Supplementary Material — Changes to Victorian Intraday Electricity Demand Following COVID-19 Restrictions

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1 Victoria, Australia COVID-19 restrictions timeline

Item	Date	Description
First case in Wuhan, China	17 Nov 2019	This occurred before COVID-19 was known to medical professionals.
WHO announced COVID-19	31 Dec 2019	-
First case in Victoria (and Australia)	19 Jan 2020	Case was a recent arrival from Wuhan.
WHO announced COVID-19 a pandemic	11 Mar 2020	-
Australia closed borders to non-residents	20 Mar 2020	-
Initial Victorian COVID restrictions	23 Mar 2020	Closed: Night life & indoor recreation. Food restricted to takeaway & delivery. Religious gatherings restricted.
Stage 3 Victorian restrictions	30 Mar 2020	Only four reasons to leave home: essential shopping, exercise, medical care & care-giving, work & education (if cannot be completed remotely).
Stage 4 Victorian restrictions	2 Aug 2020	Mandatory curfew between 8pm and 5am; 5km restriction imposed on movement; all non-essential retail outlets closed; schools closed to all students; only individuals with government-issued permits allowed to go to attend their workplace in person (with capacity limits for certain industries e.g. abattoirs).

2 Data

Half-hourly demand data from 1st January 2015 to 21st September 2020 were obtained from the Australian Energy Market Operator[1]. Daily maximum and minimum temperatures for the same period are available from the Australian Government Bureau of Meteorology (BOM) website[2].

The BOM defines Cooling Degree Days (CDD) and Heating Degree Days (HDD) as follows[3]. First, determine a threshold or BASE temperature for each. For HDD, this threshold is the temperature above which heating

[1] https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/aggregated-data

[2] http://www.bom.gov.au/climate/data/

[3] http://www.bom.gov.au/climate/map/heating-cooling-degree-days/documentation.shtml

would not be required to maintain comfortable conditions. Conversely, for CDD, days on which the mean temperature is not high enough to require cooling. In other words, on a given day with mean temperature τ_t,

$$CDD_t = max\left(0, \tau_t - \tau^C\right)$$
$$HDD_t = max\left(0, \tau^H - \tau_t\right),$$

where τ^C and τ^H are the BASE temperatures for CDD and HDD, respectively. The mean temperature, τ_t, is defined as the midpoint between the daily maximum and minimum temperatures. BOM also guides the choice of BASE temperatures: τ^C is either 18°C or 24°C, and τ^H is either 12°C or 18°C. We have elected to set

$$\tau^C = \tau^H = 18°\text{C}.$$

due to our months of focus being April and August, in which Victoria experiences lower temperatures.

3 Code and reproducibility

The analysis and Figures 2 through 5 from main text were produced in MATLAB. Figure 1 was produced in `R`. All code used for analysis and visualisation is publicly available on our GitHub repository[4]. The report was compiled using LaTeX in `Overleaf`, and available upon request.

4 Identifying peaks

For most of the days in our sample, we can easily infer from visual inspection that there are either one or two peaks, and roughly the time of day at which they occur. However, the curves are not smooth, as illustrated by the plots of an arbitrarily-selected week from our sample in Figure 1. More importantly, not every local maximum (demand at a particular time that is higher than the half-hour before and after it) is likely to be considered a peak for the day.

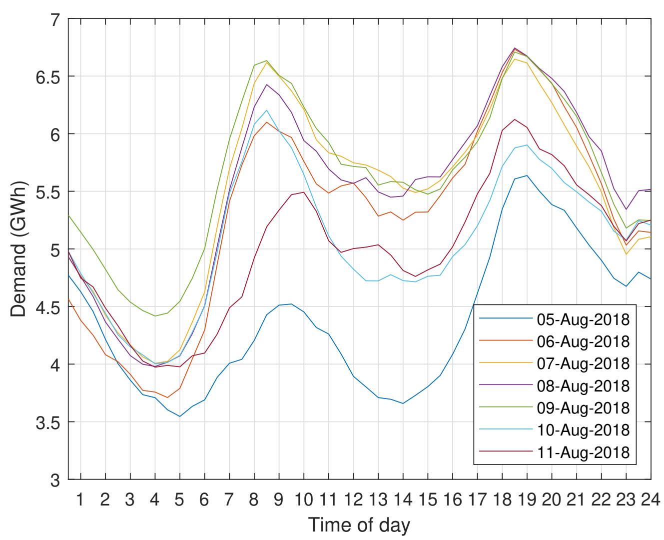


Figure 1: Daily plots of demand curves at half-hourly intervals for the week from Sunday 5th August 2018 to Saturday 11th August 2018.

