

# Simulation of 5 minute prices based on actual 1 hour data

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## Summary

This report describes a method for simulating 5 minute prices based on actual spot and regulating data. The method is used for simulation of 5 minute data for 2001-2011 for the two Danish Nordpool price areas DK1 (West of the Great Belt) and DK2 (East of the Great Belt).

Features of the method are that a limited number of shifts occur within each full hour and that the extremes of the simulated prices equals the actual regulating prices at least once each full hour. As a consequence, when the number of shifts are low the simulated 5 minute prices stay quite close to the actual hourly regulating prices. In such cases user device control system simulations might almost as well be based on actual hourly regulating prices.

Furthermore, the operational setup used for demonstration purposes is briefly described.

## 1 Introduction

This report is prepared as part of the ForskEL-project *FlexPower* (2009-1-10486) which focus on providing flexibility to the power system by utilizing one-way price signals updated every 5 minutes [1]. Since such 5 minute price signals does not exists this report considers simulation of such price signals with the purpose of using these for simulations and operation of demonstration systems.

The prices are simulated so that they follow the actual spot- and regulation- prices as these developed during the period 2001-2011. Please note that the simulated prices are not based on a full power system market simulation and hence the simulated prices should not be interpret as “what the prices would have been had the FlexPower concept been implemented”. Since the simulated 5 minute prices follow the actual hourly prices we can rather expect to be able to answer questions like “how much regulating power could have been activated using the FlexPower concept?”.

The method used for simulation is described in Section 2 and the actual spot and regulating prices are described in Section 3. The simulated data for selected simulation setups are described and summarized in Section 4. Section 5 gives a brief outline of the operational setup. Finally, Section 6 contains some concluding remarks.

## 2 Method

Based on actual spot prices  $P_{St}$ , down-regulation prices  $P_{Dt}$ , and up-regulation prices  $P_{Ut}$  the 5 minute prices are basically, simulated as

$$P_t = P_{St} + (\delta + (1 - \delta)Z_t)(P_{Ut} + P_{Dt} - 2P_{St}), \quad (1)$$

where the time index refers to 5 minute intervals and hence each hourly price is repeated 12 times in order to construct 5 minute data of actual prices. Furthermore, a constant  $0 \leq \delta \leq 1$  and a (simulated) stochastic process  $\{Z_t\}$  is applied in order to simulate 5 minute prices. The stochastic process is restricted to the interval  $[-1, 1]$ . Hence if  $\delta > 0.5$  the simulated prices will never cross the spot-price within one full hour.

With these requirements it is ensured that the simulated 5 minute price lies between the spot price and the active regulating price, or equals the spot price in case of no regulation. The constant  $\delta$  overall controls the closeness of the simulated price to the regulating price.

Note that in case of up-regulation ( $P_{Dt} = P_{St}$ ) the parenthesis involving prices equals  $P_{Ut} - P_{St} > 0$ , whereas it in case of down-regulation ( $P_{Ut} = P_{St}$ ) equals  $P_{Dt} - P_{St} < 0$ . In effect the parenthesis involving prices can be interpreted as the signed price difference.

The simulated 5 minute price should equal the regulating price at least once every hour since the regulating hourly prices are the extremes (maximum in case of up-regulation and minimum in case of down-regulation) of the actual activated bids for the particular hour. In order to achieve this for every hour the 12 five minute simulated prices are moved by a common amount so that at least one equals the actual regulating price. Due to this post-processing the effective  $\delta$  is affected by the variance of the stochastic process  $\{Z_t\}$ . For the extreme case where the mentioned variance is zero the simulated 5 minute prices follows the regulating prices and the effective  $\delta$  is therefore one.

Given the procedure described above the behavior of the simulated 5 minute prices is controlled by the stochastic process  $\{Z_t\}$ . Here we focus on simulating the current situation where only a few activations occur every hour. Consequently, the stochastic process is defined as

$$Z_t = X_t S_t + Z_{t-1}(1 - S_t), \quad (2)$$

where  $S_t$  are independently distributed Bernoulli random variables [2], fulfilling  $P\{S_t = 0\} = 1 - p_{shift,t}$  and  $P\{S_t = 1\} = p_{shift,t}$ . The stochastic process  $\{X_t\}$  is a zero-mean Gaussian AR(1) [3] process with marginal standard deviation 1/3 and the pole  $\phi$  located in 0.8. The simulated values of  $\{X_t\}$  are subsequently truncated to  $[-1, 1]$ . For initialization the first realization of  $Z_t$  is set equal to the first realization of  $X_t$ .

