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Deregulated power prices: comparison of volatility

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Abstract

We examine electrical power price variability for 14 deregulated markets. Power price volatility is measured by price velocity, the daily average of the absolute value of price change per hour. Deregulated markets show a wide variability in price velocity. Some price velocity is expected and arises from the daily diurnal price pattern, which differs significantly between markets. Even when the expected daily variability in price is removed, the residual unexpected variability differs between markets. Some deregulated markets, most notably Britain and Spain, show patterns that are predictable and consistent and have low values of unexpected price velocity. These markets create a climate conducive to consumers facing the market through real time pricing and shaping consumption behaviors in response to price changes. Other markets, for example, South Australia and Alberta, have patterns that are inconsistent and irregular, and hence are hard for a customer to interpret; a customer in such a market will have a higher incentive to avoid demand side management and escape risk through hedging mechanisms.

Keywords: Deregulated electricity market; Power prices; Price behaviour; Power price volatility; Real time pricing; Demand side management

1. Introduction

Electrical power is a basic energy commodity in an industrial society, and a great number of human activities at both work and home depend on it. Because it originated as an essential commodity often supplied by a single corporate entity, electrical power developed in most countries under regulation, with a price prescribed through some form of governmental regulatory process or outright state ownership. In the past 20 years, however, many jurisdictions have deregulated wholesale and retail electrical power prices. As discussed in a previous paper (Li and Flynn, 2003), deregulated electrical power is usually sold through a single central "pool" in order to establish a single visible price. Users and generators are free to hedge the price by side agreements to remit differences between the pool price and the price agreed to in the hedge contract. Studies of individual power markets and comparisons between markets are cited in our previous paper.

Because electrical power is not effectively storable in significant quantities, wide intraday and interday variations in price occur in deregulated markets; intraday patterns were explored in our previous paper. In this work, we look at volatility in power price, with a focus on the hourly rate of change of price, for numerous deregulated markets.

Our specific focus is looking at power price from the perspective of the consumer of electrical power. Ideally, price is a signal to consumers that shapes consumption, e.g. at times of high price consumers manage demand by changing their activities in order to consume less power. This ideal is hard to achieve in deregulated power markets. Small consumers, including domestic and small commercial sites, typically do not have a meter that records time of use, and do not in practice monitor diurnal power price changes because the information is not readily available and it has no impact on them. These consumers are *de facto* forced to be hedged against daily power price fluctuations by the current technology of metering. Larger commercial and industrial customers typically have time of use metering and access to internet sites that give hourly pricing, and in theory can respond to diurnal price changes. However, scheduling flexibility is limited when the time frame is less than one day. For example, in most jurisdictions when labor is called out it cannot be sent home on short notice, so labor costs can not be avoided if work is terminated due to a price spike within a day.

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Even given these observations, we believe that deregulated power markets that show a high degree of unpredicted or random volatility will discourage consumer response other than hedging, while in markets with a lower degree of volatility consumers should be more willing to purchase power in the open market and manage demand by tailoring their consumption behaviors based on price. For that reason, we believe that price volatility is an important metric for deregulated power markets.

2. Power price data

Hourly or half hourly power price data from 18 different deregulated power markets have been collected. Markets with a cross correlation less than 0.6 have been considered to be sufficiently independent to be treated as a separate market; applying this test, we are left with 14 power markets. Table 1 summarizes the power price data that is used in this study of volatility.

Data as received had two kinds of errors: missing data and multiple data for a single time period. Specific steps taken to "clean" the data are discussed in our previous paper, which also gives a web site reference for each market. Data cleaning is such a small fraction of total data that it is not a significant source of error.

3. Power price volatility

To look at the differences within and between markets in terms of volatility, we define two values of velocity of power price. The first is the daily average rate of hourly change of price expressed as a fraction of the overall (long term) average price in the market, which we call daily velocity based on overall average price (DVOA). DVOA is based on the absolute value of price change, i.e. a change up or down is expressed as a positive fraction. Hence, a DVOA of 0.2 means that each hour, on average, the power price changes by 20% of the long term average price in that market. Note that for markets with pricing reset every half hour, velocity is still calculated on a per hour basis.

DVDA, the daily velocity based on the daily average power price, is similar to DVOA, except that the daily average rate of hourly change of price is expressed as a fraction of the average power price on that day. Again, the absolute value of the hourly price change is used, so a change of price in either direction generates a positive velocity. See Appendix A for a mathematical definition of DVOA and DVDA.

DVOA gives a sense of the consumer's perception of daily volatility relative to a longer term view of price: what is the hourly change in power price compared to the overall average price. DVOA would more likely influence a consumer's decision to hedge and lock in a long term price. DVDA gives a sense of the uncertainty a consumer experiences in buying price on a given day, i.e. if the consumer buys power at a given hour, how high is the rate of change of price in subsequent hours of that day. Note that during a price spike, daily average price is high, and DVOA would be higher than DVDA.

We chose price velocity, based on the change in hourly or half-hourly price, rather than the variance, based on the square of the difference between actual and average price, because we believe it more closely parallels what consumers consider when they look at power price markets: if I consume power in this period, how is its price going to compare to the price of power in past and future periods, and to the past and expected future average power price?

