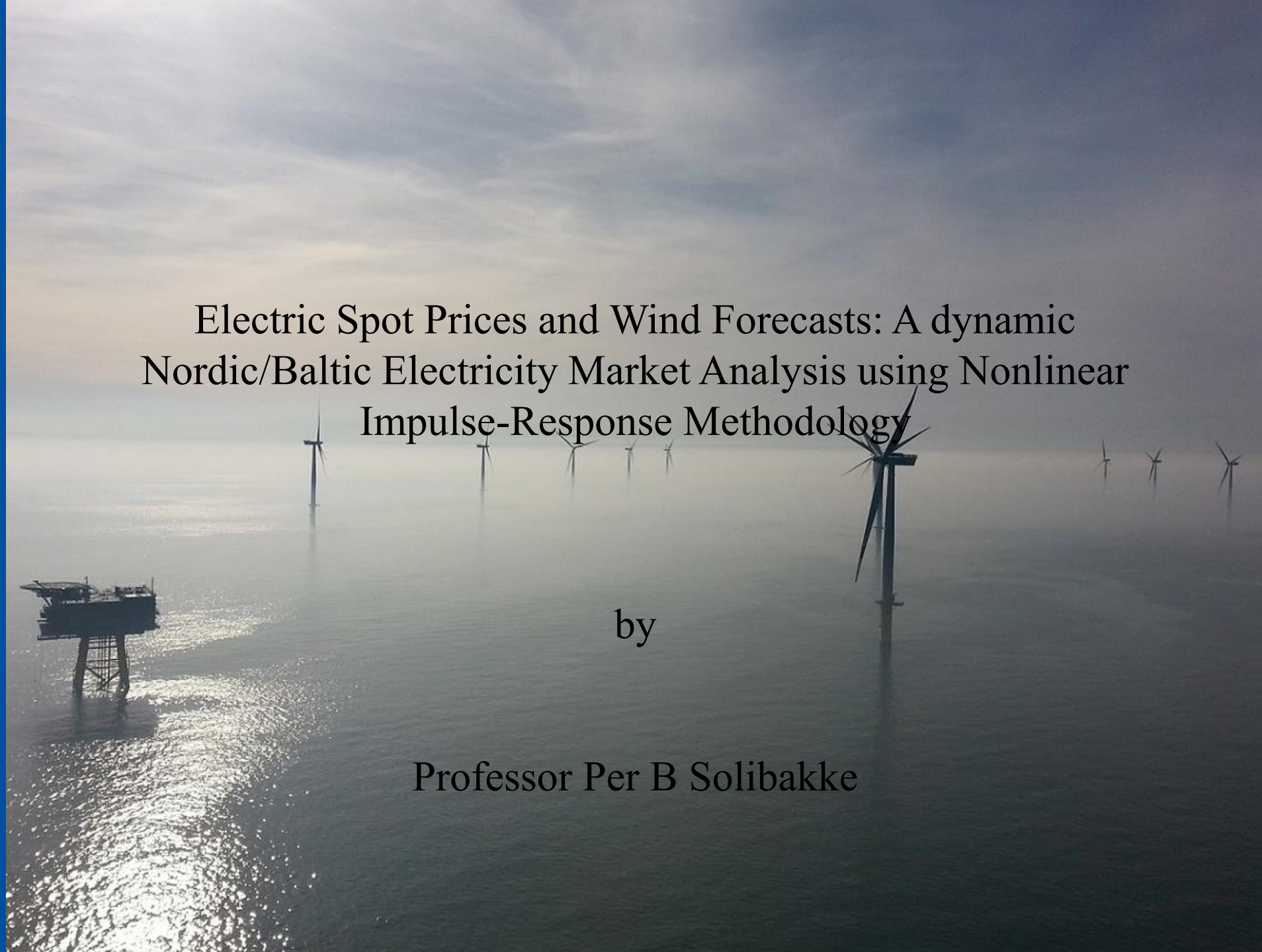

Electric Spot Prices and Wind Forecasts: A dynamic Nordic/Baltic Electricity Market Analysis using Nonlinear Impulse-Response Methodology

by

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NTNU

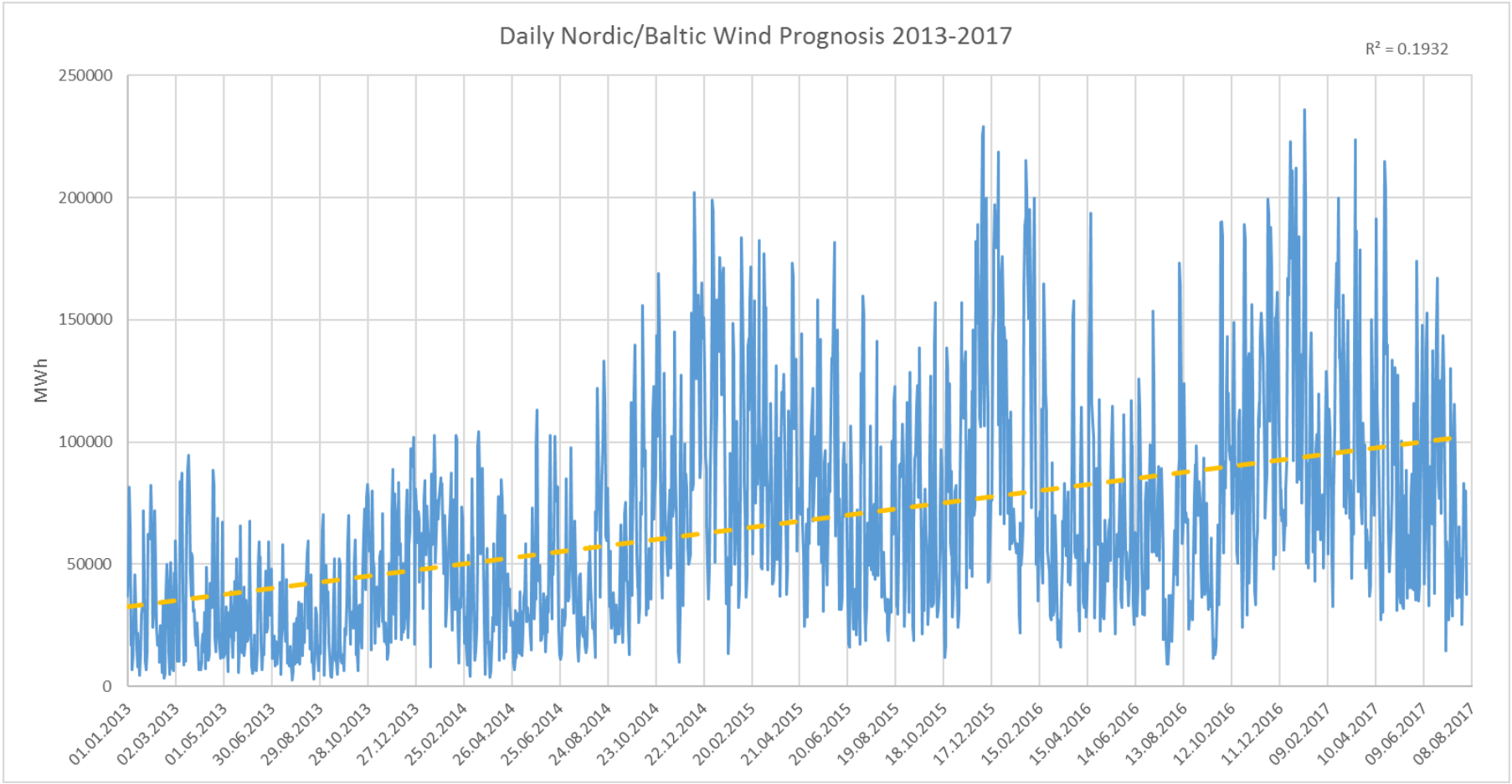
Norwegian University of Science and Technology

4.2%

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Introduction

- A dynamic daily market approach is established from the Nordic/Baltic Electricity market (NordPool). The period with available data wind forecasts is from January 2013 to May 2017. The daily wind information in MWh is shown below:



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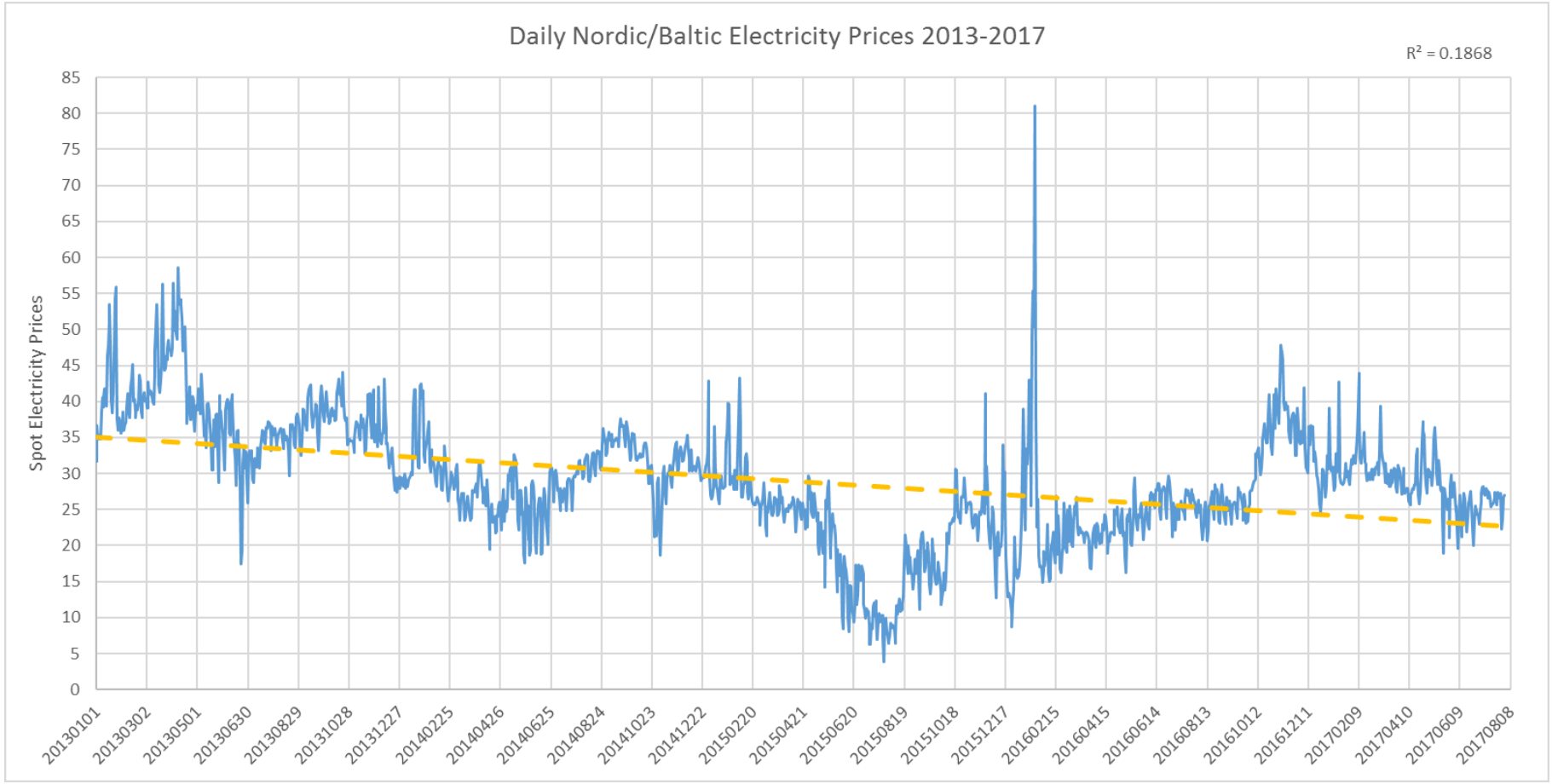
Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Introduction

- The daily electricity price information in MWh for the Nordic/Baltic Electricity market (NordPool) 2013-2017 is shown below:



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Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

The Impulse-Response Methodology

Impulse Responses for the Mean Equation:

The paper applies the methodologies outlined by Gallant et al. (1993) defining one-step ahead forecast for the mean conditioned on the history as (for a Markovian process) (y = spot price and wind forecast changes):

$$g(y_{t+1},\ldots,y_t) = E\left(y_{t+1} \mid (y_{t-k})_{k=0}^{t-1}\right)$$

We write:

$$y_j(x) = E\left(g(y_{t+j},\ldots,y_{t+j}) \mid y_t = x\right)$$
$$= E\left(E\left(y_{t+j} \mid y_{t+j},\ldots,y_{t+j}\right) \mid y_t = x\right)$$

and therefore y_j^i for i = -60,…,60 and j = 0,…,5, where $x = (y_{t-1},\ldots,y_0)$

Note that $\left\{y_j^{-10}\right\}_j^{\infty}$ represent the response to a negative 10% impulse. Here the responses depend upon the initial change x, which reflects the non-linearity.

