UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Does weather explain the Cost and Quality Performance:An Analysis of UK Electricity Distribution Companies

William Yu, Tooraj Jamasb, Michael Pollitt

EPRG Weekly Seminar, May 2008

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Motivation

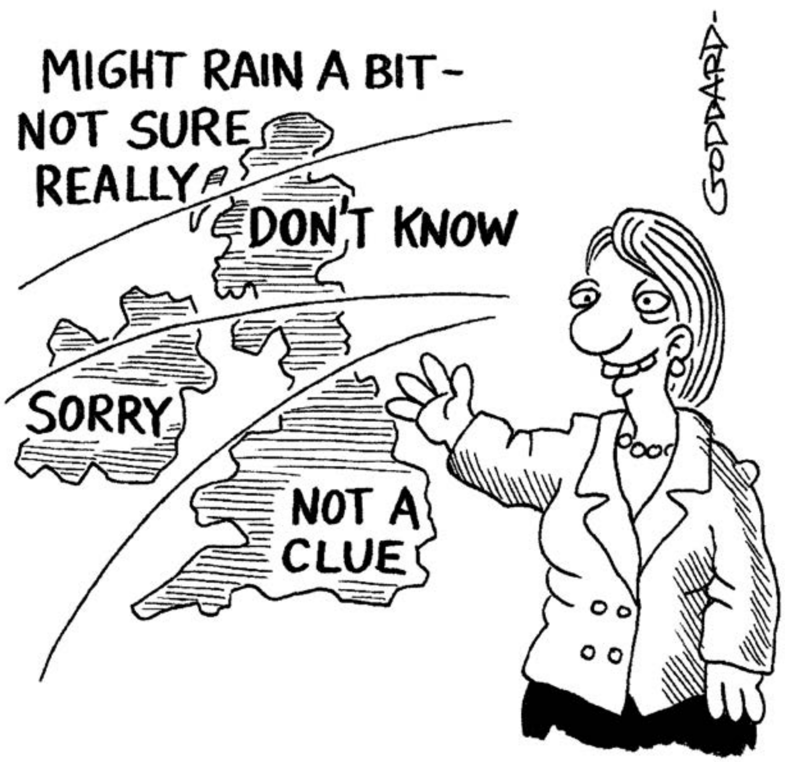
- Current regulatory benchmarking – Ofgem
  - Cost-Only Model
    → Measure DNOs' performance in terms of cost reduction.
  - Ignored the effect of input price differentials on economic efficiency.

- Giannakis et al's study (2005)
  - Cost-Quality Model
    → Some firms perform well in cost model ranked lower in cost-quality model.
    → Ofgem's benchmarking: inadequate to capture the quality aspect.

- Yu et al's study (2007)
  - Cost-Quality-loss Model
    → Measurement of Economic efficiency (Technical * Allocative efficiency) with input price.
    → Mismatch in allocating resources among expenditures, service quality, and energy losses.
    → The utilities may not be correctly incentivised to achieve socially optimal input bundles.

- An extension of Yu et al's study (2008)
  - Cost-Quality-loss-Weather Model
    → Account for the effect of environmental factors such as weather on the utilities' costs and service quality.

Environmental Factor



Honest weather forecasting.