The selected pole implies that the correlation in lag 6 is  $0.8^6 = 0.26$ , i.e. with one shift per hour the correlation across the shifts will be quite low. However, for larger shift probabilities the

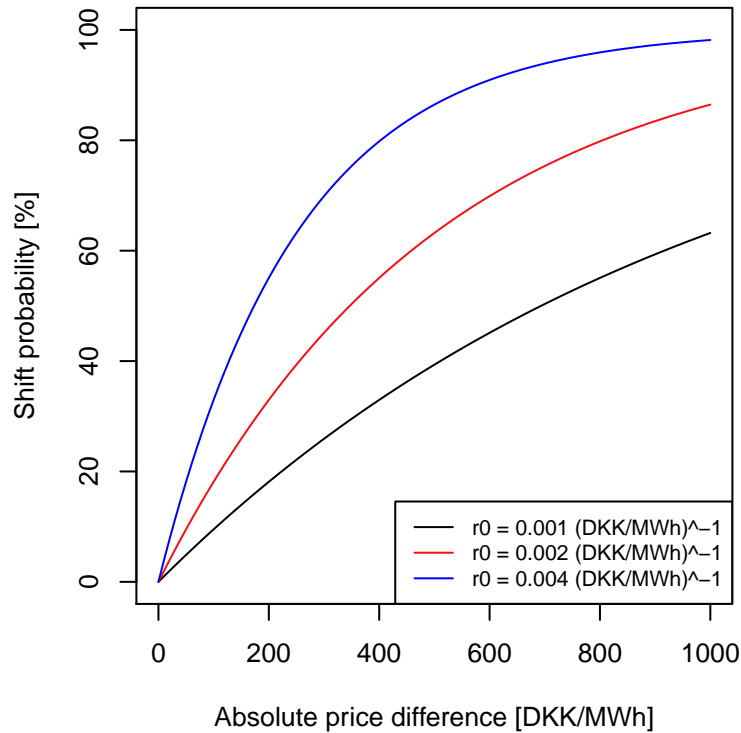


Figure 1: Shift probability for different values of  $r_0$ .

correlation will be larger, ensuring that the simulated 5 minute price does not jump completely randomly between from one time step to the next.

The probability of a shift occurring at the end of a given 5 minute interval  $p_{shift,t}$  should depend on the difference between the regulating price and the spot price so that shifts are more likely to occur when the price difference is large. In practice the following definition is used

$$p_{shift,t} = 1 - \exp(-r_0 |P_{Ut} + P_{Dt} - 2P_{St}|), \quad (3)$$

where  $r_0$  is the slope of the curve for positive price differences near zero. Figure 1 show examples for different values of  $r_0$ .

### 3 Data

The data forming the basis for the simulated 5 minute prices are actual spot and regulating prices for the two Danish Nordpool price areas DK1 (West of the Great Belt) and DK2 (East of the Great Belt). The mentioned prices are downloaded from [www.energinet.dk](http://www.energinet.dk) for the period 2000-10-01 to 2011-12-31. The spot prices are shown for 2001-2011 in Figure 2 and Figure 3 summarize the frequency of the three different regulation types by price area and year.