We report $\left\{y_j^i - y_j^0\right\}_j^{\infty}$, $i = -60,\ldots,60$ and $j = 0,\ldots,5$, which represents the effects of the shocks on the trajectories of the process itself.

A conditional profile can therefore be defined as: $E\left[g\left(y_{t+j-J},\ldots,y_{t+j}\right) / \{y_{t-k}\}_{k=0}^{t-1}\right]$, $(j = 0,1,\ldots,5)$,

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

The Impulse-Response Methodology

Impulse Responses for the Variance Equation:

Defining one-step ahead variance (volatility), is the on-step ahead forecast for the variance conditioned on the history as (y = spot price and wind forecast changes):

$$Var\left(y_{t+1} \mid (y_{t-k})_{k=0}^{\infty}\right) = E\left\{\left[y_{t+1} - E\left(y_{t+1} \mid \{y_{t-k}\}_{k=0}^{\infty}\right)\right]\left[y_{t+1} - E\left(y_{t+1} \mid \{y_{t-k}\}_{k=0}^{\infty}\right)\right]' \mid \{y_{t-k}\}_{k=0}^{\infty}\right\}$$

We write:

$$\psi_j(x) = E\left(g\left(y_{t-L+j},\ldots,y_{t+j}\right) / x_t = x\right)$$
$$= E\left(Var\left(y_{t+j} / x_{t+j-1}\right) / x_t = x\right)$$

for $j = 0,\ldots,5$, where $x = (y_{t-L+1},\ldots,y_t)$

Note that $\left\{\psi_j^{-10}\right\}_j^{\infty}$ represent the volatility response to a negative 10% impulse. The responses depend upon the initial change x.

We report $\left\{\psi_j^{i} - \psi_j^{0}\right\}_j^{\infty}$, $i = -60,\ldots,60$ and $j = 0,\ldots,5$, which represents the effects of the shocks on the trajectories of the process itself.

The conditional volatility profile is different from the path described by the j-step ahead square error process. Note that analytical evaluation of the integrals in the definition of a conditional moment profile is intractable. However, evaluation is well suited to Monte Carlo integration. For simulated realisations we write (with approximation error tending to zero almost surely as $R \to \infty$):

$$g_j(x) = \int\ldots\int g\left(y_{t+j},\ldots,y_t\right)\left[\prod_{i=0}^{j-L} f\left(y_{t+i+1} \mid y_{t+i-L+1},\ldots,y_{t+i}\right)\right] dy_{t+j}\ldots dy_{t+1}$$
$$\approx (1/R)\sum_{r=1}^{R} g\left(y_{t+j}^{r},\ldots,y_t^{r}\right)$$

Sup-norm bands (confidence intervals) are constructed by bootstrapping (changing seed generates densities and impulse response samples)

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Literature review

Spot Electricity Prices:
Goto and Karolyi (2004), Chan and Gray (2006), Theodorou and Karyampas (2008), Bystrøm (2003) and Solibakke (2002).
Higgs and Worthington (2008), Huisman and Mahieu ((2003) and Thomas et al., (2011).
De Vany and Walls (1999), Higgs and Worthington (2008), Huisman and Mahieu (2003), Huisman and Kilic (2013), Haldrup and Nilsen (2006), Knittel (2005), Li and Flynn (2004), Lindstrom and Regland (2012), Mount, Ning and Cai (2006), Robinson (2000), Robinson and Baniak (2002), Rubin and Babcock (2011), Tashpulatov (2013), and Weron (2006, 2008).
Chan and Gray (2006), Escribano, Pena and Villaplana (2011), Habell, Marathe and Shawky (2004), Higgs and Worthington (2005), Koopman, Ooms and Carnero (2007) and Solibakke (2002).
Weron (2006, 2008), Harris (2006), Geman and Roncoroni (2006), Koopman et al. (2007) and Pilipovic (2007).

Wind Forecasts:
Price changes:
Skytte, 1999, Morthorst, 2003 , Giabardo et al., 2009, and Traber and Kenfert, 2011

Price Volatility:
Green and Vasilakos (2010), Steggals et al. (2011), Woo et al. (2011), Jacobsen and Zvingilaite (2010), and Twomey and Neuhoff (2010),

The Semi-Non-Parametric Methodology (background and the impulse response methodology):

Robinson (1983)
Engle (1982)
Bollerslev (1986)
Gallant & Tauchen (2010, 2014)

} previously used for contemporaneous price – volume analysis of stocks /indices and trading volume.

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

Stationarity for price and wind forecast changes

For both series we adjust for systematic location and scale effects in both mean and volatility.

Step 1 (mean): Regress $\varpi = x \cdot \beta + u$, where *x* consists of calendar variables (trends, day of week, week number, calendar separation variable, Eastern and other sub-periods.

Step 2 (variance): For the residuals $\hat{u}$ we regress $\hat{u}^2 = x \cdot \gamma + \varepsilon$. We form $\frac{\hat{u}^2}{\sqrt{e^{x \cdot \hat{\gamma}}}}$ giving us a series with mean zero and unit variance given x (calendar variables).

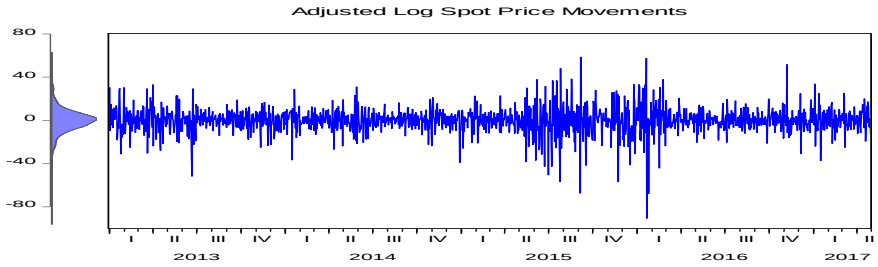
The series $\hat{\varpi} = a + b \cdot (\frac{\hat{u}}{\sqrt{e^{x\hat{\gamma}}}})$ is taken as the adjusted series. *a* and *b* are chosen so the unit of measurement of the adjusted series is the same as that of the original series.

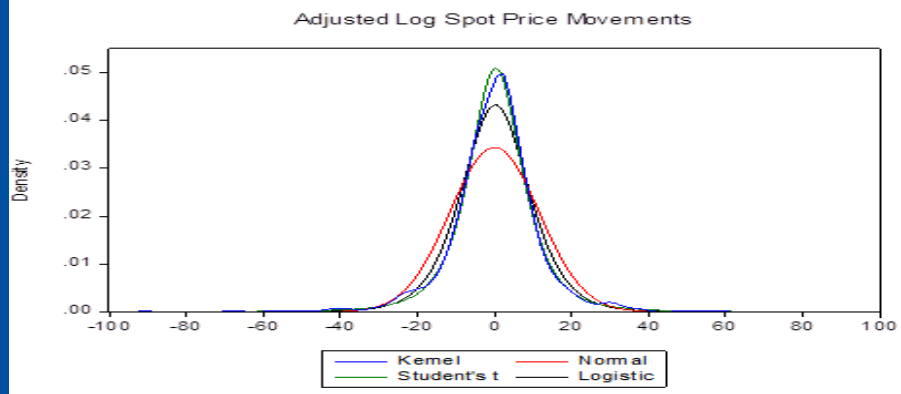
For the β and γ parameters for these two simple regressions, I refer to the manuscript.

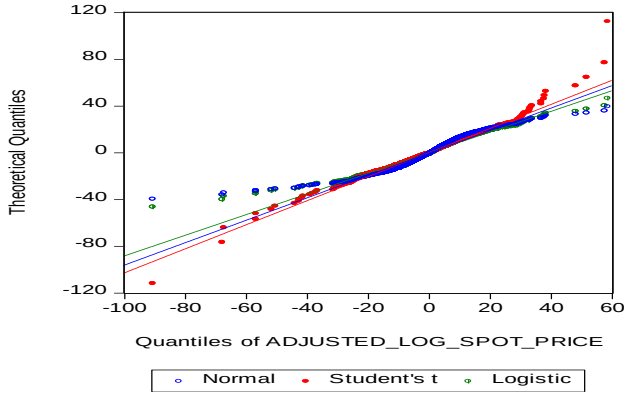
Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

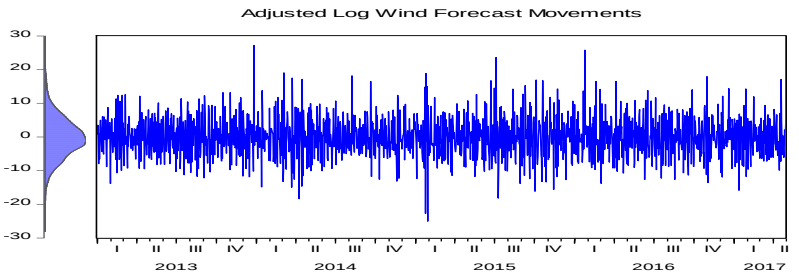
Stationary Electricity Spot Price changes (time series)

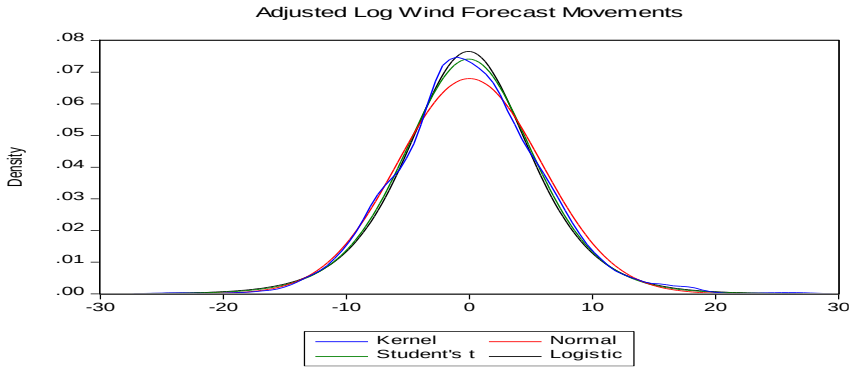


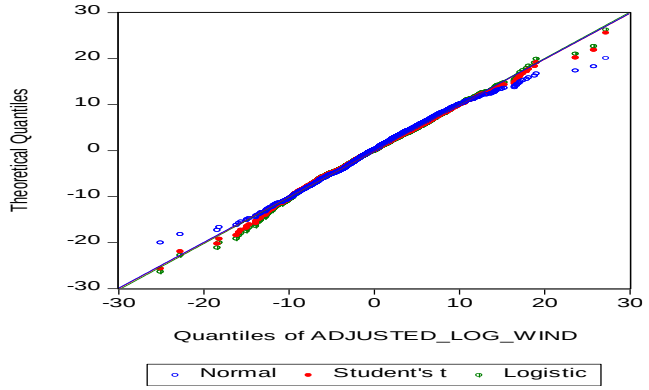




Stationary Wind Forecast changes (time series)



