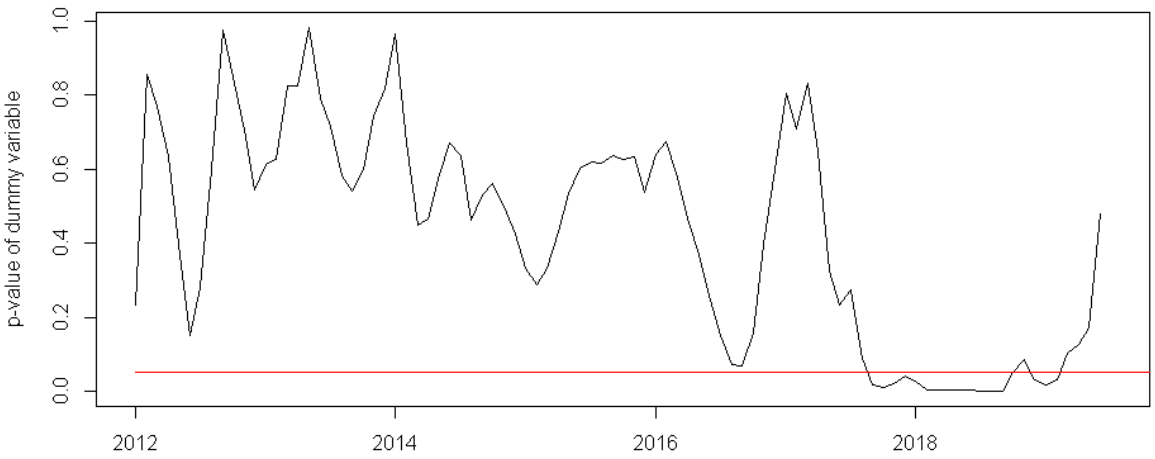
We tested a model using coal prices rather than gas prices as an explanatory variable. Figure 10 shows results from performing a Chow test at each month. A value above the red line indicates a positive Chow test, indicating a breakpoint in that month. February 2018 and subsequent months show a positive result, while 2017 does not.

Figure 10 - Multiple Chow test results



We also used the dummy variable approach. If the p-value of the dummy variable in the regression model is significant, then this indicates that there is a break point when the dummy variable changed. Figure 11 indicates a break point in late 2017 and most of 2018.

Figure 11 - Results of dummy variable approach



e) Relationship of hydro storage to electricity prices

Does average daily Benmore electricity price Granger cause daily relative storage?

We tested all lags from 1 to 10 days. All produced significant results, with p-value of less than 5%.. Output for order 6 is shown below.

```
[[6]]
Granger causality test

Model 1: rStor ~ Lags(rStor, 1:6) + Lags(ben, 1:6)
Model 2: rStor ~ Lags(rStor, 1:6)
  Res.Df Df      F    Pr(>F)
1   2180
2   2186 -6 3.8133 0.0008731 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Does average daily Benmore electricity price Granger cause daily relative storage with trimmed data?

We tested all lags from 1 to 10 days. All except 3 days' lag produced significant results, with p-value of less than 5%.

Output for order 6 and order 3 are shown below.

```
[[6]]
Granger causality test

Model 1: rStor ~ Lags(rStor, 1:6) + Lags(ben, 1:6)
Model 2: rStor ~ Lags(rStor, 1:6)
  Res.Df Df      F  Pr(>F)
1   1746
2   1752 -6 2.6949 0.01316 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

[[3]]
Granger causality test

Model 1: rStor ~ Lags(rStor, 1:3) + Lags(ben, 1:3)
Model 2: rStor ~ Lags(rStor, 1:3)
  Res.Df Df      F  Pr(>F)
1   1755
2   1758 -3 2.5615 0.05335 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```