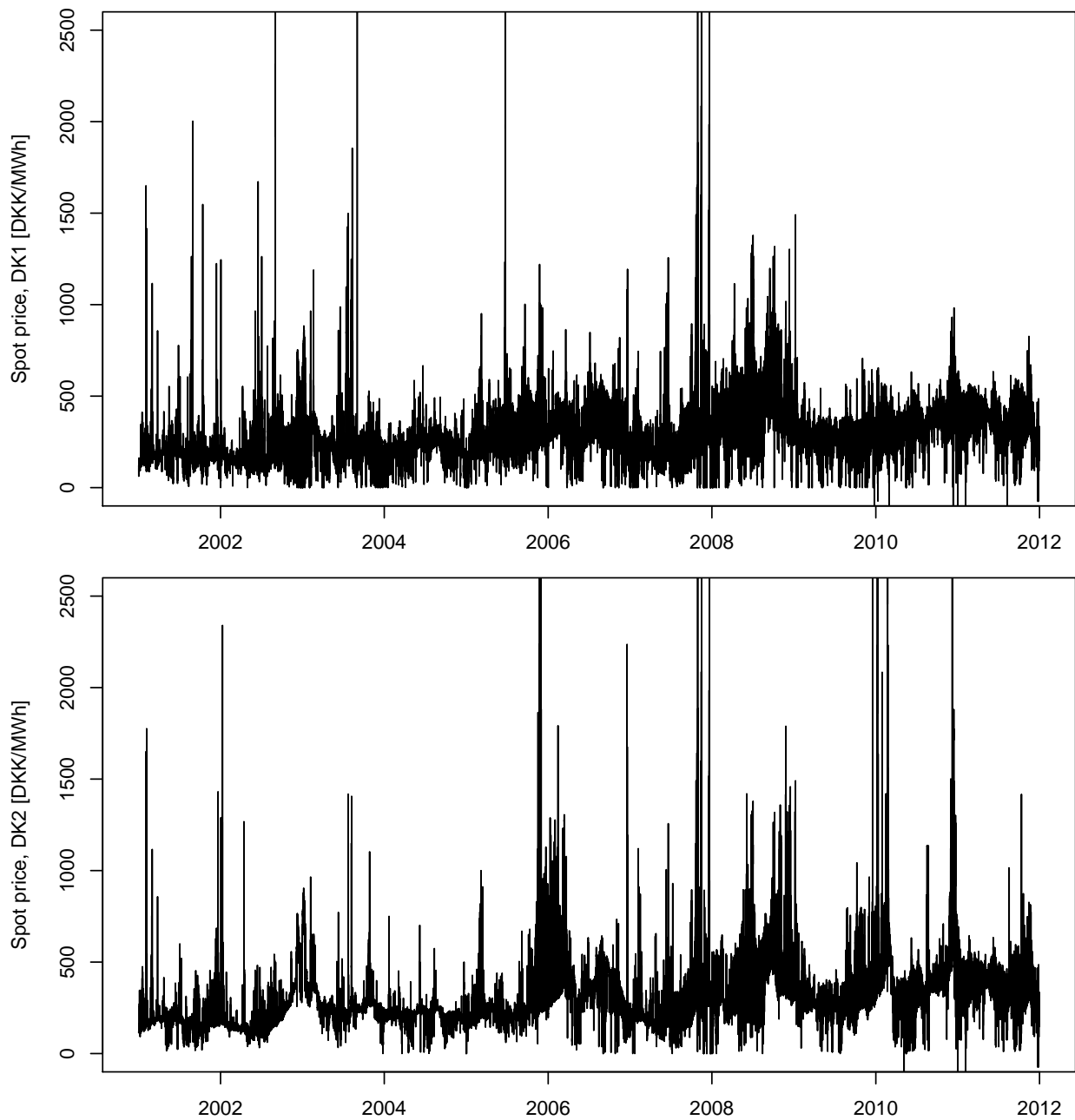


Figure 2: Development of the spot price for the years 2001-2011 for the two Danish Nordpool spot areas. Please note that a few values outside the range shown exists.

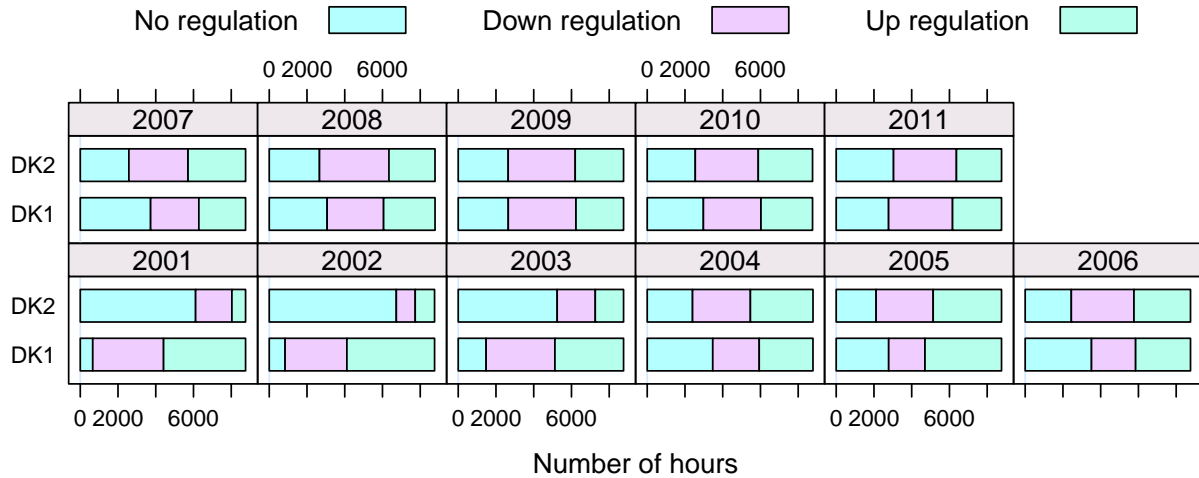


Figure 3: Distribution of no-, down-, and up-regulation for each year in the period 2001-2011. The classification is based on the sign of the price difference as defined in Section 2. Hours where the price differences is less that 10 DKK/MWh are classified as hours without regulation.

## 4 Simulated data

Based on actual prices as described in Section 3 simulated 5 minute data sets are created for the nine combinations of  $\delta = 0.3, 0.6, 0.9$  and  $r_0 = 0.001, 0.002, 0.004$  (DKK/MWh) $^{-1}$ . Here  $r_0$  controls the average number of shifts and  $r_0$  and  $\delta$  in combination determines the actual effective  $\delta$  as also outlined in Section 2.

In order to remove the effect of the initialization in the simulations, cf. Section 2, data back to October, 2000 are used in the simulations. However, results are only reported for 2001 and onwards.

As an example Figure 4 depicts actual spot and regulation prices, together with the simulated 5 minute price, in DK2 during one day in early 2008. As indicated in Section 2 for  $\delta = 0.3$  the 5 minute price and the regulating price may occur on different sides of the spot price. Rounding to integer price differences in DKK/MWh this occurs for 1419 intervals of 5 minutes during the considered 11 year period for  $\delta = 0.3$  and  $r_0 = 0.004$ . This rather infrequent occurrence is presumably caused by the moving of the simulated prices as described in Section 2.