This approach is similar but not identical to Mount et al. (2000), who compare price volatility in three US markets. Mount et al. find evidence of markets switching from low priced cost based bids to high price market based bids in all three markets. The switch is related to load in New England and California, but not in PJM, which is attributed to the high degree of interconnection in the PJM market. Periods of high price are more likely to occur during periods of high load, but the correlation is not high. This is similar to a finding in our previous paper that in most deregulated markets the correlation of price to load is low; the correlation is above 0.4 for only three of the 14 markets. Most other analyses of variability of power price have been within a single market, and are often aimed at characterizing volatility for the purpose of predicting price variability or pricing options for future power purchases; see, for example, Niemeyer (2000), Robinson and Baniak (2002), and Mount (1999). Duffie et al. (1999) provide a good overview of the analysis of volatility in futures markets, and Masson (1999) reviews price risk management strategies and specifically discusses four markets, Scandinavia, Britain, California and Australia.

Table 2 shows the average and maximum values and the coefficient of variation (CV, standard deviation divided by mean) of DVOA and DVDA for the 14 markets in this study, ranked in increasing value of average DVOA. It is clear that normalized average hourly price change differs sharply between deregulated power markets. There is a ten-fold range in average price velocity, and a significant difference in variation in velocity.

The distribution of velocity values also illustrates significant differences between deregulated power markets. Fig. 1 shows the reverse cumulative distribution of the weekday and weekend price velocity in each of the 14 markets, for each of the two velocities; the plots are truncated at a velocity of one. Table 3 shows the fraction of days for which the two weekday velocities exceed 0.1, 0.2, and 0.5 (the choice of these values is arbitrary).

Table 1
Deregulated power price data

Market	Data type	Time period	No. of data points	% of Data Cleaned (%)
1. Canada:Alberta	Hourly	1996/01/01–2001/12/31	52,608	0.02
2. USA:Northern California	Hourly	1998/04/01–2001/01/31	24,888	0.73
3. USA:PJM	Hourly	1997/04/01–2001/12/31	41,424	0.87
4. USA:New England	Hourly	1999/05/01/–2001/12/31	23,424	1.07
5. Germany:Leipzig Exchange	Hourly	2000/06/16–2001/12/31	13,536	0.01
6. Netherlands	Hourly	1999/05/26–2001/12/31	22,824	0.34
7. Britain	Half-hourly	1996/01/01–1997/12/31, 1998/03/01–2001/2/28	87,696	0.08
8. Spain	Hourly	1998/01/01–2001/12/31	35,064	0.03
9. Scandinavia	Hourly	1992/05/04–2001/12/31	84,696	0.01
10. Australia:South Australia	Half-hourly	1998/12/13–2001/12/31	53,520	0.03
11. Australia:New South Wales	Half-hourly	1998/12/13–2001/12/31	53,520	0.04
12. Australia:Queensland	Half-hourly	1998/12/13–2001/12/31	53,520	0.04
13. Australia:Victoria	Half-hourly	1998/12/13–2001/12/31	53,520	0.04
14. New Zealand:Benmore	Half-hourly	1996/11/01 ~ 2001/12/31	90,576	0.50

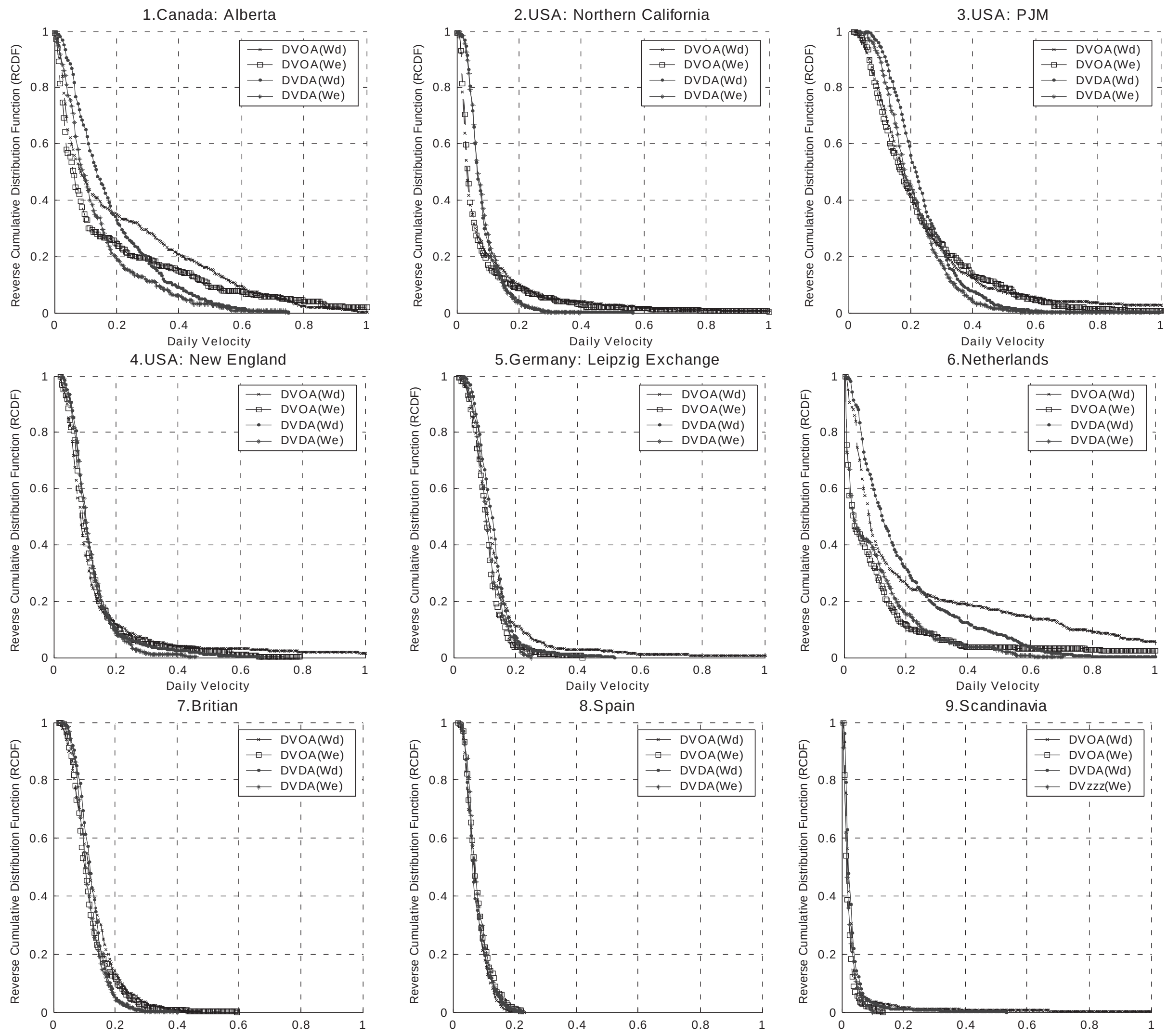
Table 2
Average, maximum and coefficients of variation of price velocity DVOA and DVDA