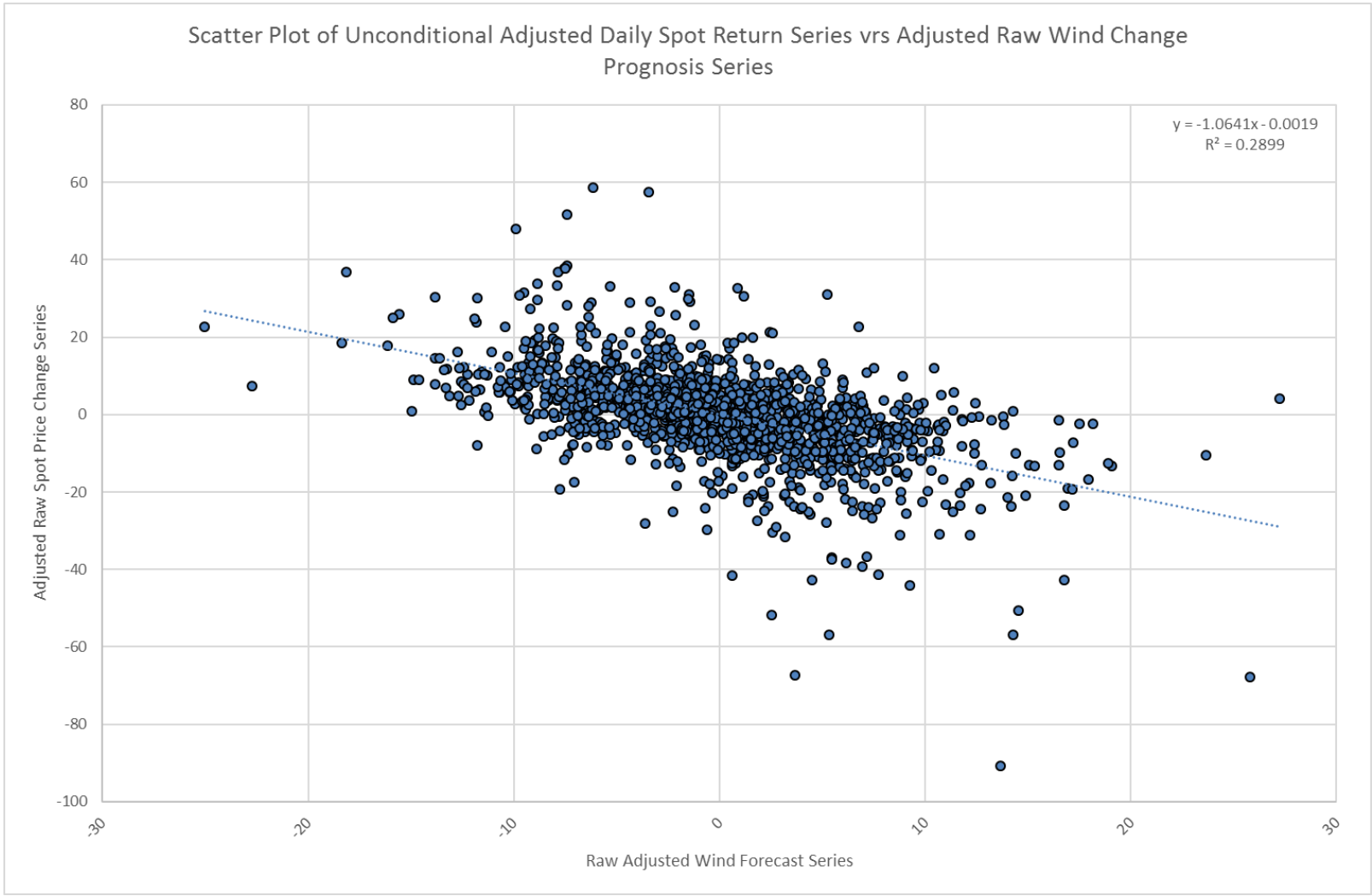




Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

- An unconditional electricity price and wind forecast scatterplot for the Nordic/Baltic Electricity market (NordPool) 2013-2017:



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

The Semi-Non-Parametric Model (SNP) specification is (7,1f,1f,1,4,0,0,0) :

Table 3 Bivariate SNP model: System Price and Wind Forecast Movements

Hermite Polynomials:

Descriptor	theta (q)	std.error	t-statistics
a0[1] 01	0.003650	0.013460	0.271200
a0[2] 02	0.006930	0.045740	0.151410
a0[3] 03	0.020350	0.014580	1.395410
a0[4] 04	0.045730	0.013890	3.293160
a0[5] 10	0.015520	0.013410	1.157010
a0[6] 11	0.075410	0.041690	1.808600
a0[7] 12	0.014110	0.013560	1.040860
a0[8] 13	0.006130	0.014560	0.420890
a0[9] 20	-0.061270	0.031000	-1.976550
a0[10] 21	0.009340	0.014770	0.632550
a0[11] 22	0.074460	0.019310	3.856170
a0[12] 30	-0.035190	0.013160	-2.674140
a0[13] 31	-0.077760	0.015550	-5.000740
a0[14] 40	0.097900	0.017700	5.530400

SNP-model Specification	71f1f14000
Schwarz (BIC) criterion:	2.58437
-2 ln like	-3863.7969
Largest eigenvalue of mean function m	0.8066450
Largest eigenvalue of variance functio	0.9755410

Bivariate Mean Equation:

B(1,1)	-0.08566	0.02711	-3.15912
B(2,1)	-0.07452	0.02662	-2.79971
B(1,2)	-0.03662	0.02054	-1.78293
B(2,2)	-0.16742	0.02761	-6.06407
B(1,3)	-0.19678	0.0241	-8.1656
B(2,3)	-0.12116	0.02451	-4.94372
B(1,4)	-0.0876	0.01883	-4.65134
B(2,4)	-0.27569	0.02522	-10.93305
B(1,5)	-0.1116	0.02619	-4.26184
B(2,5)	-0.0857	0.02535	-3.38087
B(1,6)	-0.06927	0.01936	-3.57859
B(2,6)	-0.17957	0.02536	-7.08009
B(1,7)	-0.10934	0.02412	-4.53263
B(2,7)	-0.08699	0.02546	-3.41674
B(1,8)	-0.04989	0.02081	-2.39682
B(2,8)	-0.15402	0.02552	-6.03628
B(1,9)	-0.07901	0.02403	-3.28807
B(2,9)	-0.02042	0.02467	-0.8276
B(1,10)	-0.00458	0.02076	-0.22045
B(2,10)	-0.11758	0.0251	-4.68487
B(1,11)	-0.00852	0.02236	-0.38124
B(2,11)	-0.04396	0.0251	-1.75105
B(1,12)	-0.07347	0.02028	-3.62268
B(2,12)	-0.07348	0.02289	-3.21028
B(1,13)	0.05547	0.0234	2.3709
B(2,13)	-0.10655	0.02314	-4.60529
B(1,14)	-0.12123	0.01922	-6.30833
B(2,14)	0.01929	0.02336	0.82597

Bivariate Volatility Equation:

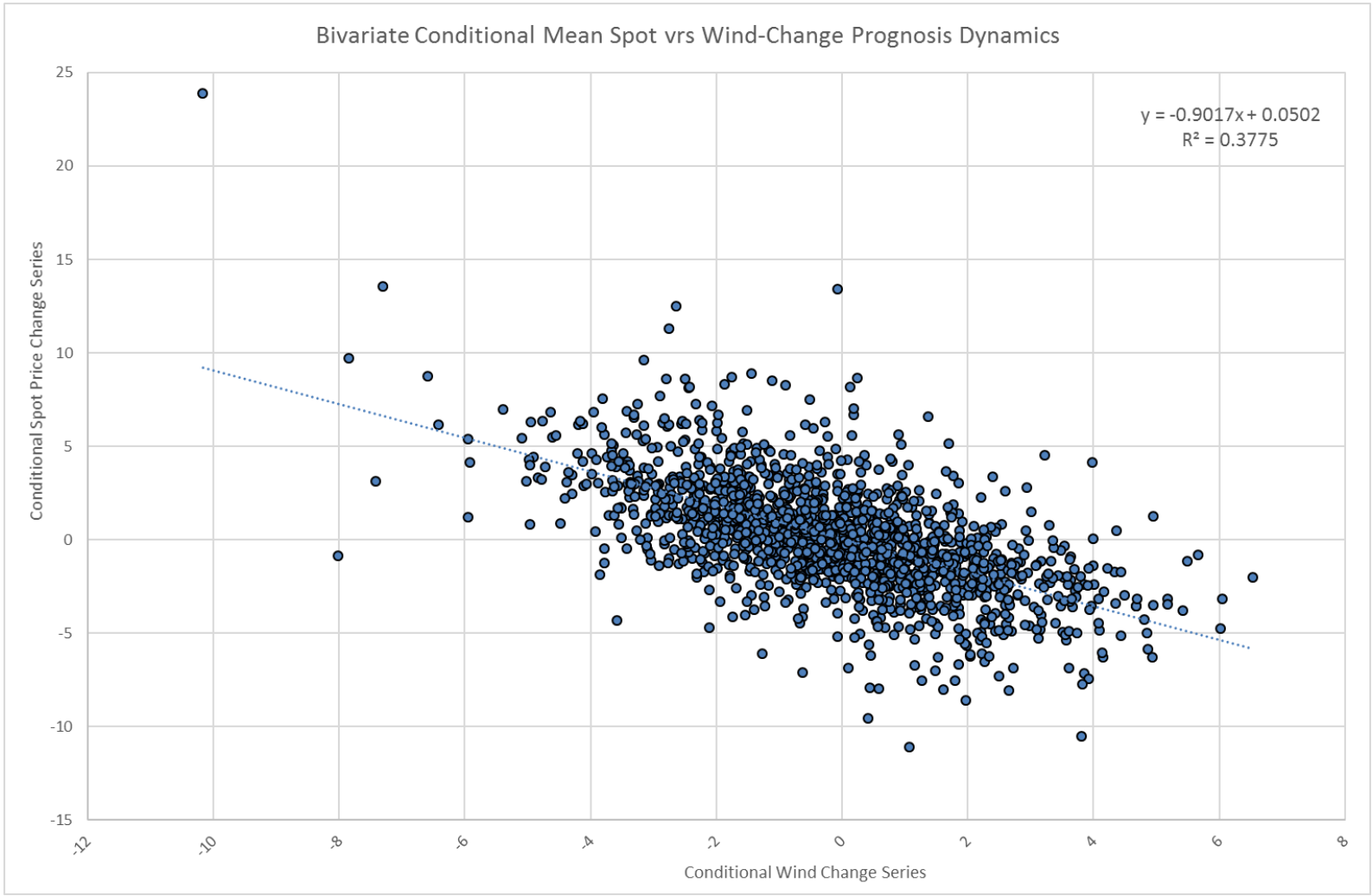
R0[1]	-0.01099	0.26732	-0.04111
R0[2]	0.0472	0.06662	0.70847
R0[3]	0.41671	0.05854	7.11852
P(1,1) f	0.30213	0.03693	8.182
P(2,1) f	0.02454	0.04954	0.49522
P(1,2) f	-0.03601	0.03339	-1.07851
P(2,2) f	0.11589	0.06099	1.9003
Q(1,1) f	0.94536	0.01392	67.92248
Q(2,1) f	-0.06081	0.02073	-2.93342
Q(1,2) f	0.03061	0.02986	1.02518
Q(2,2) f	0.80747	0.04446	18.16252
V(1,1) f	-0.07647	0.12246	-0.62444
V(2,1) f	0.12017	0.06385	1.882
V(1,2) f	-0.08933	0.0582	-1.53472
V(2,2) f	0.40645	0.04965	8.18706
W(1,1) f	0.46589	0.06356	7.32965
W(2,1) f	-0.19548	0.04687	-4.17062
W(1,2) f	-0.2029	0.04856	-4.17829
W(2,2) f	0.06024	0.05947	1.01296

A BIC-optimal bivariate model for the mean and volatility (parametric) and hermite functions (higher order terms) to capture departures from that parametric model.