The effective  $\delta$  is quantified as the average of the ratio between the price differences for cases where these are different from zero, or more precisely

$$\delta_{eff} = \frac{1}{N} \sum_{t \in \mathcal{T}} \frac{P_t - P_{St}}{P_{Ut} + P_{Dt} - 2P_{St}} \quad (4)$$

where  $\mathcal{T}$  indicates the time points where the denominator is non-zero, and  $N$  is the number of such time points. We may further choose to split the data in up-/down-regulation hours



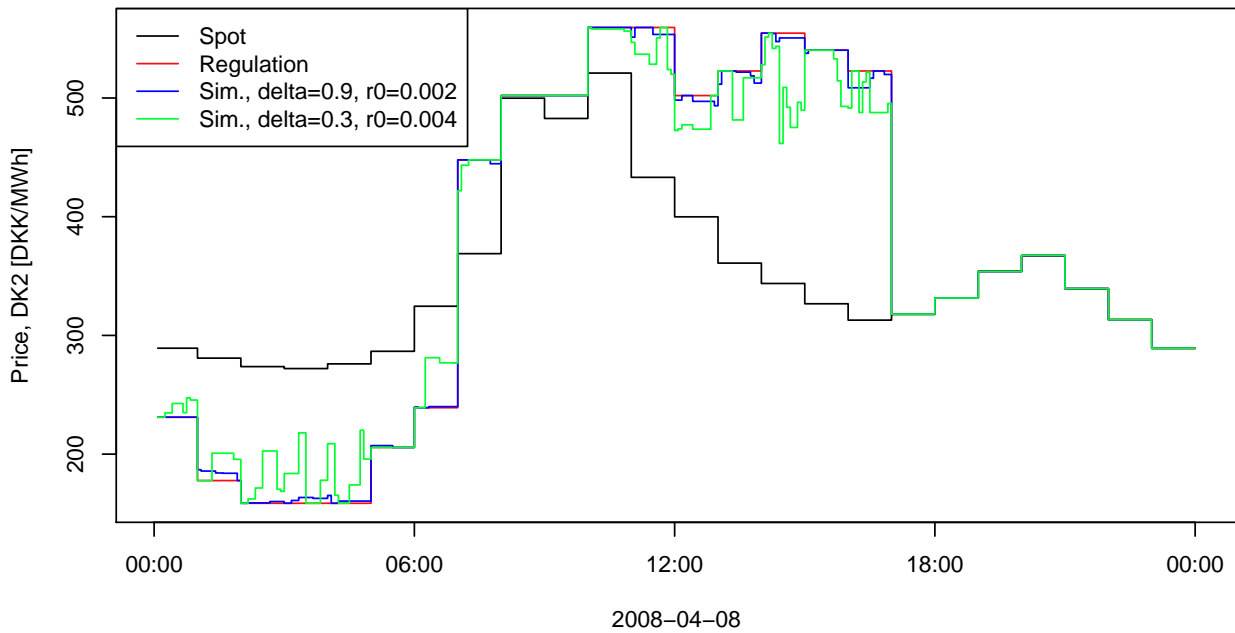


Figure 4: Example of actual spot and regulation prices for DK2, together with the simulated 5 minute price for two different simulation setups.

and by year before calculating  $\delta_{eff}$ . In practice only cases where the price difference (i.e. the denominator in (4)) is numerically larger than 10 DKK/MWh is used in the calculations.

Figure 5 show  $\delta_{eff}$  for the nine combinations of  $\delta$  and  $r_0$  for each of the two price areas and data split by year and regulation type. It is evident that for small shift probabilities  $\delta_{eff}$  is close to one, even for low values of the actual  $\delta$ .

Figure 6 show the average number of shifts per hour for the various simulation setups for each combination of year and price area. Here the high ratio of hours without regulation for DK2 for the first part of the period is evident, see also Figure 3.