[4] `https://github.com/nspyrison/melb_datathon2020`

To deal with this issue, we smooth each daily curve using a simple seven half-hour moving average. Suppose we denote demand at the h-th half-hour of day t as $\delta_{t,h}$ ($h = 1, 2, \ldots, 48$). Then the smoothed demand curve, denoted $\delta^*_{t,h}$, is defined by

$$\delta^*_{t,h} = \frac{1}{7} \sum_{j=h-3}^{h+3} \delta_{t,j}, \tag{1}$$

for $h = 4, 5, \ldots, 45$. This method of smoothing makes the strong but reasonable assumption that demand between 11:00pm and 1:30am each day does not affect our choice of the daily peaks.

The morning peak on any day t, if it exists, is $\delta_{t,h_{am}}$ such that

1. $\delta^*_{t,h_{am}} > \delta^*_{t,h}$ for all $h \in \{8, 9, \ldots, 24\}$,
2. $\delta^*_{t,h_{am}} > \frac{1}{3} \sum_{p=1}^{3} \delta^*_{t,h_{am}-p}$,
3. $\delta^*_{t,h_{am}} > \frac{1}{3} \sum_{q=1}^{3} \delta^*_{t,h_{am}+q}$.

The first condition requires that the smoothed demand at the morning peak must be the largest of all values between 4am and 12pm on that day. The second and third conditions are largely irrelevant except for cases where the point which satisfies the first condition lies close to 4am or 12pm. In such cases, we want to ensure that it still a local maximum within three half-hourly intervals before and after, instead of simply being part of an upward trend which continues beyond the morning. Note that our smoothed series, $\delta^*_{t,h}$ for $h = 4, \ldots, 45$, is used only to choose the time at which the peak occurs; the demand at the peak is then the actual demand at the half hour selected using the smoothed series.

Evening peaks, $\delta_{t,h_{pm}}$, are similarly selected using

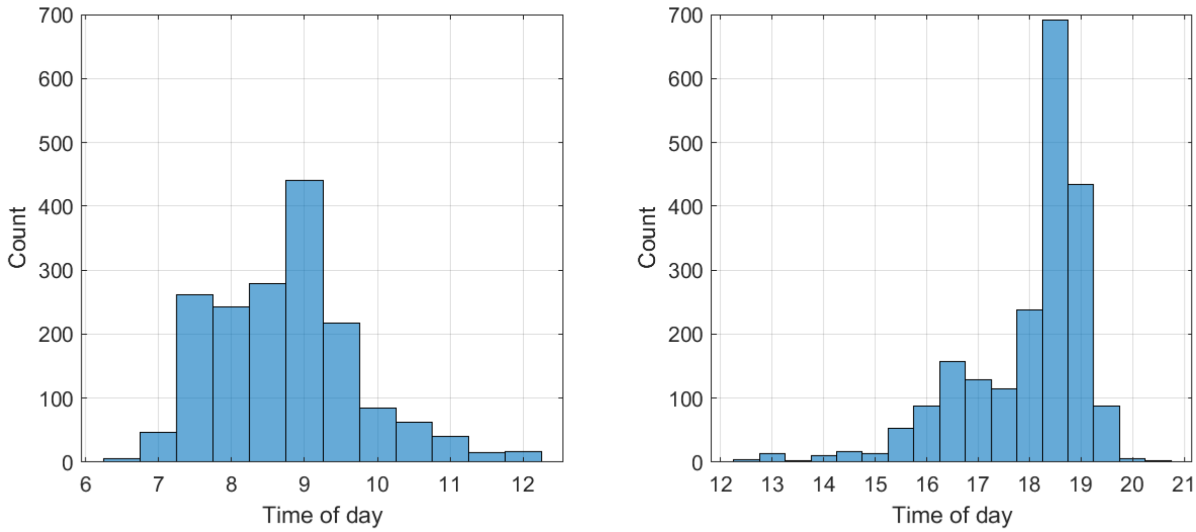
1*. $\delta^*_{t,h_{pm}} > \delta^*_{t,h}$ for all $h \in \{25, 26, \ldots, 42\}$,