Market	DVOA			DVDA		
	Average	Max	CV	Average	Max	CV
9: Scandinavia	0.03	1.86	0.39	0.03	0.53	0.89
8: Spain	0.08	0.24	2.21	0.08	0.22	2.19
2: USA:Northern California	0.09	2.93	0.46	0.08	0.57	1.54
14: New Zealand:Benmore	0.11	1.97	0.63	0.11	1.03	0.91
7: Britain	0.13	0.51	1.70	0.12	0.40	2.58
5: Germany:Leipzig Exchange	0.14	4.66	0.55	0.13	0.52	2.27
4: USA:New England	0.15	12.82	0.32	0.12	0.67	1.53
11: Australia:New South Wales	0.18	8.72	0.29	0.12	1.46	1.02
1: Canada:Alberta	0.20	1.23	0.81	0.17	0.75	1.21
13: Australia:Victoria	0.21	14.89	0.25	0.13	1.18	1.10
6: Netherlands	0.23	3.65	0.53	0.16	1.45	0.96
3: USA:PJM	0.26	4.92	0.64	0.23	1.02	2.12
10: Australia:South Australia	0.30	10.78	0.34	0.19	1.51	1.00
12: Australia:Queensland	0.34	19.53	0.32	0.20	1.23	1.02

Markets in Table 3 are ordered in increasing number of days for which DVOA exceeds 20% of the average price on that day.

We can make several observations from Fig. 1 and Table 3:

- There are significant differences in distribution of price velocity between markets. Compare, for example, Alberta and Britain. In Alberta, the average hourly price change has exceeded 50% of the average long term price of power on 15% of days, while in Britain this occurred in only two of the 1827 days in the sample set. To a consumer, this large a change on an hourly basis must seem like a highly chaotic market, and again we note that this kind of market chaos creates a higher driving force for consumers to opt out by hedging. It is interesting to note that despite its press coverage of price excursions, Northern California does not show a high price velocity compared to other markets. This suggests that the issue in the California power crisis was high price, not high price variability.
- From the perspective of distribution of price velocity, specifically not having a high extent of days of high rate of change of price, Scandinavia, Spain, Northern California, and Britain have a small fraction of "high velocity" days, while Alberta, PJM, the Netherlands, South Australia, Queensland have a high fraction. The remaining markets have intermediate values.
- In all markets, the price velocity on weekdays is higher than on weekends. The difference between weekday and weekend price velocity is small in all markets except Alberta, PJM, the Netherlands and



(a)

Fig. 1. Reverse cumulative distribution of the Weekday (Wd) and Weekend (We) price velocity DVOA and DVDA.