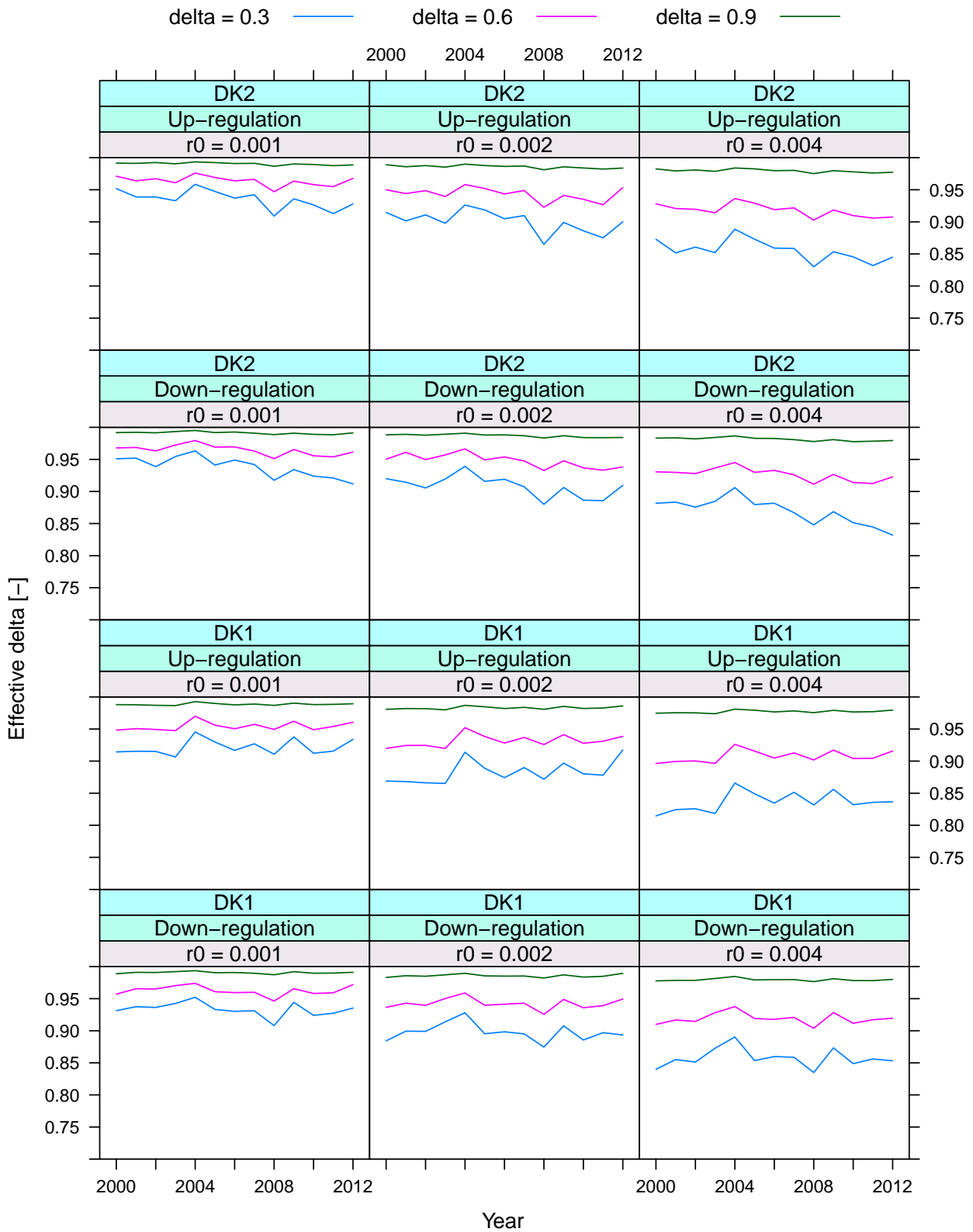


Figure 5:  $\delta_{eff}$  for the various simulation setups.