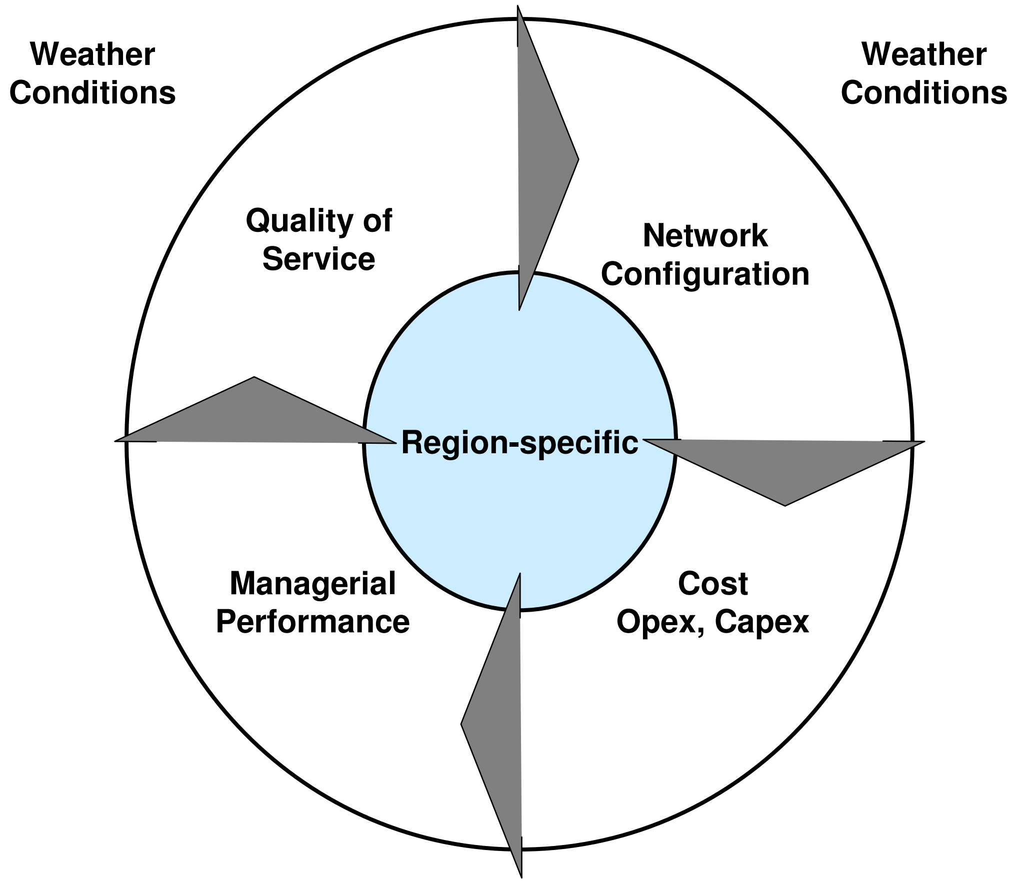
Authorized by cartoonstock.com

- Weather – Non-discretionary variables
- Beyond management control
- Weather-related failures
- Insufficient empirical evidence

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Controllable Vs Uncontrollable Factors



E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Weather–Cost–Quality Matrix

Infrastructure	Capex	Opex	Resistance to Weather impact	Quality Performance
Underground Cables	High	Low	High	High
Overhead lines	Low	High	Low	Low

Climatic Significance

Weather Impact on Quality

- Significant correlation between weather parameters such as rain, wind and temperature and the power interruptions, Coelho,(2003); Dornijan,(2003).
- In adverse weather conditions, the failure rate of a component can be considerably larger than that in the normal condition, Billinton,(1984).
- Either very low or very high temperature leads to the maximum usage of power
  - → placing heavy load on the transformers.
  - → the impact of higher temperature on transformer failure interruptions is more significant than that of lower temperatures, Dornijan,(2003).

Weather-related Power Outages

Aggregate Weather Effects

- Increased importance of 'combined weather variables for utilities' decisions with respect to their operating environment, Hackney (2003)

  → combined effects of weather conditions

Weather/Tree-related Power Outages

- Distribution lines: threatened by weather primarily through falling or breaking trees
- Heavy rainfall combined with high winds

  → might damage primary systems: feeders, laterals, oil circuit breakers

  → soften the soil: ↑ likelihood of trees being uprooted by the strong winds (E.g. Supply interruption following Boxing Day in 1998)

Current Research

- 12 DNOs in the U.K.

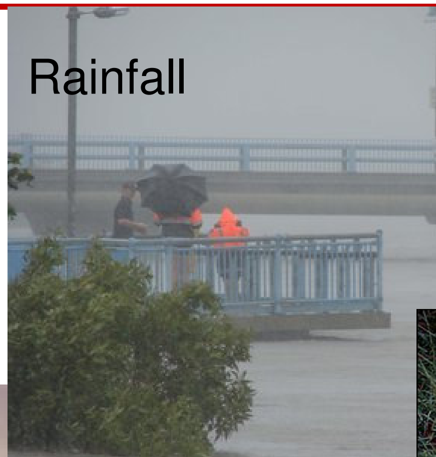
- Methodology : Exploratory Factor Analysis (EFA);
  Multi-stage Data Envelopment Analysis (DEA)

- Technical & Economic Efficiency Measurement

- Benchmarking Model	: Cost-Quality-Loss-Weather model
- Quality dimension	: Customer Minutes Lost (CML)
- Cost dimension	: Totex, Opex
- Other dimension	: Energy Loss,
- Environmental dimension	: 9 weather parameters (Normal weather conditions)
- Input price factors	: WTP, Electricity price
- Dataset	: 1995/96 to 2003/04 (9 years of data)