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

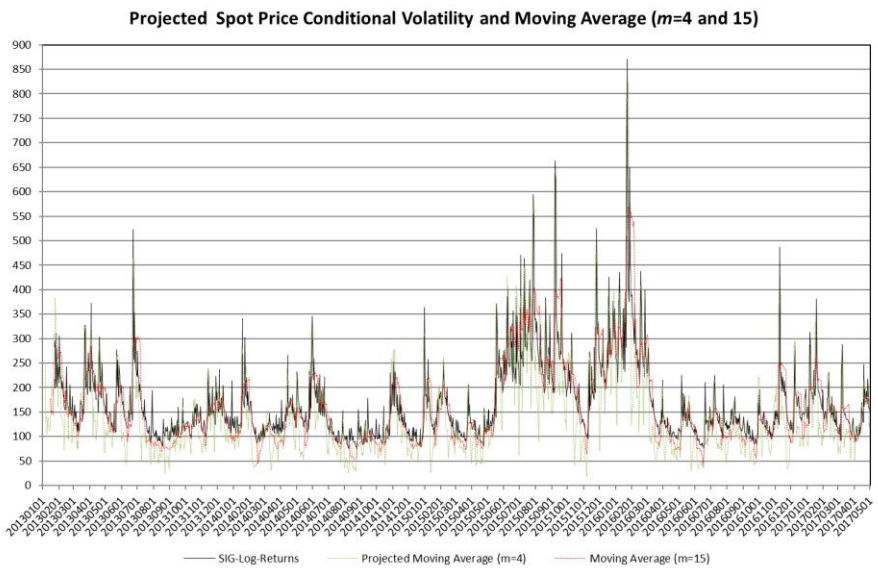
The bivariate SNP Model specification is (7,1f,1f,1,4,0,0,0): A conditional Scatter plot:

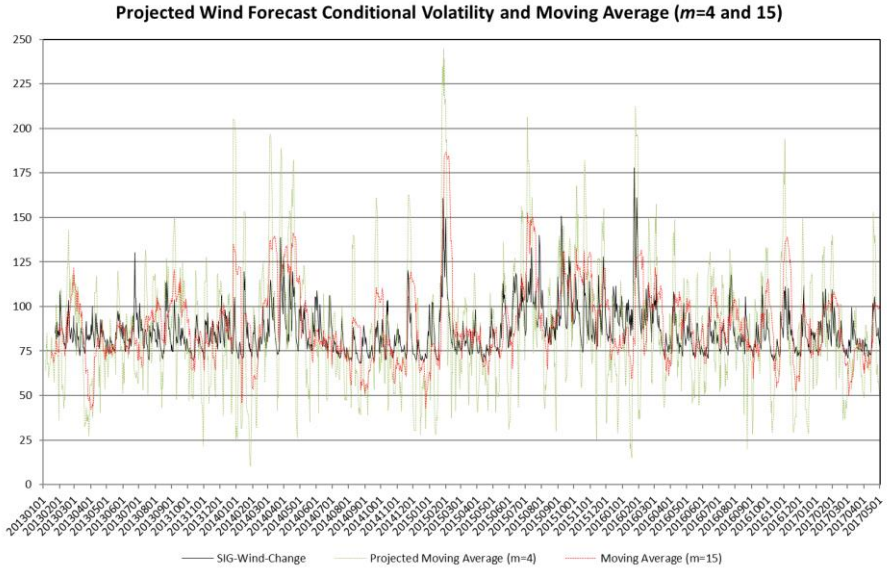


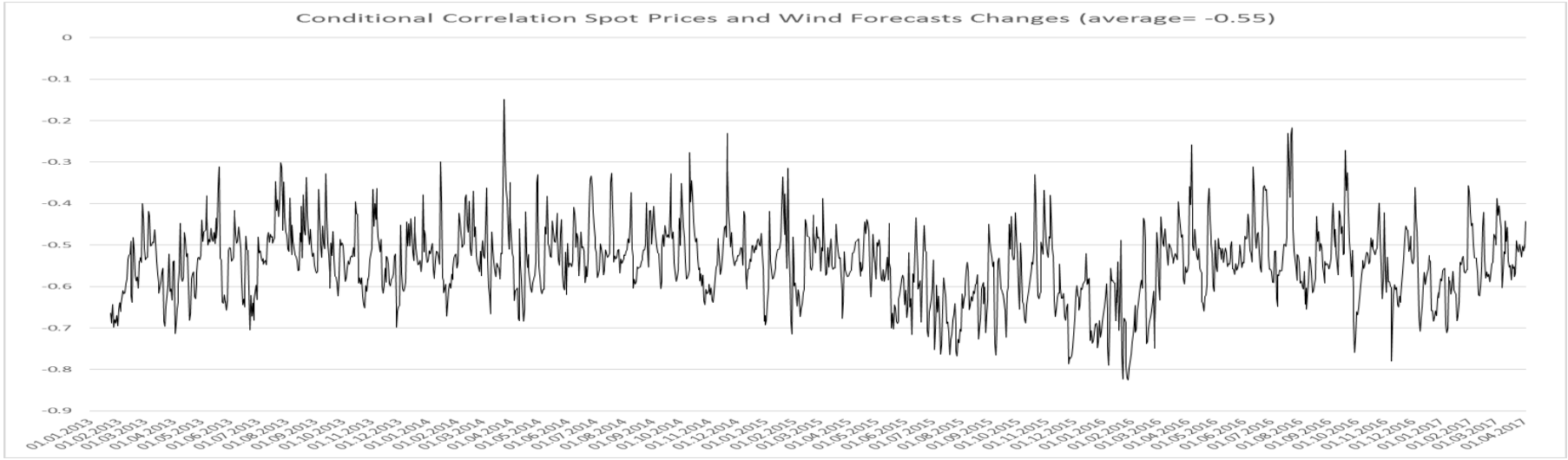
Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

The bivariate SNP Model specification is (7,1f,1f,1,4,0,0,0) properties: Conditional Volatility and Price – Wind Forecast Correlation







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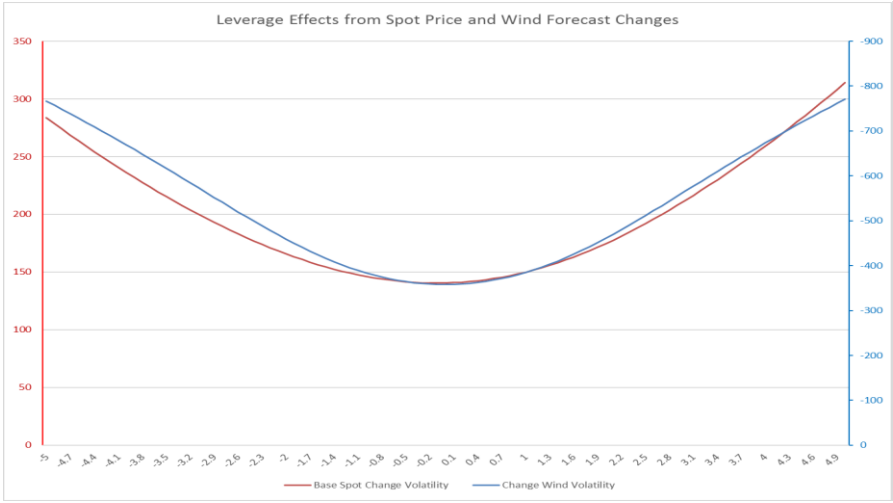
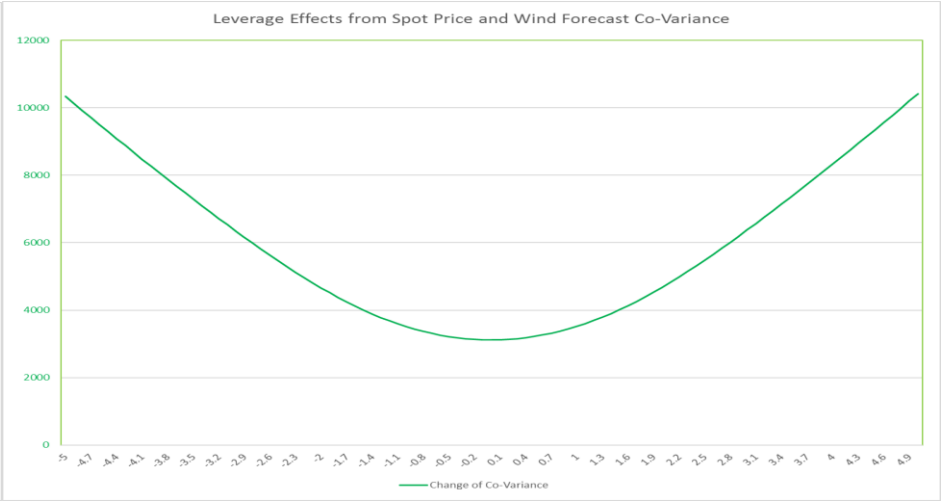
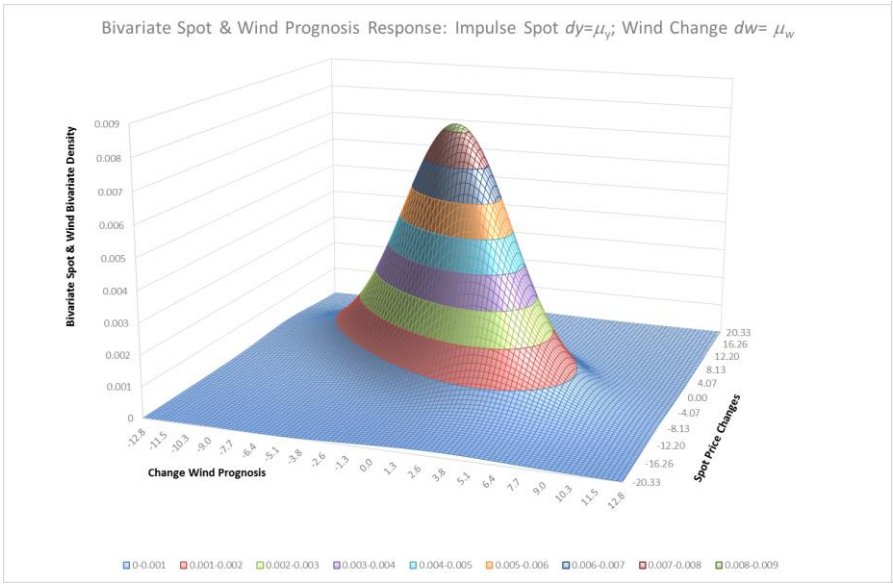
Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

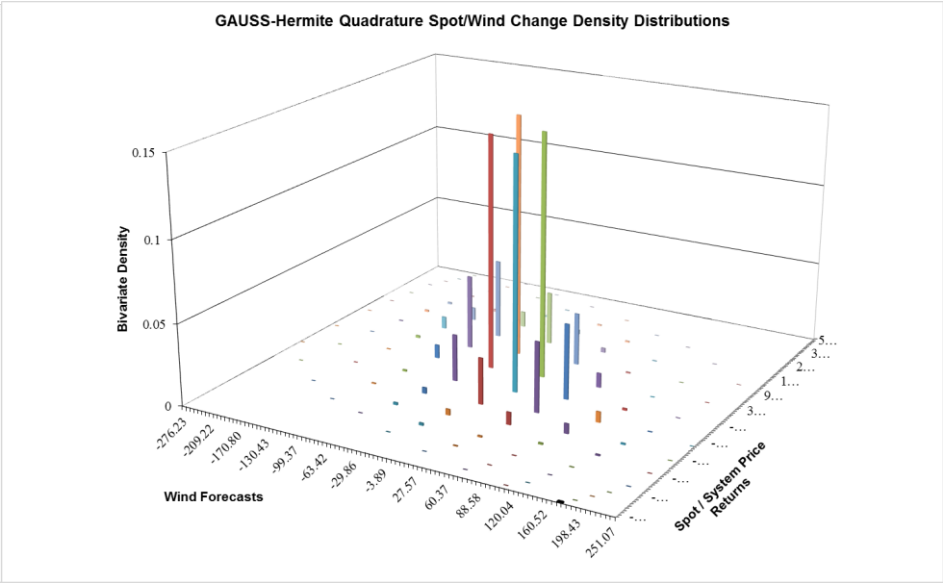
Empirical Model Analysis

The bivariate SNP Model specification is (7,1f,1f,1,4,0,0,0) properties (cont.): Leverage Effects and Bivariate Unconditional Densities