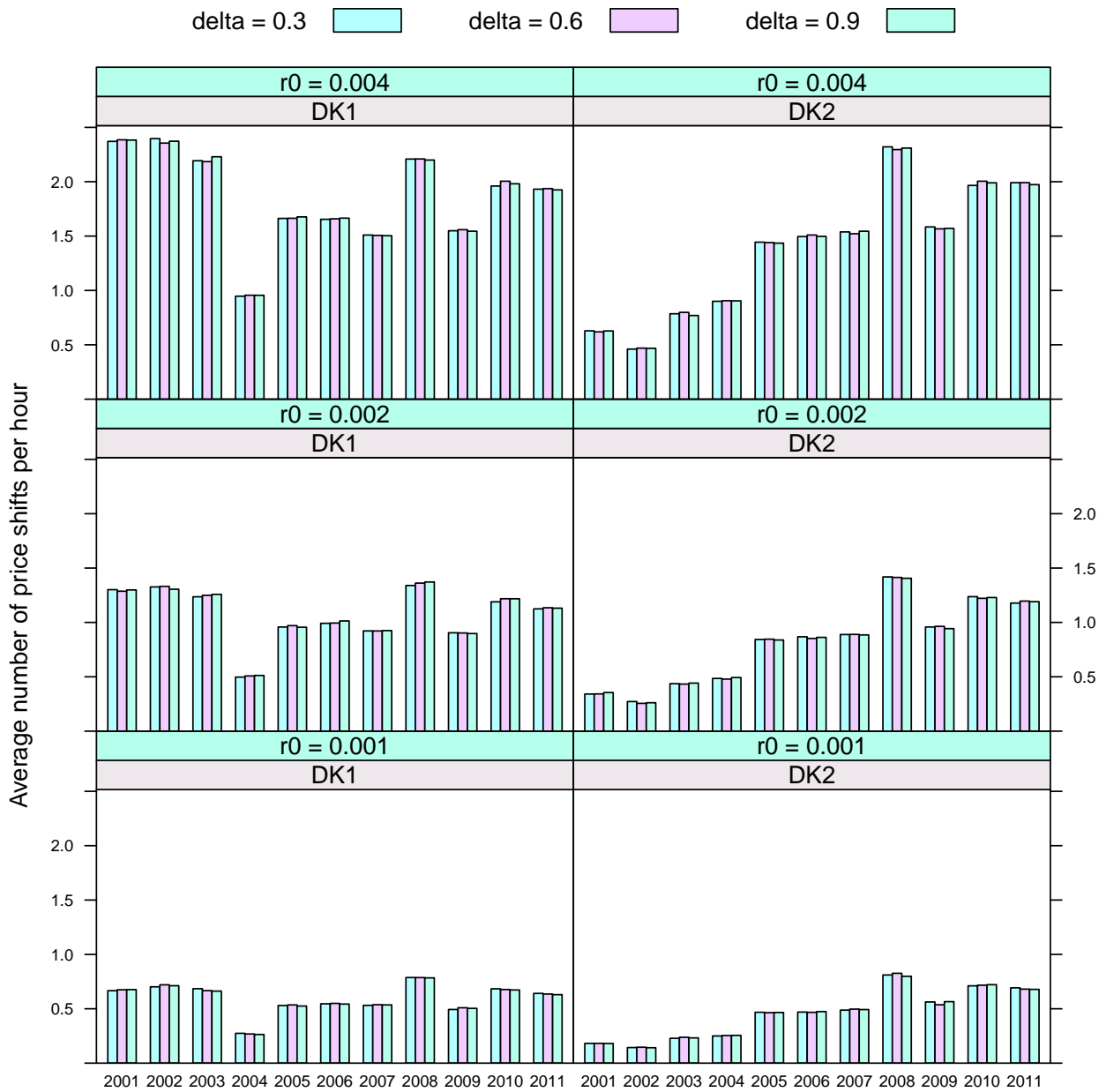


Figure 6: Average number of shifts per hour for the various simulation setups.

## 5 Operational implementation

As described above the simulated 5 minute prices follows the actual spot-, down-, and up-regulation prices. In order to perform the simulation operationally it is therefore required that the actual spot and regulation prices are downloaded online. The FlexPower concept requires the 5 minute price to be available in the *beginning* of the 5 minute interval. Therefore, it is necessary to shift prices in time in order to emulate the FlexPower concept operationally. Furthermore, regulation prices are only available with some delay as compared to the end of the hour for which they are valid. The operational setup is outlined in Figure 7.

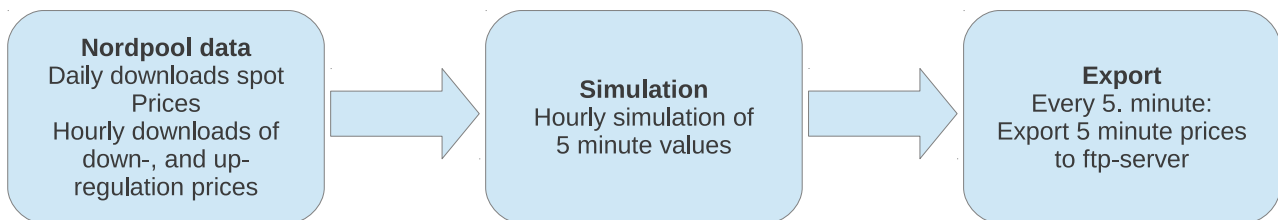


Figure 7: Outline of the operational procedure applied in order to export simulated 5 minutes prices every 5. minutes. Since the actual regulation prices are delayed the export shifts time in order to be able to export prices for the coming 5 minute interval.

In the operational FlexPower setup the time shift is set to 6 hours. The three parameters controlling the simulations are selected as  $\phi = 0.8$ ,  $\delta = 0.6$  and  $r_0 = 0.002 \text{ (DKK/MWh)}^{-1}$ . The operational setup is run for the Eastern Danish price area (DK2).

Figure 8 show the actual delays of and Figure 9 summarize the cumulative frequency of the delays. From Figure 9 it is seen that saturation is reached in 4 hours. Figure 8 reveals that in a few cases, not including the special events mentioned in the caption, the delay is even longer.

Figure 10 show the average delay when grouped by time of day and day of week, respectively. Note that since the data is nearly balanced these means can be meaningfully calculated separately. The largest delay occur Monday early morning, whereas the smallest delay occur Thursday and Friday after Noon.