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

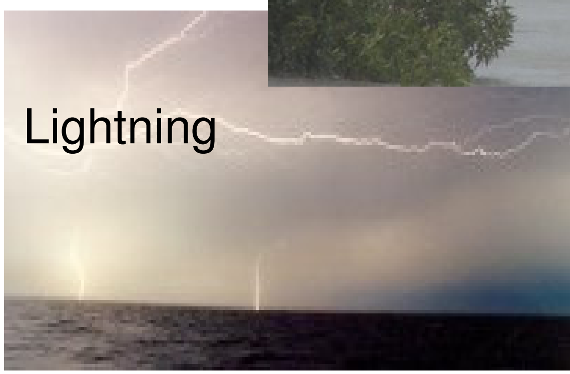
Rainfall



Hail

Ground Frost

Lightning



Min / Max Temp

Concrete Temperature

Air Frost

Gale

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Weather Parameters

Weather Composite variables

- 2 MET observation stations to represent each DNO (source: U.K. MET office).
- Some weather parameters not available for London and CN West → 2 DNOs excluded.
- Construct composite variables to represent 9 weather parameters.

Individual Weather parameters

TMAX	**Max. Temp.**	Maximum air temperature (degrees C).
TMIN	**Min. Temp.**	Minimum air temperature (degrees C).
TOTRN	**Ttl Rainfall**	Total rainfall (mm).
DHAIL	**Hail**	Number of days when hail fell (00-24 GMT) ie. solid precipitation (of which outer parts are clear ice) with a diameter 5mm or more.
DTHND	**Thunder**	Number of days when thunder was heard (00-24 GMT).
DAIRF	**AirFrost**	Number of days when minimum air temperature was below zero degrees C.
DGRSF	**GroundFrost**	Number of days when minimum grass temperature was below zero degrees C.
DCNCF	**Concrete Temp**	Number of days when minimum concrete temperature was below zero degrees C.
DGALE	**Gale**	Number of days when mean wind speed over any 10 minute period reached 34 knots or more (Force 8) (00-24 GMT).

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Yearly Avg. Data – Weather Parameters

Yearly Average	Max. Temp.	Min. Temp.	Ttl Rainfall	Hail	Thunder	AirFrost	GroundFrost	Concrete Temp	Gale
	Degree C	*Degree C*	*mm*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
EDF - EPN	23.15	0.33	661.35	1.55	19.84	48.17	90.59	62.64	2.96
CN East	22.13	1.05	670.67	1.10	16.26	37.17	88.41	68.64	1.48
SP Manweb	20.62	1.40	760.43	0.72	7.55	39.38	89.06	47.52	14.07
CE - NEDL	20.06	-0.57	788.12	1.93	8.36	56.52	109.28	75.00	2.59
UU	21.07	0.79	1155.41	3.56	14.11	36.00	76.89	51.67	0.67
EDF - SPN	22.84	1.69	740.86	2.22	17.86	27.71	73.42	46.28	2.82
SSE - Southern	23.10	0.63	848.59	0.56	11.05	50.43	100.19	66.44	1.84
WPD S Wales	20.00	2.42	977.17	8.24	7.62	19.83	55.75	38.85	24.27
WPD S West	20.20	3.54	1026.25	0.58	8.69	11.72	54.81	31.69	8.81
CE - YEDL	20.79	1.35	629.21	0.40	5.73	21.46	65.66	35.44	7.20
SSE - Hydro	17.73	-0.10	973.83	3.58	4.09	53.13	117.01	79.22	16.78
SP Distribution	19.07	-0.28	1199.15	2.41	5.39	64.22	126.18	95.44	3.62

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Exploratory Factor Analysis (EFA)

- Variable reduction technique.
- Estimates factor (underlying latent construct) which influences responses on measured variables (9 weather parameters).
- Factors account for common variance in the data.
- Include unreliability due to measurement error.

Principal Component Analysis (PCA)

- Variable reduction technique.
- Makes no distinction between common and unique variance.
- Consider total variance.
- Assumes the absence of outliers in the data.