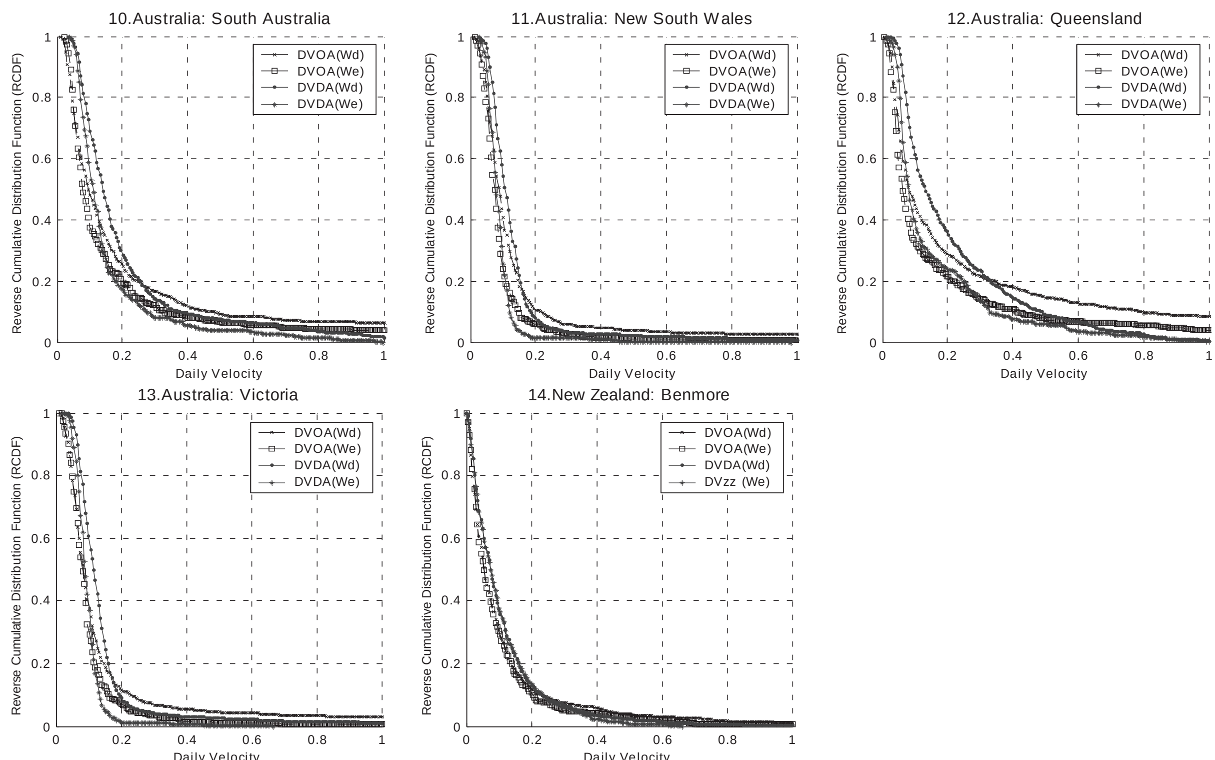
Queensland. The reasons for this difference in these four markets are not known.

4. Unexpected price velocity

A thoughtful consumer will expect some variability in power price, which arises from the diurnal pattern; for example, on average power always costs more at 3 P.M. than at 3 A.M., so there are predictable price movement over the course of a day. In our previous paper we showed the average diurnal price pattern for each of the 14 markets in this study; Fig. 2 shows the average hourly weekday and weekend price for two of the 14 markets, Netherlands and Scandinavia. These two markets illustrate that diurnal price patterns, which reflect among other things the mix of generation in each market, differ sharply: the average maximum to minimum price ratio in the Netherlands 4.62, while in Scandinavia it is 1.40. Hence, a thoughtful consumer in the Netherlands will expect more variability in hourly power price than in Scandinavia.

We use the average diurnal price pattern to calculate an expected daily velocity, EV, for each market. DVOA will equal EV if the price of power on a given day follows its historic average pattern. By subtracting EV from DVOA, we can obtain the unexpected velocity of power price (UVOA). As with DVOA, UVOA is a daily value: the daily average of hourly price change (absolute value) minus the component that is expected from the average diurnal price pattern. Note that UVOA can have a negative value, which will occur on a day in which the actual price variability is less than that expected from the average diurnal price pattern. See Appendix B for a mathematical definition of EV and UVOA.

Table 4 shows EV for each of the 14 markets in this study, and also shows value of UVOA that is exceeded



(b)

Fig. 1 (*continued*).

Table 3
Fraction of days for which weekday price velocity DVOA and DVDA exceed 0.1, 0.2, and 0.5

Market	DVOA			DVDA		
	>0.1	>0.2	>0.5	>0.1	>0.2	>0.5
8: Spain	0.20	0.00	0.00	0.21	0.00	0.00
9: Scandinavia	0.03	0.01	0.01	0.03	0.01	0.00
11: Australia:New South Wales	0.14	0.07	0.04	0.46	0.06	0.02
13: Australia:Victoria	0.20	0.07	0.04	0.61	0.08	0.03
4: USA:New England	0.21	0.08	0.03	0.48	0.09	0.01
2: USA:Northern California	0.18	0.09	0.03	0.24	0.04	0.00
5: Germany:Leipzig Exchange	0.54	0.09	0.02	0.66	0.07	0.00
14: New Zealand:Benmore	0.27	0.11	0.04	0.36	0.13	0.02
7: Britain	0.59	0.13	0.00	0.66	0.05	0.00
6: Netherlands	0.41	0.24	0.16	0.55	0.29	0.08
10: Australia:South Australia	0.46	0.24	0.08	0.65	0.27	0.07
12: Australia:Queensland	0.40	0.26	0.13	0.55	0.34	0.09
3: USA:PJM	0.74	0.31	0.07	0.95	0.53	0.02
1: Canada:Alberta	0.46	0.35	0.15	0.63	0.32	0.04

on 30%, 20% and 10% of days (again, the choice of these values is arbitrary). Note that the Netherlands shows the highest value of EV because of its high maximum to minimum diurnal pattern, and that the value of EV for Scandinavia is low, for the opposite reason. Fig. 3 shows the reverse cumulative distribution of UVOA for each of the 14 markets.