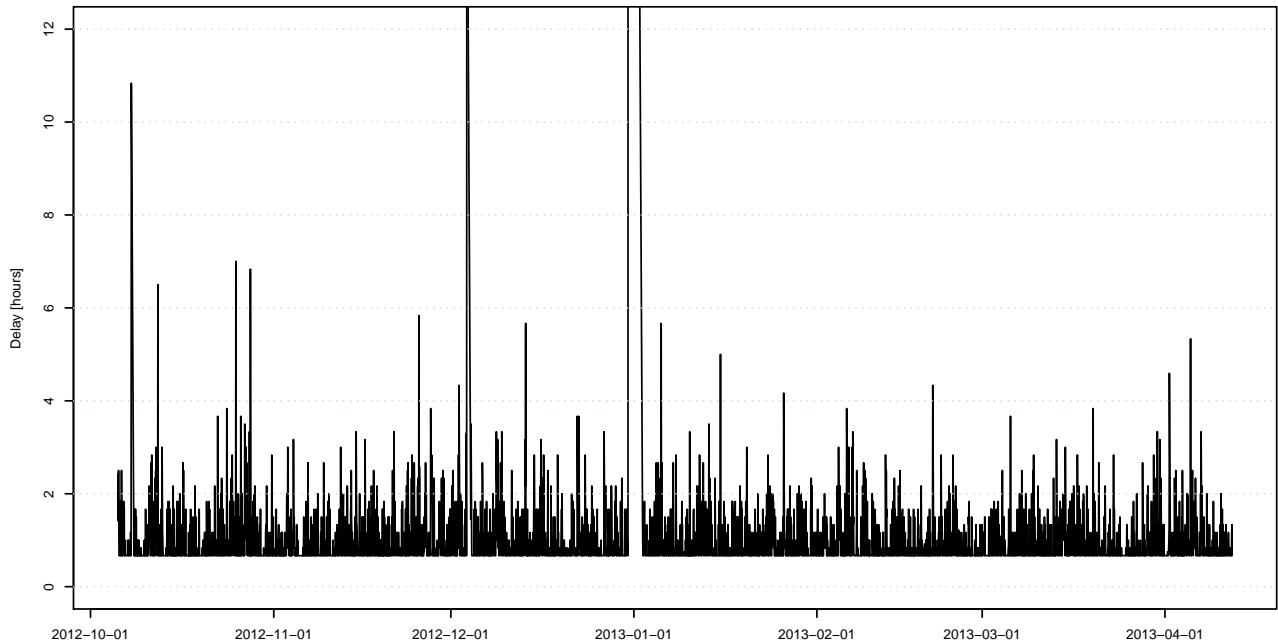


Figure 8: Actual operational delay when downloading regulation prices from Nordpool and initiating the download process 40 minutes past the full hour. Retries are performed every 5 minutes until the data is received. The large delays in the beginning of October, December, and January were caused by reconfiguration of the system.

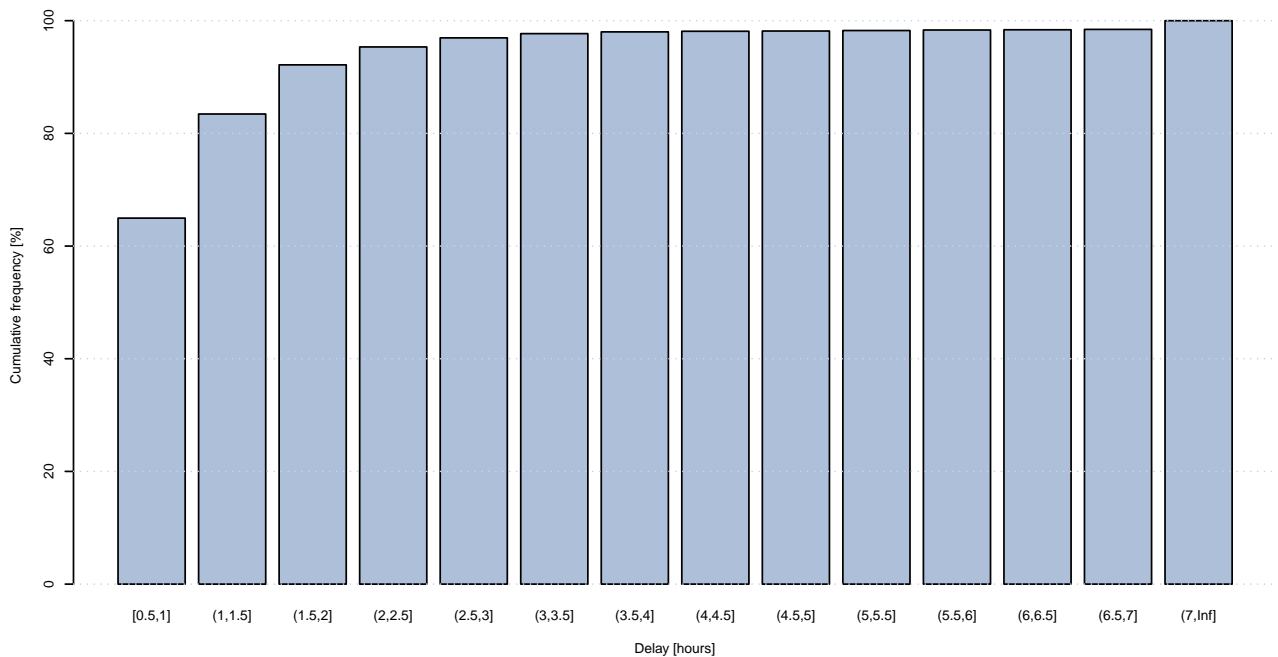


Figure 9: Cumulative frequency of the delay shown in Figure 8.