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

EFA – Factor Extraction

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	3.73756	1.82643	0.6215	0.6
2	1.91113	1.44308	0.3178	**0.9**
3	0.46805	0.07982	0.0778	1.0

- Eigenvalues: indicate the amount of variance explained by each factor.
- Eigenvalue > 1
- 2 Factors retained
  → explain 94% of variation
- Varimax Rotation

Results of Barlett factor scoring

Weather Parameters	Factor I Score Coefficient	Factor II Score Coefficient
MaxTemp (℃)	-0.05904	-0.37193
MinTemp (℃)	-0.23366	0.03888
TtlRainfall (day)	-0.0248	0.31742
Hail (day)	-0.05639	0.29188
Thunder (day)	-0.09252	-0.32773
Airfrost (day)	0.25303	0.02233
Groundfrost (day)	0.25693	0.05034
ConcreteTemp (day)	0.2539	0.04499
Gale (day)	-0.07844	0.30018

– Weather composite variable_1 (Factor I):
0.05904(MaxTemp)−0.23366(MinTemp)−0.0248 (TtlRainfall)−0.05639(Hail)−0.09252(Thunder)+0.25303(Airfrost)+0.25693(Groundfrost)+0.2539(ConTemp)−0.07844(Gale)

– Weather composite variable_2 (Factor II):
0.37193(MaxTemp)−0.03888(MinTemp)+0.31742 (TtlRainfall)+0.29188(Hail)−0.32773(Thunder)+0.02233(Airfrost)+0.05034(Groundfrost)+0.04499(ConTemp)+0.30018(Gale)

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Multi-Stage DEA

- 2-stage method
  - 1st stage: DEA using traditional input & output
  - 2nd stage: the efficiency score (1st stage) are regressed upon the environmental variables.
  - Tobit regression method is used.

- The second stage regression
  - Tobit regression

$$Y^* = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \mu$$

$$Y = Y^* \quad for \quad Y^* > 0$$

$$Y = 0 \quad for \quad Y^* \leq 0$$

- (Weather index I and II) and $\beta 1$ and $\beta 2$ are regression coefficients.
- The error term μ is assumed to be normally distributed i.e. μ ~N (0, σ 2).

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Model specifications – input/output

Model	1	2	3	4	5	6
Inputs						
OPEX	√	√		√		
TOTEX			√		√	√
CML		√	√	√	√	√
ENGY LOSS		√	√	√	√	√
Input price						
1 (TOTEX)				√	√	√
WTP (CML)				√	√	√
ENGY PRICE(LOSS)				√	√	√
Output						
CUST NO. (CN)	√	√	√	√	√	√
ENGY DEL (ED)	√	√	√	√	√	√
NETL (NL)	√	√	√	√	√	
Efficiency						
	TE	TE	TE	EE	EE	EE

OPEX: *Operating expenditure*
TOTEX: *Total expenditure*
CML: *Duration of interruptions*
ENGY LOSS: *Energy physical loss*
WTP: *Willingness-to-pay*
ENGY PRICE: *Energy Price*
CUST: *Total number of customers*
NETL: *Total network length*
ENGY DELV: *Energy delivered*
TE: *Technical efficiency*
EE: *Economic efficiency*

Average technical and economic efficiency scores (Model 1-6)

Cost/ Cost-Quality-Loss Model 1995/96-2003/04	M1 Opex Only TE	M2 Opex-CML-Loss TE	M3 Totex-CML-Loss TE	M4 Opex-CML-Loss EE	M5 Totex-CML-Loss EE	M6 Totex-CML-Loss Drop NL EE
EDF – EPN	0.84	0.99	1.00	0.84	0.93	0.90
CN East	0.55	0.94	0.99	0.67	0.79	0.77
SP Manweb	0.64	0.94	0.96	0.89	0.90	0.86
CE – NEDL	0.56	0.93	0.94	0.68	0.80	0.78
UU	0.67	1.00	1.00	0.83	0.88	0.88
EDF – SPN	0.73	0.91	0.94	0.72	0.87	0.88
SSE - Southern	0.93	0.96	0.99	0.89	0.91	0.91
WPD S Wales	0.52	0.87	0.86	0.52	0.60	0.57
WPD S West	0.77	0.98	0.98	0.90	0.94	0.78
CE YEDL	0.71	1.00	1.00	0.93	0.97	0.99
SSE – Hydro	0.88	1.00	1.00	0.87	0.93	0.50
SP Distribution	0.74	0.89	0.95	0.78	0.81	0.71
Sector Average	**0.71**	**0.95**	**0.97**	**0.80**	**0.86**	**0.80**
Weather Composite*	**Significant**	insignificant	insignificant	insignificant	**Significant**	**Significant**

Summary of Tobit regression results of 6 models

Model No.	Input	Output	DEA result	DEA Score Sector Average	Weather composite *
Model 1	Opex	CN, ED, NL	TE	0.71	Significant (wI)
Model 2	Opex-CML-Loss	CN, ED, NL	TE	0.95	not significant
Model 3	Totex-CML-Loss	CN, ED, NL	TE	0.97	not significant
Model 4	Opex-CML-Loss	CN, ED, NL	EE	0.80	not significant
Model 5	Totex-CML-Loss	CN, ED, NL	EE	0.86	Significant (wII)
Model 6	Totex-CML-Loss	CN, ED	EE	0.80	Significant (wI,wII)

wI: Weather Index I; wII: Weather Index II
** Tobit regression*

Analysis

Technical Efficiency (TE)

– Weather composite variables show significance to simple cost model (M1 – Model Opex)
→ Opex relative efficiency are affected by the weather variables

– Weather effect drops out in more comprehensive model (M2 – Model Opex-CML-Loss; M3 – Model Totex-CML-Loss).