Fig. 3 offers a powerful comment on the markets as seen by consumers: deregulated markets vary widely in their predictability. Compared to the other markets, Alberta, PJM, the Netherlands, South Australia and Queensland have significantly higher unexpected velocity, while Scandinavia, Spain and Britain have significantly lower unexpected velocity. Note that market size does not appear to drive volatility. Alberta and New Zealand both have small populations relative to the other markets in our study; Alberta has high volatility, and New Zealand has lower than average volatility. One

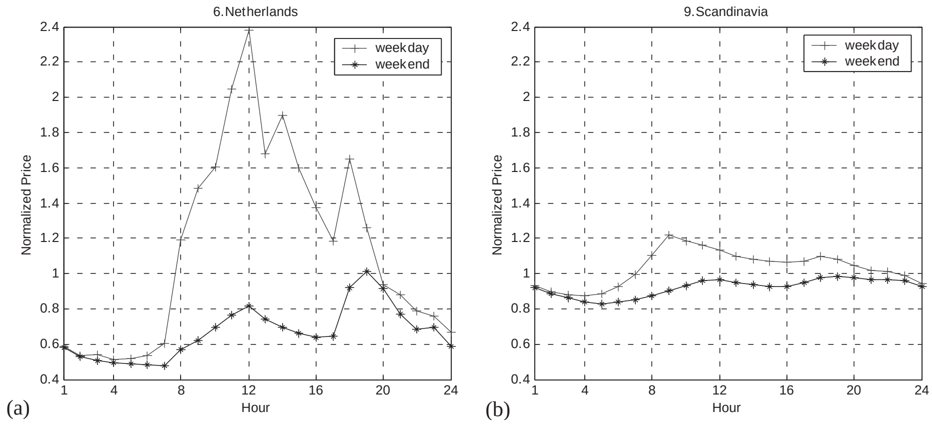


Fig. 2. Average hourly price for Netherlands and Scandinavia.

Table 4
Expected price velocity EV and unexpected price velocity UVOA that is exceeded on 10%, 20% and 30% of days

Market	EV	>0.3	>0.2	>0.1
9: Scandinavia	0.03	0.02	0.02	0.03
13: Australia:Victoria	0.12	0.04	0.04	0.19
8: Spain	0.06	0.03	0.04	0.07
2: USA:Northern California	0.05	0.01	0.07	0.16
11: Australia:New South Wales	0.11	0.07	0.07	0.16
14: New Zealand:Benmore	0.06	0.06	0.08	0.18
4: USA:New England	0.07	0.08	0.08	0.21
5: Germany:Leipzig Exchange	0.11	0.04	0.08	0.13
6: Netherlands	0.16	−0.02	0.09	0.57
7: Britain	0.08	0.06	0.09	0.14
10: Australia:South Australia	0.11	0.12	0.23	0.44
3: USA:PJM	0.11	0.15	0.25	0.34
12: Australia:Queensland	0.12	0.08	0.28	0.67
1: Canada:Alberta	0.10	0.13	0.29	0.50

outstanding question is whether price velocity reduces as a market matures, in particular, in a post-Enron era, will volatility of power price in North America decrease?

5. The relation between volatility and price

Comparing trends in DVDA, the normalized velocity of price relative to the average price on a given day, to trends in the normalized average price on that day, allows a comparison between markets of the "burstiness", or tendency to cluster, of periods of high velocity and of high price. Fig. 4 shows this data for four selected markets. Note that the range for the axes is different for each market; price velocity in Britain would appear substantially lower than in the other three markets if plotted on a common axis. Also note that the choice of the range on the Daily Average Price axis removed 4 points from California and 18 points from South Australia. Similar plots for the other ten markets in this study are shown in Appendix C. Table 5 shows the correlation between DVDA and daily average price and load for all 14 markets. We can make several observations:

- Price and volatility are "bursty", i.e. clustered, in some but not all markets. Alberta, for example, has a large cluster of high price from days 160 to 360 (May–December 2000). California shows three periods of higher velocity, each corresponding to high power demand in summer. Note, however, that clustering is not evident in South Australia, and the occurrence of high price and high price change appears more random. Mount (1999) notes that despite broad ownership of generation, power price in Australia is erratic.
- As noted, annual periodicity in California is evident in volatility but not price, while in Britain annual periodicity is evident in price but not volatility. No periodicity is evident in South Australia.
- There is no consistent correlation between DVDA and daily average power price or load, i.e. periods of high price correlate to high volatility in some but not all markets. For example, in New South Wales there