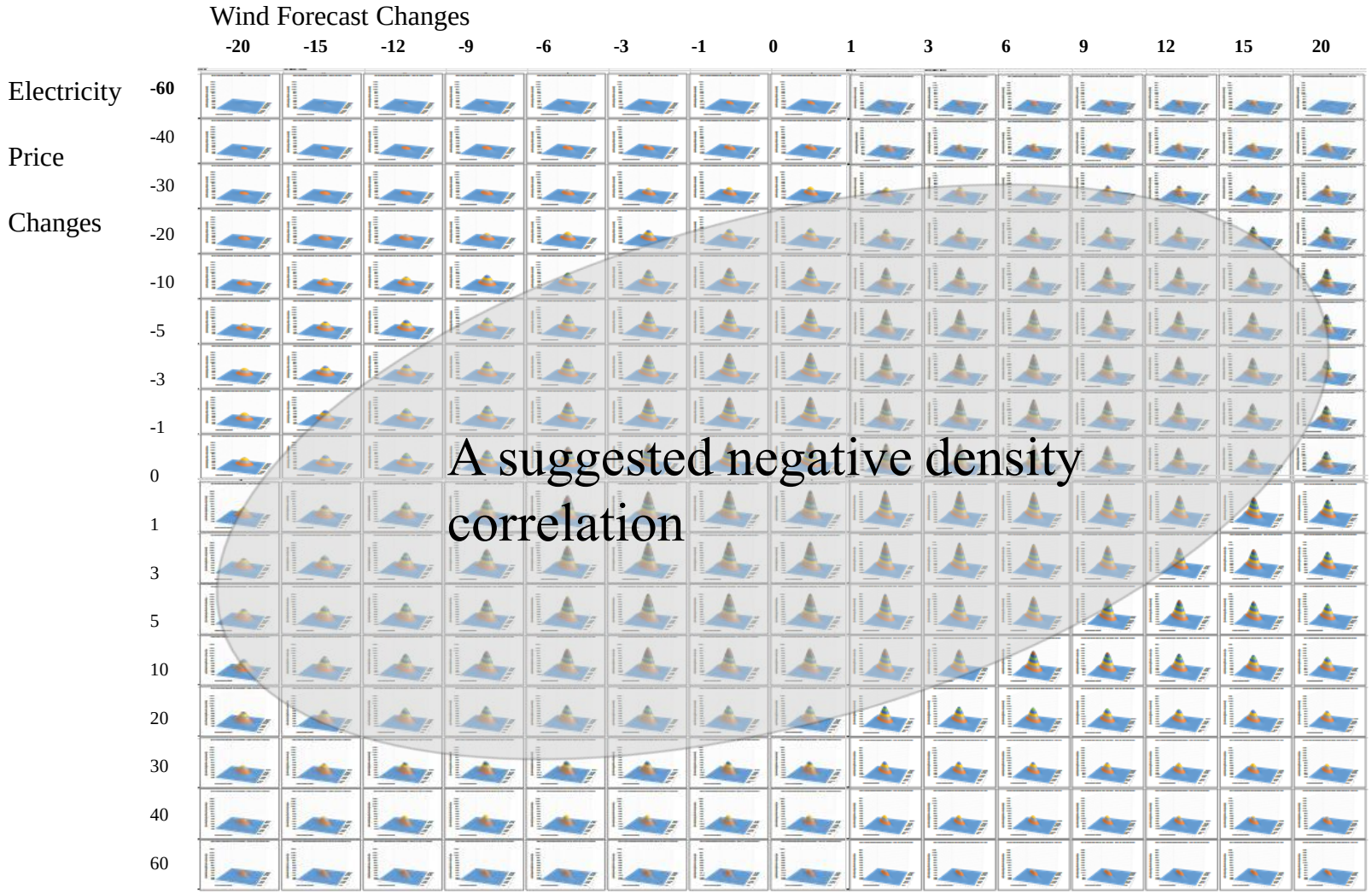




Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Empirical Model Analysis

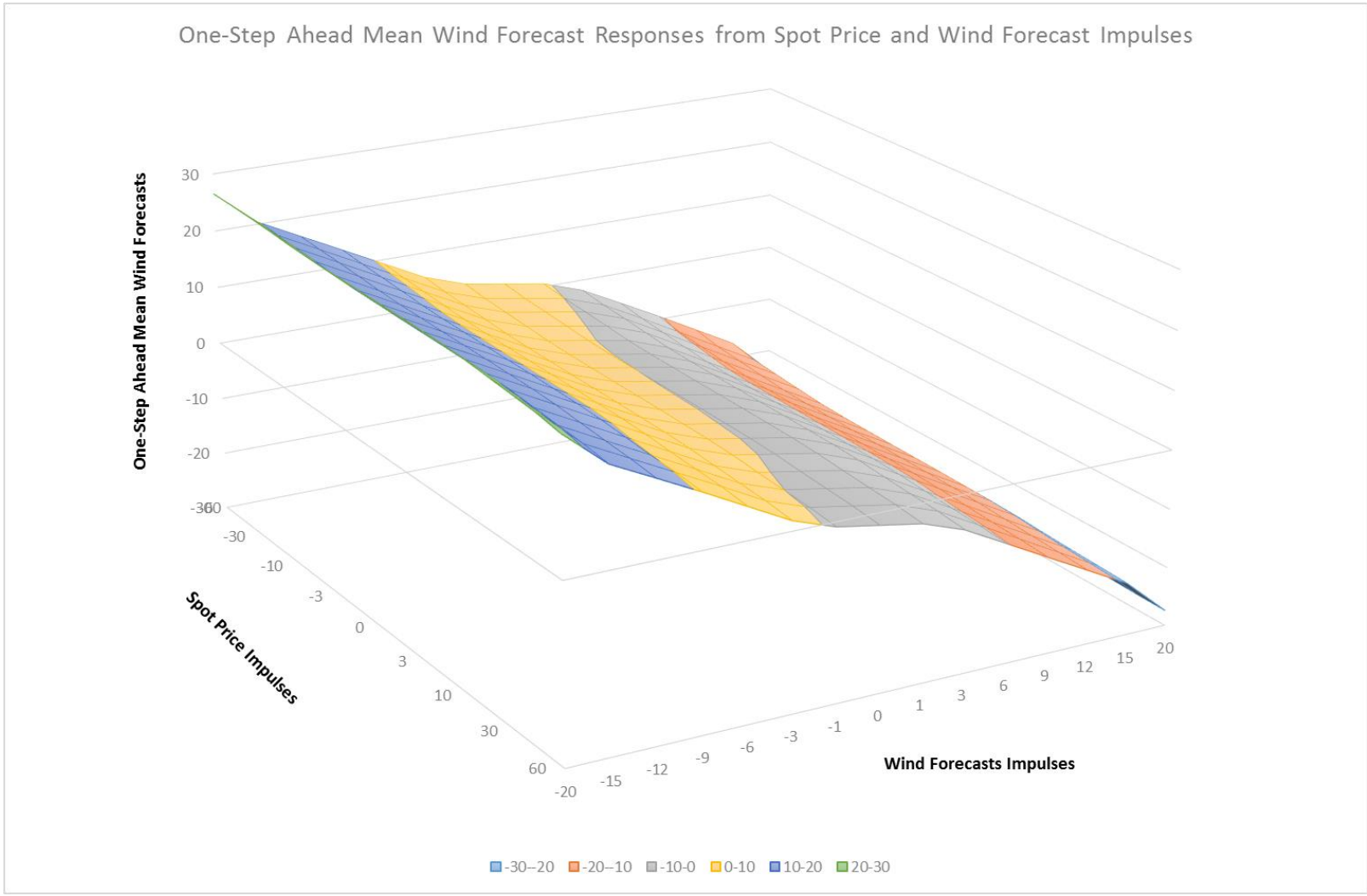
The bivariate SNP Model specification is (7,1f,1f,1,4,0,0,0) properties (cont.): bivariate conditional density plots (matrix)



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

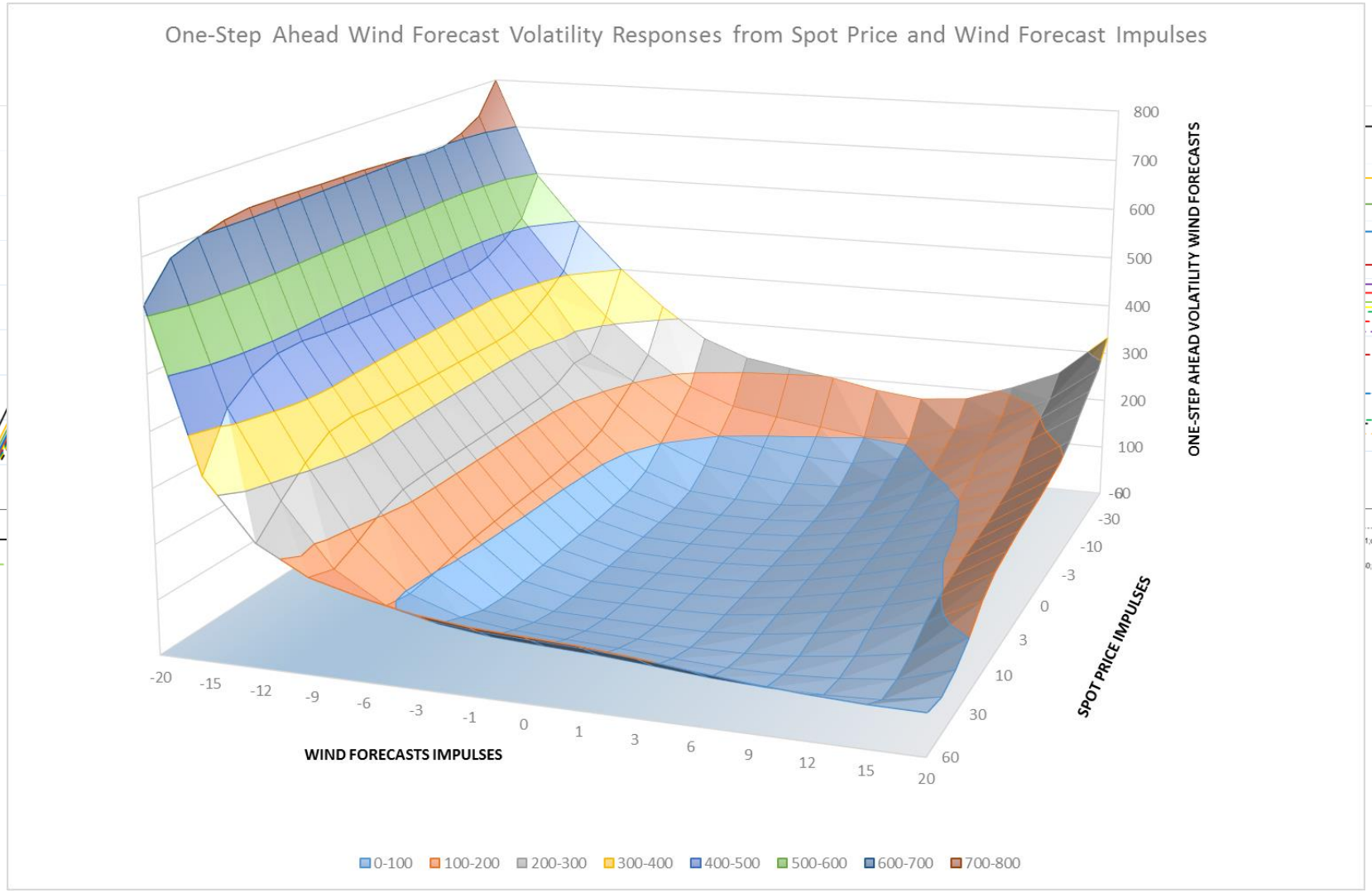
There are NO wind mean responses from spot price changes (important for model acceptance)