2*. $\delta^*_{t,h_{pm}} > \frac{1}{3} \sum_{p=1}^{3} \delta^*_{t,h_{pm}-p}$,

3*. $\delta^*_{t,h_{pm}} > \frac{1}{3} \sum_{q=1}^{3} \delta^*_{t,h_{pm}+q}$,

so that they can only occur between 12:30pm and 9:00pm, inclusive. If no observations satisfy all three conditions for the morning (evening) case, then we say that particular day has no morning (evening) peak.

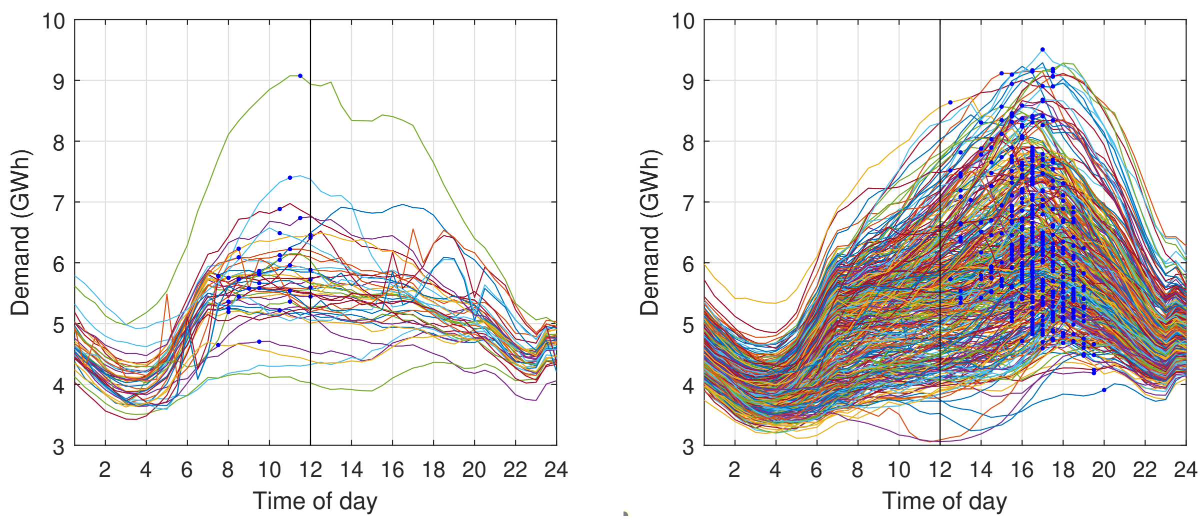
The distribution of the timing of our peaks is shown in Figure 2. More morning peaks occur at 9am than at any one other time. However, there is still a considerable proportion of peaks occurring between 7:30am and 9:30am. On the other hand, evening peaks are largely concentrated around 6:30pm to 7:00pm. In our sample of 2091 days, 436 have only an evening peak, and 30 have only a morning peak, as shown in Figure 3, clearly showing that evening peaks are a more dominant feature.



(a) Morning peaks

(b) Evening peaks

Figure 2: Timing of peaks



(a) 30 days with only morning peaks and no evening peak

(b) 436 days with only evening peaks and no morning peak

Figure 3: Plots of daily demand at half-hourly intervals on days with only one peak

5 Testing for significant changes

We conduct a test for significant changes in model parameters, also known as a structural break test, to investigate the effect of the restrictions (Chow, 1960). The model we use to test for a structural change in the level of the peaks is defined in full as

$$y_t = \sum_{k=1}^{K} \Big(c_k + \mathbb{1}(\mathrm{S3}_t) d_{1k} + \mathbb{1}(\mathrm{S4}_t) d_{2k} \Big) x_{kt} + f_{seas}(t) + \varepsilon_t, \tag{2}$$

where $x_{1t} = 1$ (whose coefficient is the intercept), the variables $x_{2t}, x_{3t}, \ldots, x_{7t}$ are dummies for when the observation falls on a Monday, Tuesday, ..., Saturday, respectively, x_{8t} is HDD_t and x_{9t} is CDD_t. ε_t is an error term with mean of zero. $f_{seas}(t)$ controls for long-run seasonality such as business cycles, the four seasons in the year, as well as any other annual seasonalities, and is defined as

$$f_{seas}(t) = \gamma_1 \sin\left(\frac{2\pi}{365}t\right) + \gamma_2 \cos\left(\frac{2\pi}{365}t\right) + \gamma_3 \sin\left(\frac{2\pi}{365}(2t)\right) + \gamma_4 \cos\left(\frac{2\pi}{365}(2t)\right). \tag{3}$$