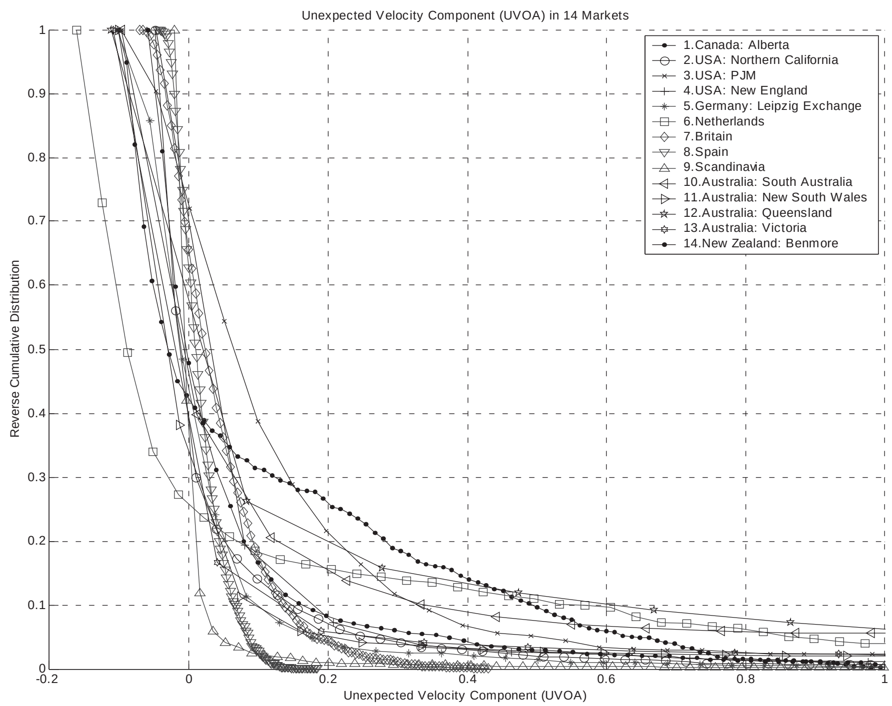


Fig. 3. Reverse cumulative distribution of unexpected price velocity UVOA for 14 Markets.

is a high correlation, but the correlation is negative in Spain and negligible in New Zealand and Northern California.

From the perspective of the consumer, we can see significant differences between deregulated power markets: Britain, for example, has predictable price patterns, as discussed in our previous paper, and relatively stable volatility, while South Australia has no clear pattern or consistency in either.

6. Some reflections on power price variability

Electrical power markets contain a great deal of short term information which in an ideal world would guide some actions by consumers as well as generators. In actual power markets it is dubious that significant demand side responses to short term price changes are being acted on by the majority of consumers.

Two reasons for this are technical: most consumers of electrical power have no knowledge of the price of power at any given hour or half-hour, and most meters for small and medium power consumers do not record the time at which power is used. Hence, the retailing of power to small and medium sized users is usually based on a flat rate. A third reason that short term price changes often do not affect power consumption patterns is that hedging mechanisms are available that allow customers to lock in fixed pricing. For very large consumers, hedging contracts may reflect time of use consumption and pricing, but for small and medium customers hedging mechanisms usually fix a price that is constant over one or more years and is independent of time of day. Hence, practically all small and medium consumers are shielded from time of use due to metering equipment, and hedged small, medium and large consumers are shielded over a longer period from changes in average power price. In deregulated power markets, a great deal of hourly or half-hourly price data simply does not impact the majority of consumers in a way that they can or need respond to, although markets with high and unexpected price variability generate concern in consumers and an erosion of support/tolerance for deregulation.

In a perfect world, all power consumers would know the hourly or half-hourly power price, and to the extent that they were capable, would manage demand by making some adjustment in their behavior; real time pricing would create an incentive for this. Consumers in the Netherlands, which has the highest diurnal variation in average power price, would then find a strong incentive to use a home appliance such as an electrical dryer in the early hours of the morning, by having a timed start. Industrial operations that were high consumers of power, such as electric arc welding, would schedule their work to concentrate power usage in the same time frame. However, as this study makes clear, the ability of a consumer to make sense of price patterns in deregulated markets varies strongly between markets. Britain and Spain are examples of markets with low unexpected velocity. In contrast, Alberta and South