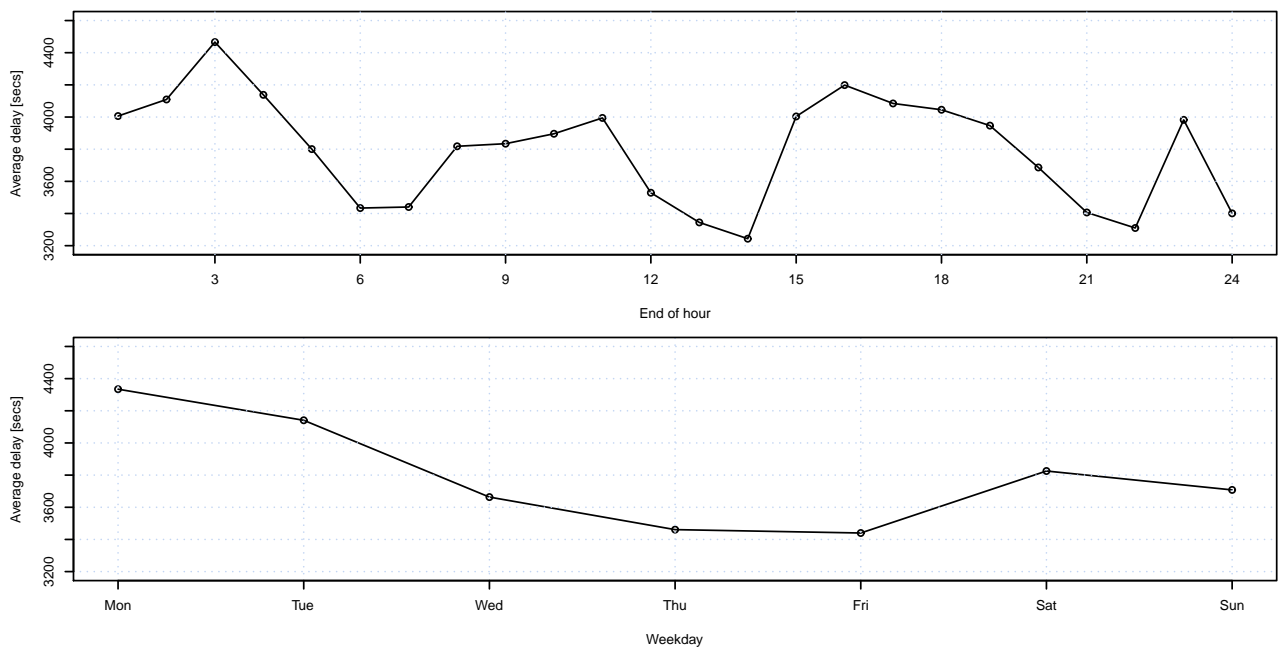


Figure 10: Average delay of the data shown in Figure 8 when split by hour of the day (top) and day of week (bottom). Delays larger than 6 hours are truncated before averages are calculated.

## 6 Conclusion and discussion

A method for simulation of 5 minute prices, allowing the number of shifts per hour to be controlled, is presented. The method is constructed so that the simulated prices follow actual hourly spot and regulating prices for a historic period.

The method is used for generating simulated 5 minute prices for the two Danish Nordpool price areas DK1 (West of the Great Belt) and DK2 (East of the Great Belt). Simulated prices for nine simulation setups are constructed and the features of these are summarized.

The scalar  $r_0$  controls the average number of 5 minutes price shifts per full hour. Focusing on the last part of the 11 year period considered a value of

- $0.001 (DKK/MWh)^{-1}$  results in approximately 0.7 shifts per hour,
- $0.002 (DKK/MWh)^{-1}$  results in approximately 1.2 shifts per hour and,
- $0.004 (DKK/MWh)^{-1}$  results in approximately 2.0 shifts per hour.

The scalar  $\delta$  influence the average distance between the simulated price and the spot price as compared to the difference between the spot and regulating prices. This average is called  $\delta_{eff}$  and the shift probability strongly influence this quantity also. E.g. even for  $\delta = 0.3$ , when the shift probability is low ( $r_0 = 0.001 (DKK/MWh)^{-1}$ ),  $\delta_{eff}$  is typically larger than 0.9, whereas for higher shift probabilities ( $r_0 = 0.004 (DKK/MWh)^{-1}$ ) it is 0.85 or even lower in some cases. This is caused by the requirement that the simulated 5 minute price coincide with the actual hourly regulating price at least once hourly. As a consequence, when the shift probability is low the effect of using the simulated prices over the actual hourly regulating prices is likely to be low.

The underlying stochastic process as defined in Section 2 consists of a partly hidden AR(1) process to which the output switch controlled by an independent Bernoulli process. As a consequence both small and large jumps occur, which are then amplified by the actual difference between spot and regulating prices. The method may be further extended by including a dependence of the AR(1) process on the shifty probability.

## References

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