Estimates and their p-values are presented in Table 1. Within each panel, the coefficient estimates are split into three columns. Statistically-significant estimates in the second column indicate that Stage 3 restrictions introduce a change in the effect of relevant variables on demand. Statistically-significant estimates in the third column indicate that Stage 4 restrictions lead to a significant change in the effect of the relevant variables compared to the situation during Stage 3 restrictions. Values in red are coefficients which are different from 0 at the 5% level of significance.

Table 1: Output from estimating equation (2), using the demand at the morning peaks as y_t (Panel A) and demand at the evening peaks as y_t (Panel B). Coefficient estimates which are significant at the 5% level of significance are highlighted in red.

	Panel A: Morning peaks						Panel B: Evening peaks					
	Coefficients			p-values			Coefficients			p-values		
	c_k	d_k	d_{2k}	c_k	d_k	d_{2k}	c_k	d_k	d_{2k}	c_k	d_k	d_{2k}
Intercept	3.96	-0.64	-0.14	0.00	0.00	0.50	4.78	0.16	-0.21	0.00	0.20	0.38
Monday	1.18	0.09	-0.01	0.00	0.43	0.95	0.67	-0.11	-0.08	0.00	0.40	0.74
Tuesday	1.33	0.17	-0.24	0.00	0.14	0.27	0.73	-0.20	-0.03	0.00	0.12	0.91
Wednesday	1.36	0.19	-0.17	0.00	0.11	0.45	0.75	-0.15	-0.11	0.00	0.26	0.66
Thursday	1.35	0.23	-0.09	0.00	0.05	0.70	0.72	-0.12	-0.11	0.00	0.38	0.66
Friday	1.34	0.11	-0.15	0.00	0.36	0.49	0.54	-0.23	0.07	0.00	0.08	0.78
Saturday	0.42	-0.17	0.17	0.00	0.15	0.42	-0.06	-0.07	0.16	0.05	0.60	0.50
HDD_t	0.10	0.07	-0.00	0.00	0.00	0.93	0.11	0.01	0.03	0.00	0.56	0.30
CDD_t	0.12	-0.23	0.32	0.00	0.26	0.30	0.28	-0.31	0.17	0.00	0.17	0.63
$\sin\left(\frac{2\pi}{365}t\right)$	-0.03	-	-	0.01	-	-	0.00	-	-	0.76	-	-
$\cos\left(\frac{2\pi}{365}t\right)$	-0.40	-	-	0.00	-	-	-0.58	-	-	0	-	-
$\sin\left(\frac{2\pi}{365}(2t)\right)$	0.09	-	-	0.00	-	-	0.11	-	-	0	-	-
$\cos\left(\frac{2\pi}{365}(2t)\right)$	0.15	-	-	0.00	-	-	0.17	-	-	0	-	-

From the first column on Panel A of Table 1, we see that demand on Wednesday and Thursday mornings at rush hour is largest on average, and Sundays have the lowest morning peak. In the second column, the intercept term becomes statistically-significantly smaller after Stage 3 was imposed. This means that the morning peaks on Sundays are smaller than they were before the restrictions, after controlling for other factors. The fact that the coefficients on other day-of-week dummies are unchanged means that the difference between demand at the peaks on Sundays and any other day remains unchanged. Since Sunday peaks are lower, this translates to every other day having lower morning peaks also, indicating staggering usage of electricity in the mornings. Interestingly, the effect of heating-degree-days is slightly larger. This may be because instead of a smaller number of workplaces providing heating for a large number of individuals, heating is now performed individually at the household level.

In Panel B of Figure 1, none of the coefficients are significantly different from zero at the 5% level of significance, suggesting that energy consumption in the evenings remains unchanged.

References

Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica: Journal of the Econometric Society*, pages 591–605.