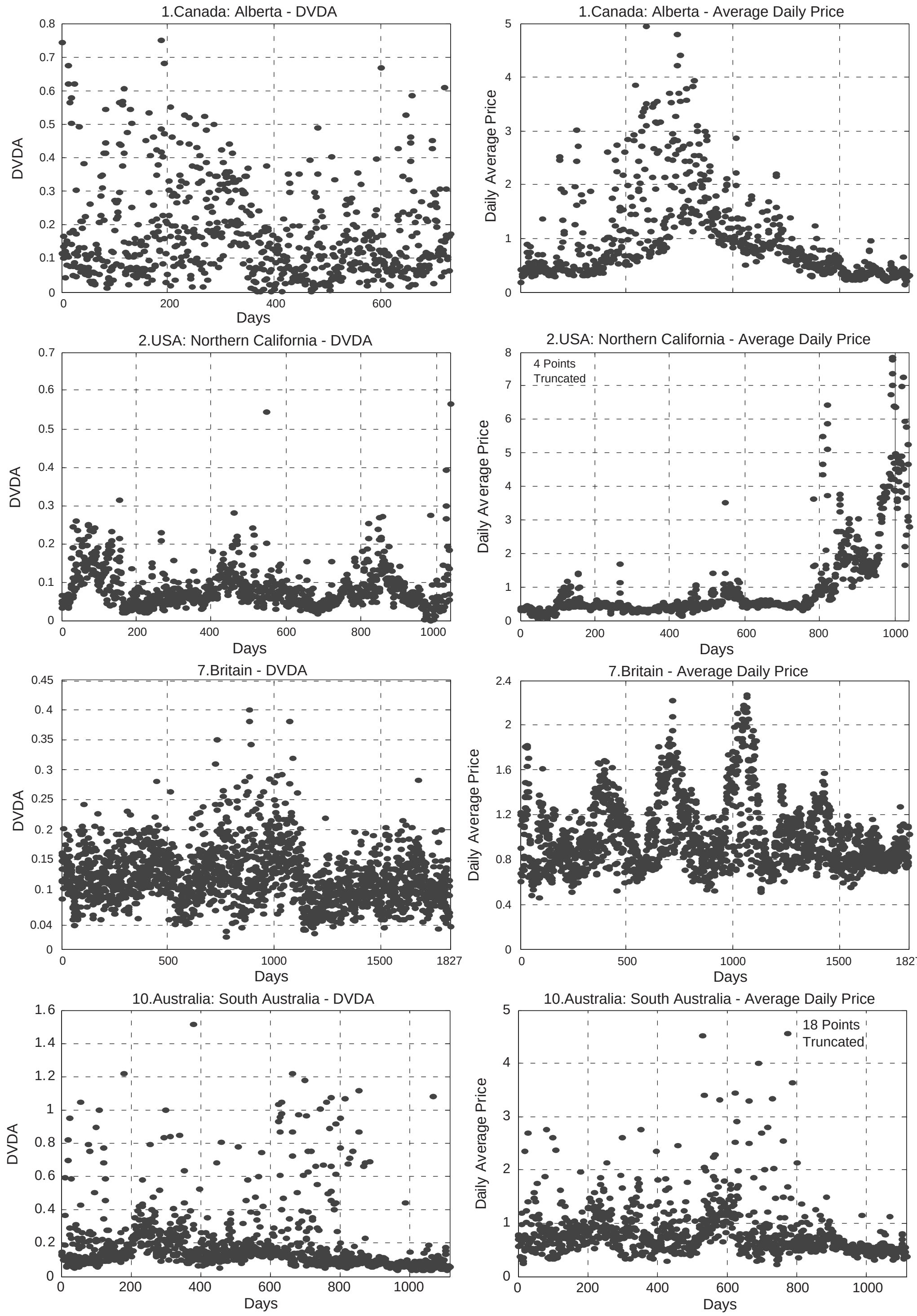


Fig. 4. Price velocity DVDA and daily average price for four selected markets.

Australia show high unexpected velocity, and customers in these markets are justifiably on guard against unexplained and unexpected price spikes and periods of high hourly price change. Our previous paper demonstrated that Britain and Spain have more consistent diurnal patterns of price, and a greater correlation between price and load. A consumer would be far more inclined to shape consumption behavior in Britain and Spain, while facing the market through real time pricing, and would be more likely to hedge in order to be indifferent to time of use in Alberta and South Australia. We speculate that highly volatile markets suppress demand side management; one interesting future comparison between deregulated markets would

Table 5
Correlation between price velocity DVDA and daily average price and load

Market	DVDA vs. daily average price	DVDA vs. daily average load
1: Canada:Alberta	0.28	0.14
2: USA:Northern California	0.06	0.27
3: USA:PJM	0.34	0.22
4: USA:New England	0.30	0.14
5: Germany:Leipzig Exchange	0.47	−0.33
6: Netherlands	0.48	0.42
7: Britain	0.38	0.12
8: Spain	−0.19	0.04
9: Scandinavia	0.18	No load data available
10: Australia:South Australia	0.39	0.19
11: Australia:New South Wales	0.62	0.23
12: Australia:Queensland	0.47	0.15
13: Australia:Victoria	0.44	0.26
14: New Zealand:Benmore	−0.01	No load data available

be the extent and form of hedging that is selected by consumers, to test if this can be related to the predictability of power price.

Conclusions

All of the power markets in this study are industrialized countries with high per capita GDP's. Despite this common economic base, price movement in deregulated power markets, measured in this work by price velocity, shows significant differences between markets. Some price velocity arises because of an expected diurnal pattern of price change, and some is unexpected. Deregulated power markets differ widely in the amount of unexpected price velocity, i.e. the average price change per hour that is not attributable to expected daily price patterns. Markets also differ in both the "burstiness" and periodicity of price level and volatility, and the extent to which high volatility correlates with high price. Deregulated power markets differ in their "consumer friendliness", i.e., the extent to which price patterns are comprehensible and periods of high unexpected price movement are rare.

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Appendix A. Definition of DVDA and DVOA

Mathematically, N is the number of days in the corresponding time period; i the index of day, generally $i = 1, 2, \ldots, N$; M the number of time periods during one day; for hourly power price $M = 24$, for half-hourly power price $M = 48$; j the index of time period, generally $j = 1, 2, \ldots, M$; p_{ij} the power price at the jth time period in the ith day; DVDA_i the daily average price velocity in the ith day referenced to the daily average price in the ith day; DVOA_i the daily average price velocity in the ith day referenced to the overall average price; DVOA of the ith day can be described as

$$\text{DVOA}_i = \frac{1}{M}\left\{\left[\left(\sum_{j=1}^{M-1}\left|p_{i,j+1} - p_{ij}\right|\right) + \left|p_{i-1,M} - p_{i,1}\right|\right]/\bar{p}_{\bullet,\bullet}\right\}, \quad i = 1, 2, \ldots, N,$$

where $\bar{p}_{\bullet,\bullet}$ is the overall average price in the studied period

$$\bar{p}_{\bullet,\bullet} = \frac{1}{M \times N}\sum_{i=1}^{N}\sum_{j=1}^{M} p_{i,j}, \quad i = 1, 2, \ldots, N,$$

DVDA of the ith day can be described as

$$\text{DVDA}_i = \frac{1}{M}\left\{\left[\left(\sum_{j=1}^{M-1}\left|p_{i,j+1} - p_{ij}\right|\right) + \left|p_{i-1,M} - p_{i,1}\right|\right]/\bar{p}_{i,\bullet}\right\}, \quad i = 1, 2, \ldots, N,$$

where $p_{0,M}$ is the power price at the time spot preceding the studied period, and $\bar{p}_i$ is the average daily price in the