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

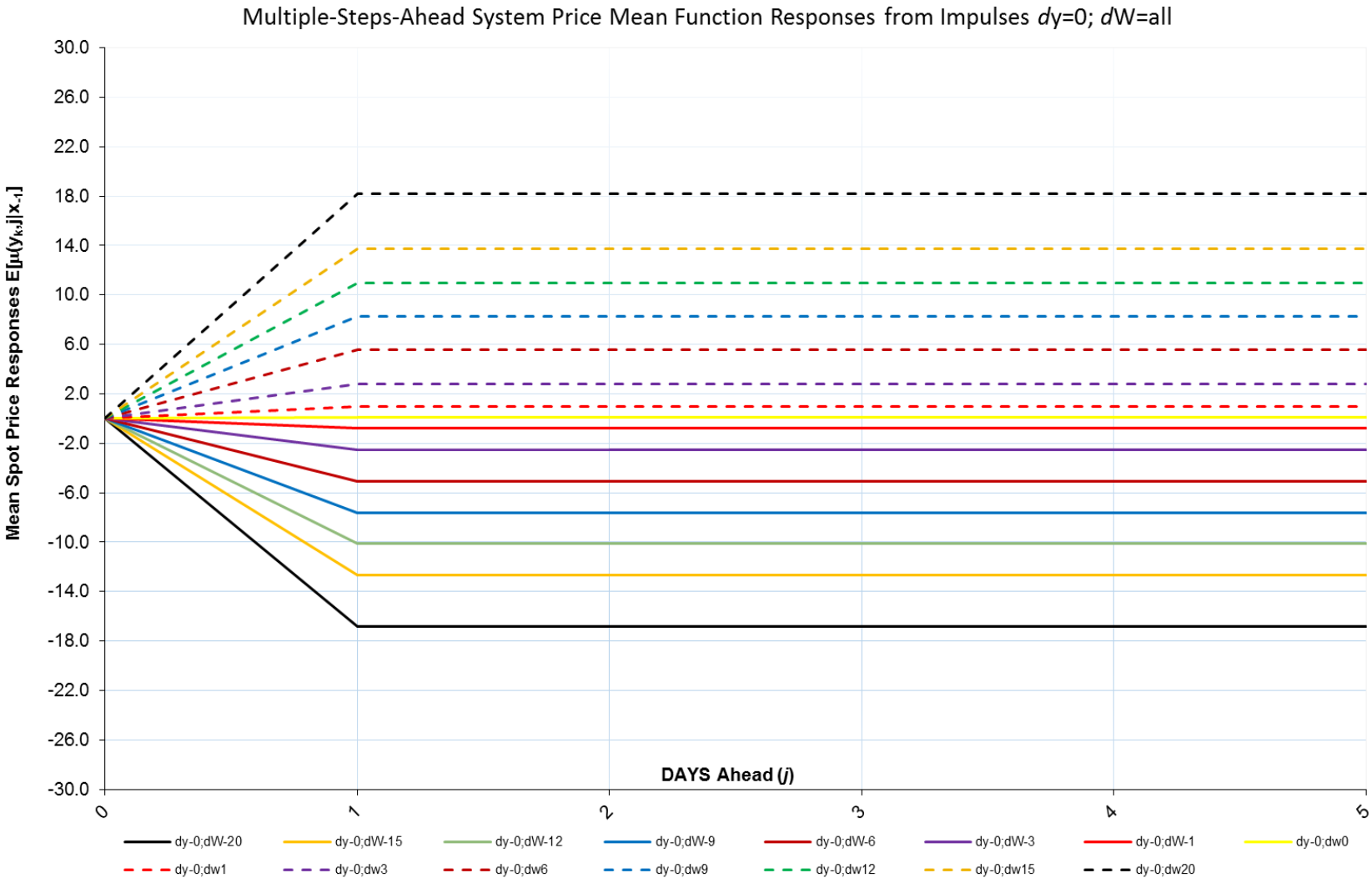
There are NEGLECTIBLE wind variance responses from spot price changes; low wind suggests higher uncertainty around future wind



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

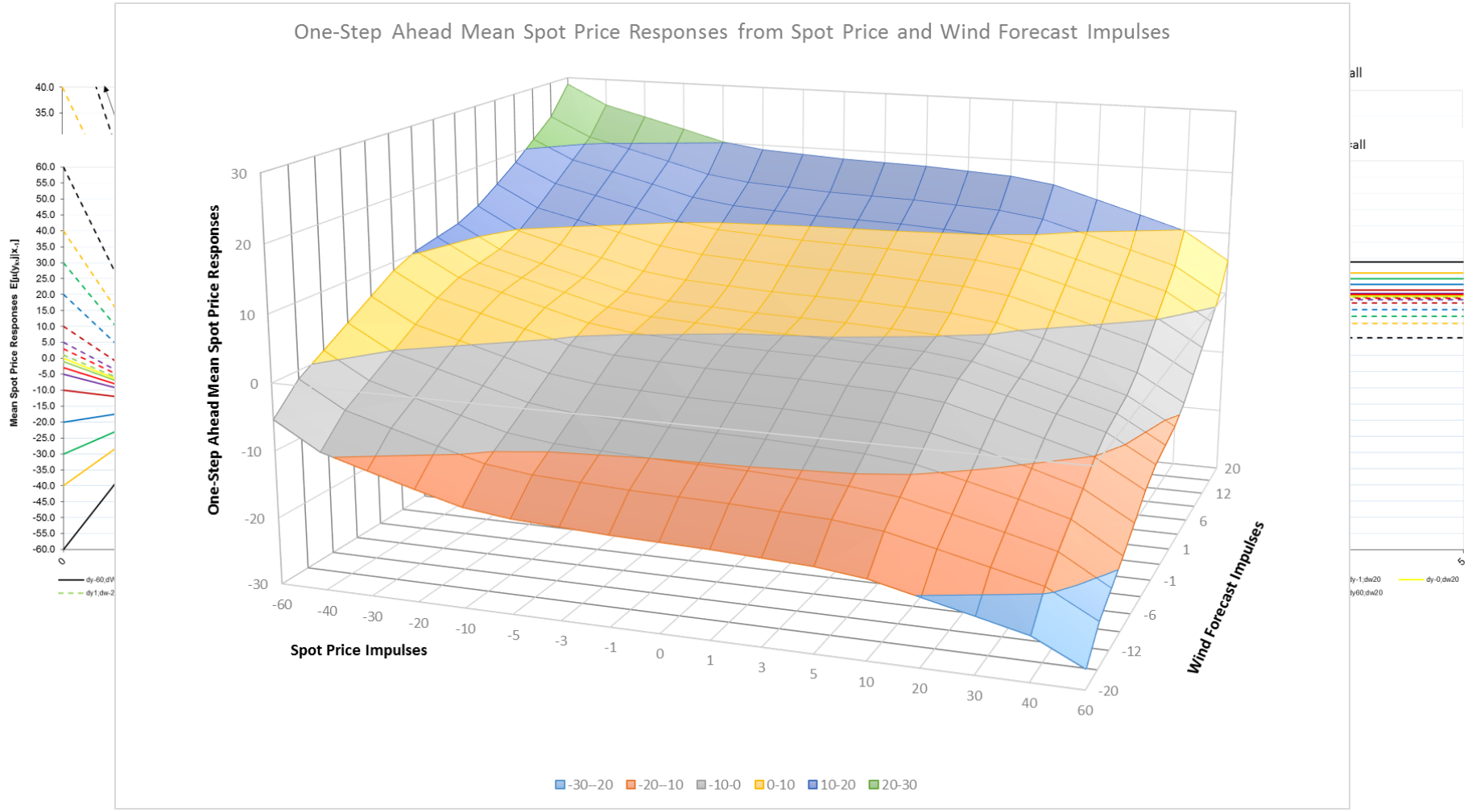
Step-Ahead Spot Price Mean Responses from Spot Price and Wind Forecast Change Impulses:



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

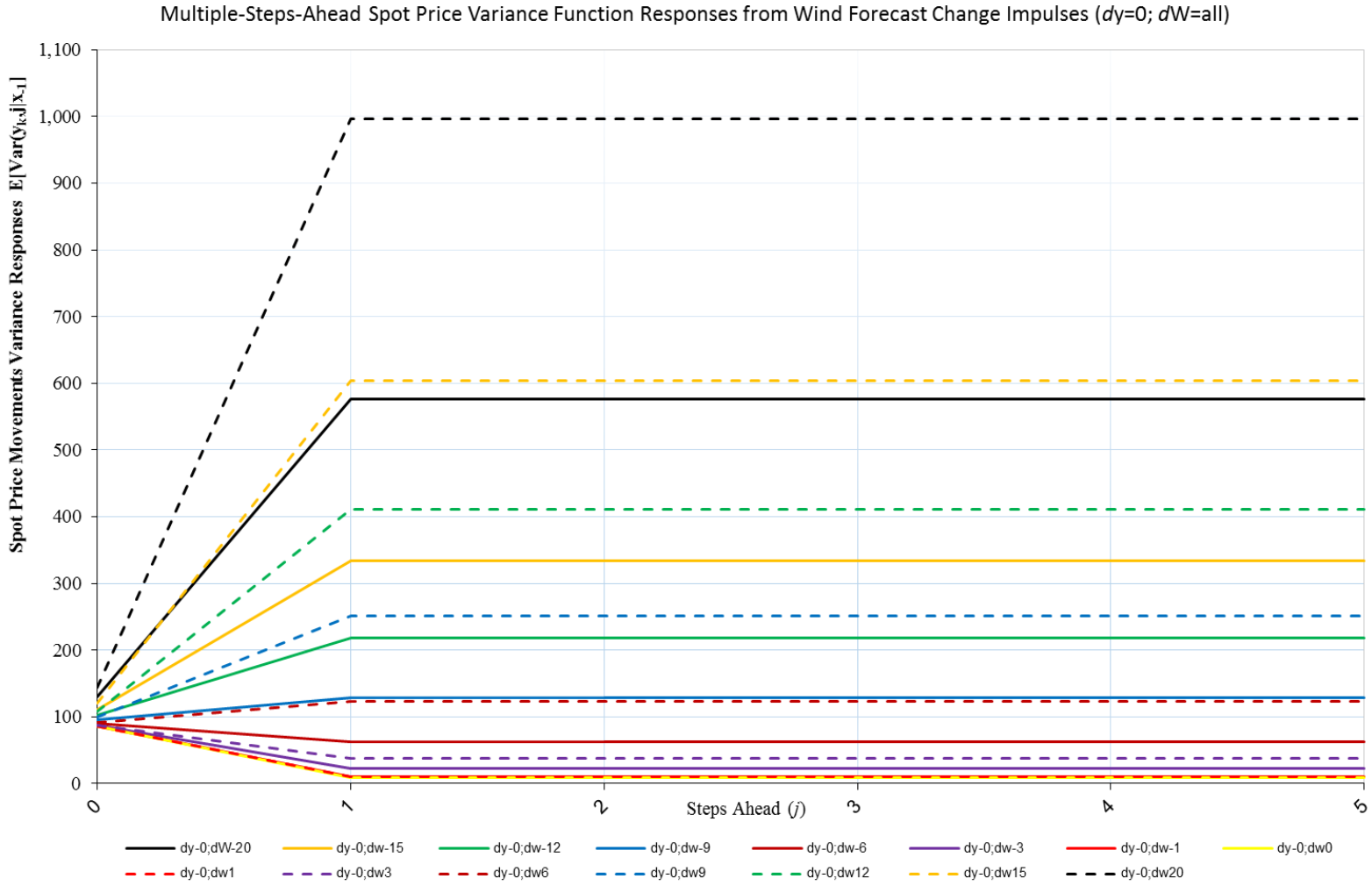
Step-Ahead Spot Price Mean Responses from Spot Price and Wind Forecast Change Impulses:



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

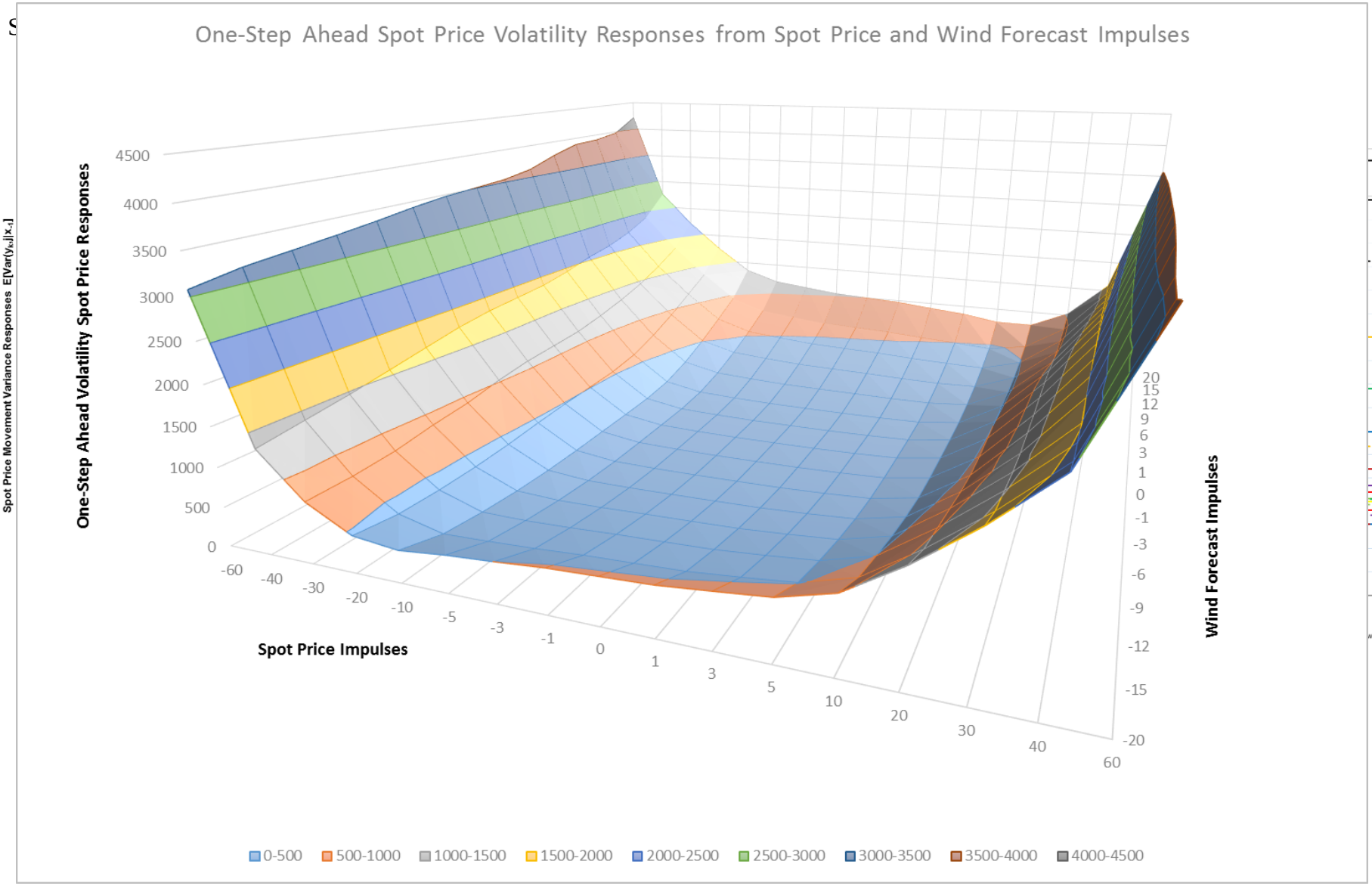
Impulse Response Analysis

Step-Ahead Spot Price Volatility Responses from Spot Price and Wind Forecast Change Impulses:



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

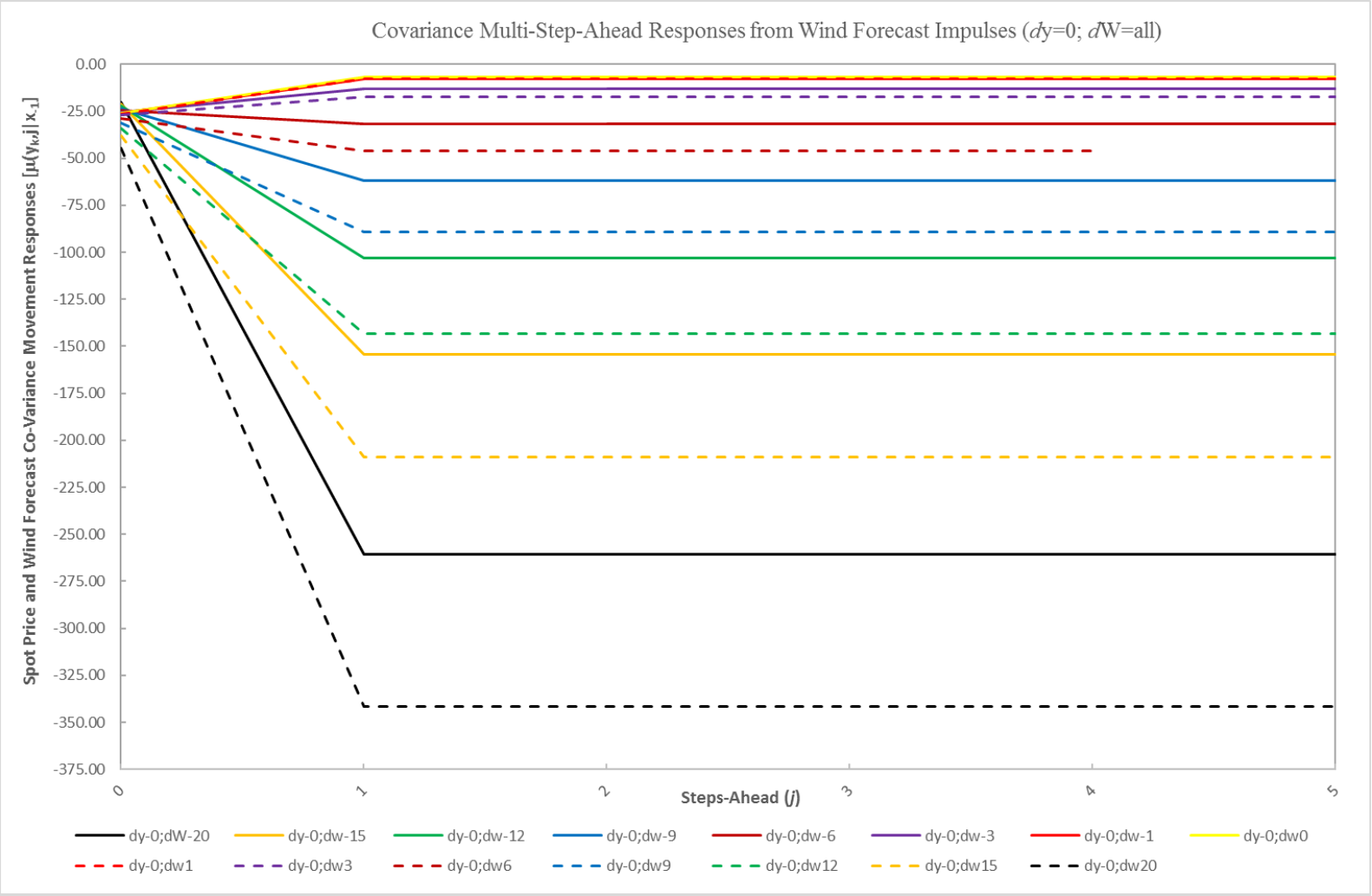
Impulse Response Analysis



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

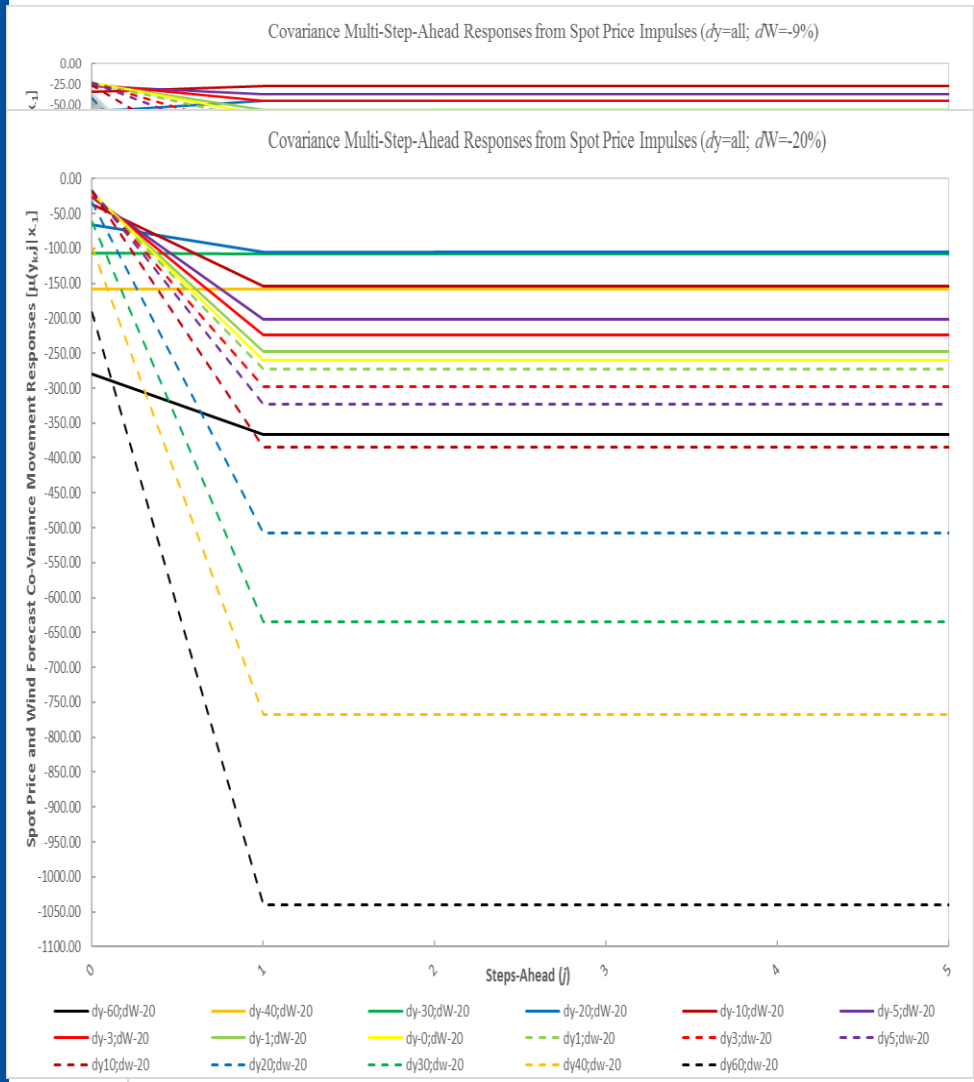
Step-Ahead Spot Price and Wind Forecast Co-variance Responses from Spot Price and Wind Forecast Change Impulses