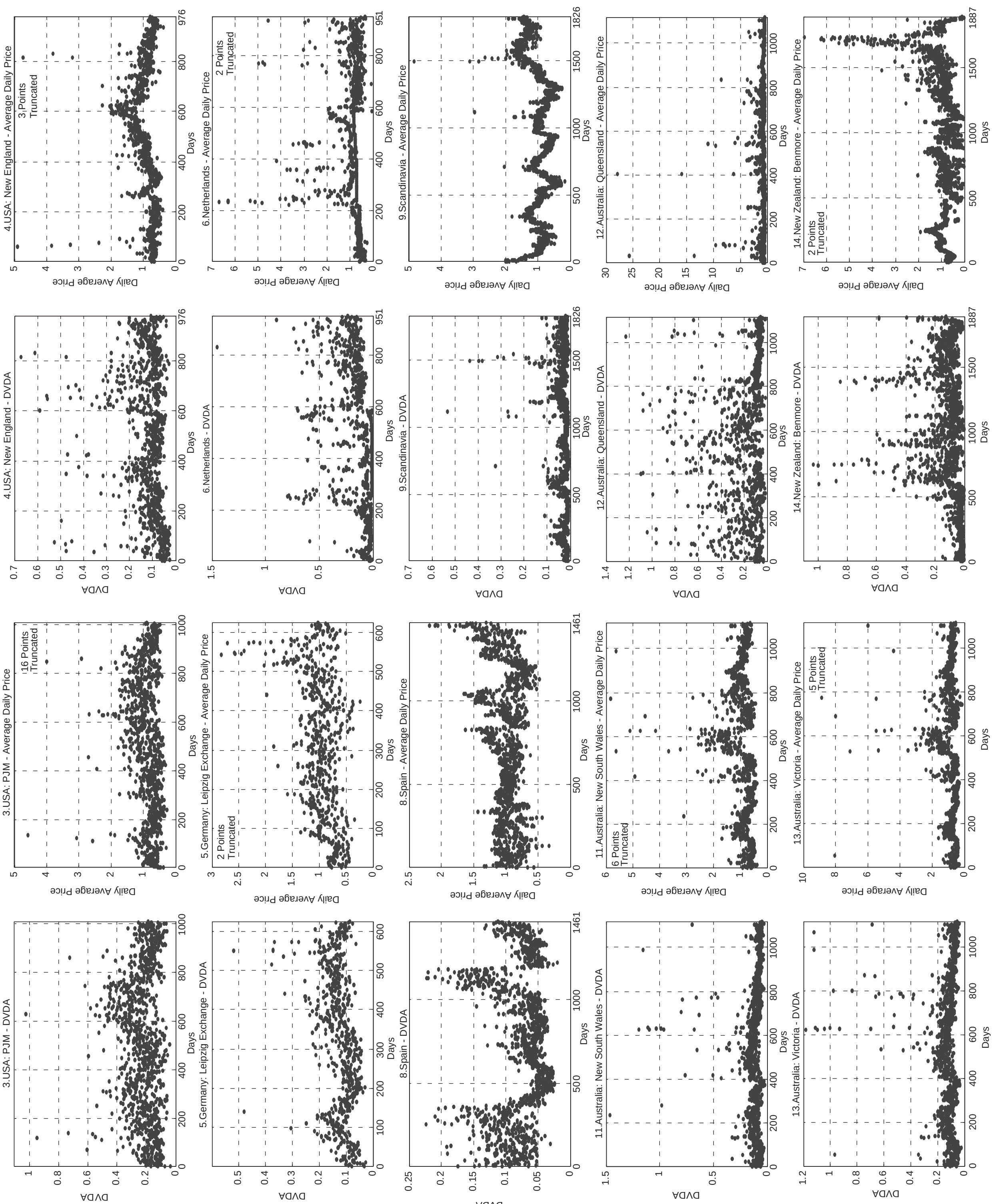

Fig. 5. Price velocity DVDA and daily average price for 10 Markets.

ith day as follows:

$$\bar{p}_{i,\bullet} = \frac{1}{M}\sum_{j=1}^{M} p_{i,j}, \quad i = 1, 2, \ldots, N.$$

Appendix B. Definition of EV and UVOA

Again, mathematically, for each market the "expected component" of the price velocity (EV) arising from daily pattern is defined as

$$\mathrm{EV} = \frac{1}{M}\left[\left(\sum_{j=1}^{M-1}\left|\bar{p}_{\bullet,j+1} - \bar{p}_{\bullet,j}\right| + \left|\bar{p}_{\bullet,M} - \bar{p}_{\bullet,1}\right|\right)/\bar{p}_{\bullet,\bullet}\right].$$

The "unexpected component" of the price velocity, UVOA, can be calculated relative to the overall average price as

$$\mathrm{UVOA}_i = \mathrm{DVOA}_i - \mathrm{EV}, \quad i = 1, 2, \ldots, N.$$

Note that UVOA can have a negative value, which would occur on a day in which the actual price velocity is less than that expected from the average diurnal pattern of price.

Appendix C

DVDA and daily average price for 10 markets are summarized in Fig. 5.

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