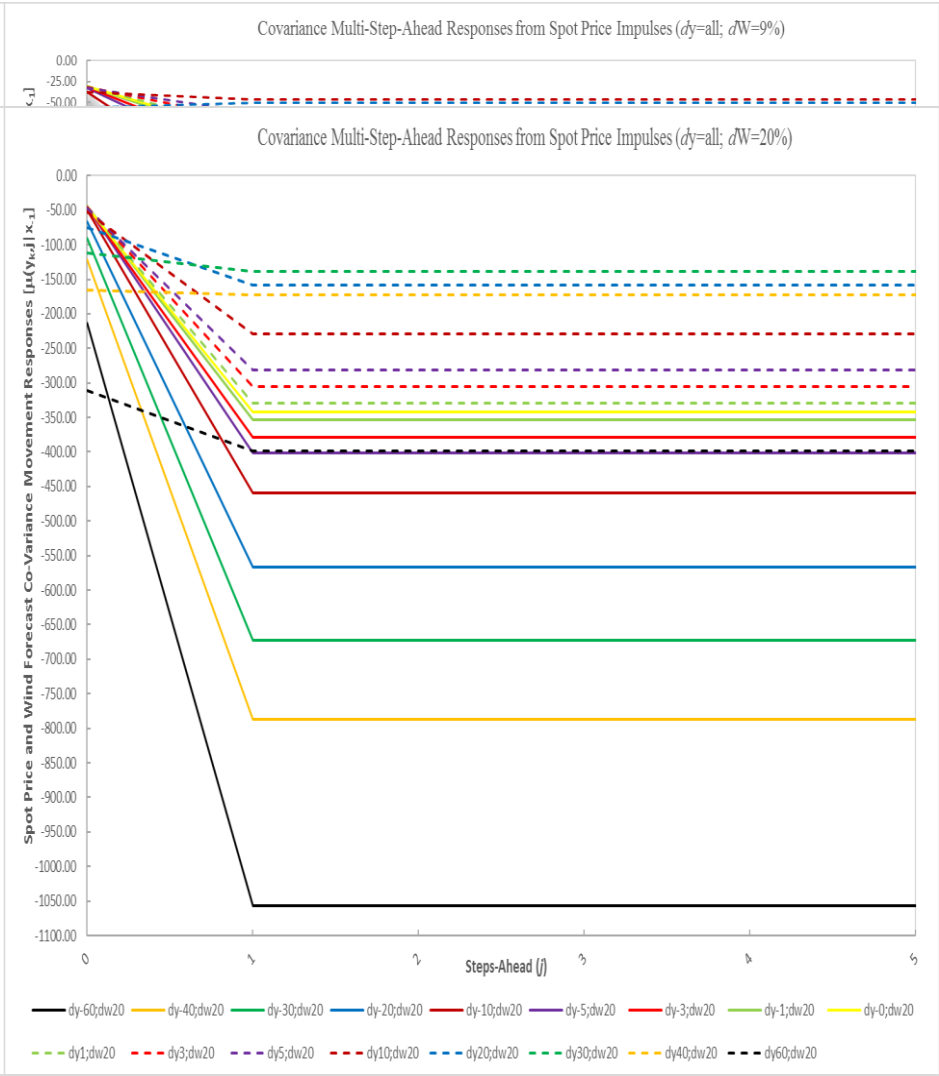


Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

Step-Ahead Spot Price and Wind Forecast Co-variance Responses from Spot Price and Wind Forecast Change Impulses





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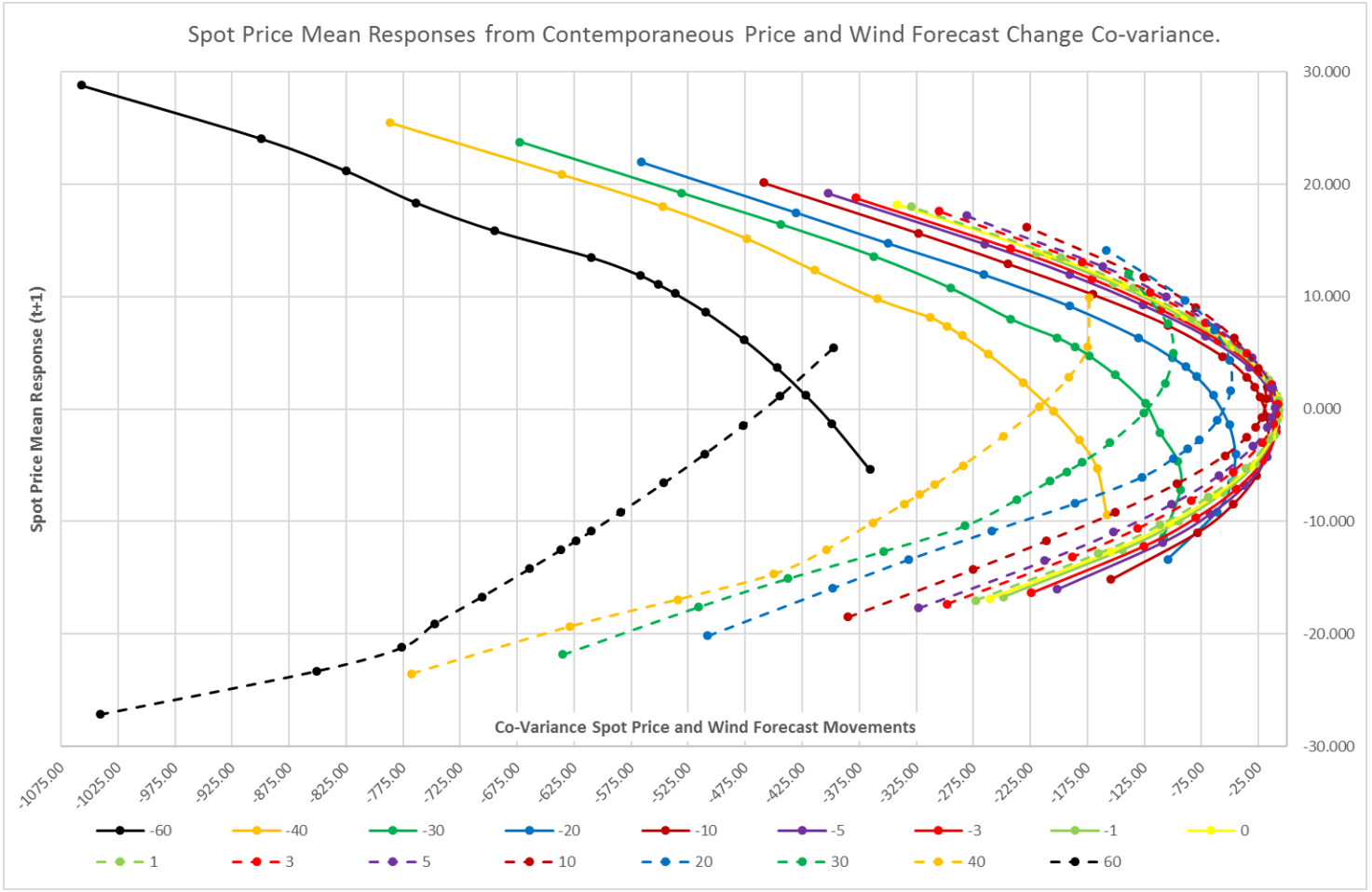
Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

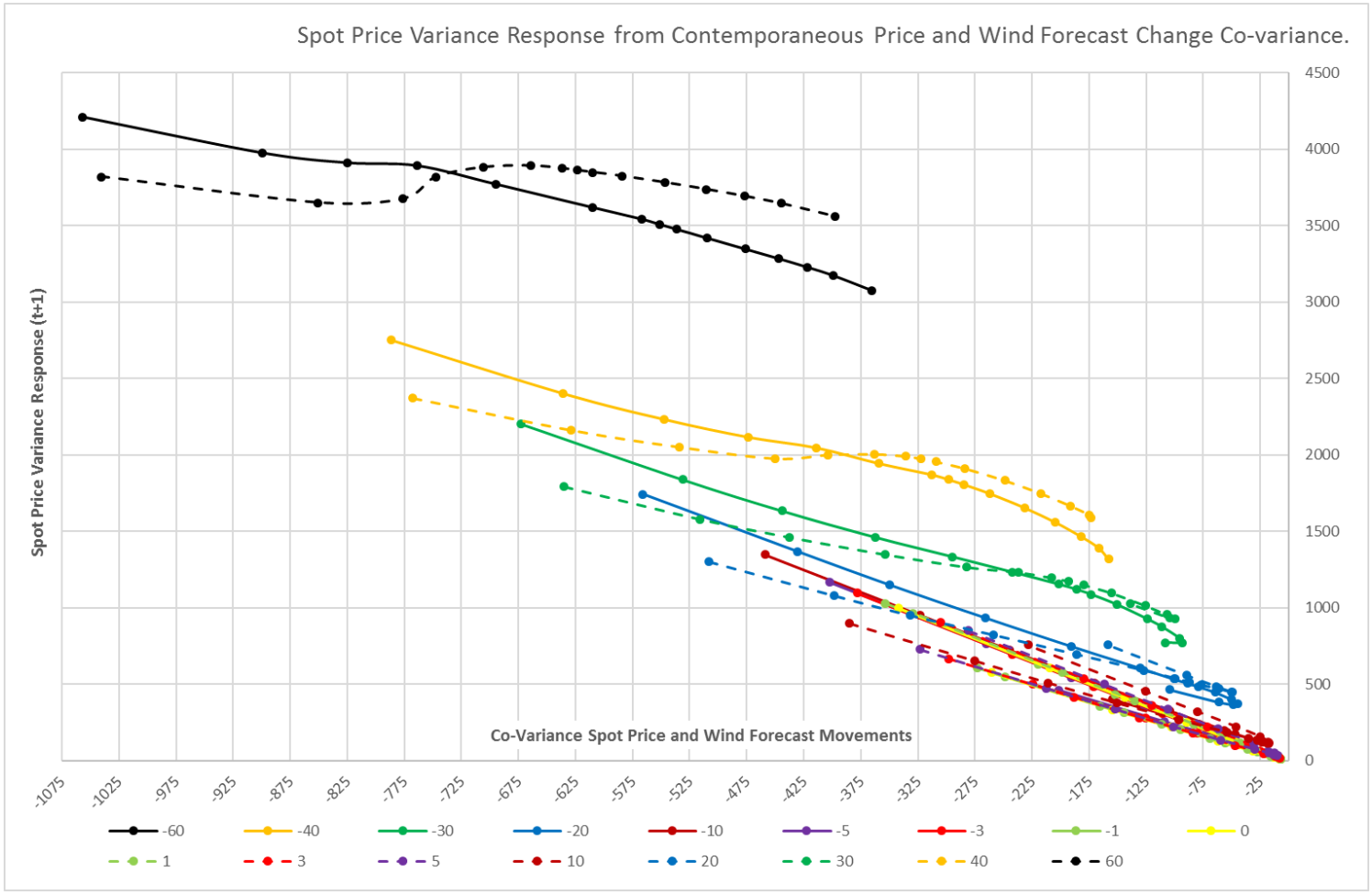
One-step Ahead Spot Price Mean Response Forecasting from Spot Price and Wind Forecast Change Co-variance



Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Impulse Response Analysis

One-step Ahead Spot Price Volatility Response Forecasting from Spot Price and Wind Forecast Change Co-variance



95.8%

Spot Electricity Prices and Wind Forecasts. Dynamic Impulse-Response Analysis

Stationarity and Electricity Market Price and Wind Forecast adjustments

Summary

- A bivariate impulse response analysis for the Baltic/Nordic Electricity system
- The time series analysis requires stationary series using calendar and trend adjustments for interpretations /validity
- A Semi-Non-Parametric model (mean, volatility and higher moments adjustments) is dynamically estimated (daily)
- One-step Ahead spot price and price – wind covariance analysis
- Dynamically sort spot price change and volatility over one-step-ahead covariance
- A methodology for one-step ahead spot, forward/futures and derivatives market positioning.
- Note, variance and co-variance are latent (non-observable). A model is therefore needed for explicit variance/co-variance measures for dynamic market positioning.