Economic Efficiency (EE)

– Comprehensive model is significant (M6 – Totex-CML-Loss) when network length as output is excluded

→ Network length is correlated with the weather effect.

→ Network length per unit of input is higher in worse weather DNOs and hence the network length output is counteracting the weather effect.

– Weather composite variables show significance to M5 Model Totex-CML-Loss but not M4 Opex-CML-Loss.

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Tobit regression – Individual weather parameters and Opex DEA

Opex_DEA	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
MaxTemp	0.0216359	0.0157794	1.37	0.173	-0.00967	0.052946
MinTemp	0.0265975	0.0270312	0.98	0.328	-0.02704	0.080233
TtlRainfall	0.0001253	0.0001056	1.19	0.238	-8.4E-05	0.000335
Hail	-0.0149549	0.0091481	-1.63	0.105	-0.03311	0.003197
Thunder	-0.0030895	0.0044049	-0.7	0.485	-0.01183	0.005651
Airfrost	0.0064577	0.0029302	2.2	0.030	0.000644	0.012272
Groundfrost	0.0034928	0.0023349	1.5	0.138	-0.00114	0.008126
ConcreteTemp	-0.005717	0.0025871	-2.21	0.029	-0.01085	-0.00058
Gale	0.0009786	0.0031124	0.31	0.754	-0.0052	0.007154
_cons	-0.0277535	0.4224417	-0.07	0.948	-0.86597	0.810462
_se	0.1887842	0.014513	(Ancillary	parameter)		

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Average weather conditions

Tobit Regression

- correct the efficiency scores for environmental factor.
- use the estimated regression coefficients* to adjust all efficiency scores to correspond to a common level of environment (e.g. the sample means).

* Model 4: β1 (-0.001936) for weather index I ; β2 (0.0009696) for weather index II

Size of adjustment on efficiency score

- To what extent does the weather variable affects the efficiency scores?
- Percentage of adjustment
  - Highest: 12.3%
  - Lowest: -26.1%
  - For some models, the adjustment is significant
  - The ranking has changed
  - For most of the firms, the adjustment is not significant

Magnitude of Weather Impact on efficiency Scores

M1: Model Opex - TE

1995-2003	DEA Score	Weather_1	Weather_2	diff. WI	diff. WII	Adjusted Magnitude	Adjusted %	Adjusted DEA Score
EDF – EPN	0.84	31.37	204.62	9.04	-70.82	0.02	2.8%	0.86
CN East	0.55	29.68	208.50	7.35	-66.94	0.02	3.4%	0.57
SP Manweb	0.64	22.67	243.22	0.34	-32.22	0.00	0.1%	0.64
CE – NEDL	0.56	39.74	251.42	17.41	-24.02	0.04	**8.0%**	0.60
UU	0.67	10.34	362.55	-11.99	87.11	-0.03	-4.6%	0.64
EDF – SPN	0.73	15.51	228.77	-6.82	-46.67	-0.02	-2.4%	0.71
SSE – Southern	0.93	31.62	267.05	9.29	-8.39	0.02	2.6%	0.95
WPD S Wales	0.52	0.15	315.02	-22.17	39.58	-0.06	**-11.0%**	0.46
WPD S West	0.77	-3.91	322.79	-26.23	47.35	-0.07	-8.7%	0.70
CE YEDL	0.71	13.04	197.82	-9.29	-77.62	-0.02	-3.4%	0.69
SSE – Hydro	0.88	36.55	317.89	14.22	42.45	0.04	4.2%	0.92
SP Distribution	0.74	41.18	385.63	18.85	110.19	0.05	6.5%	0.79
Sector Average	**0.71**	**22.33**	**275.44**				**-0.21%**	

[1] WI, WII: each weather index is subtracted from average weather and adjusted based on β1 (0.002568) for weather index I

Magnitude of Weather Impact on efficiency Scores

Model 1, 5,6

Model	M1	M5	M6
Average DEA Score	0.71	0.86	0.80
Significance	Weather I	Weather II	Weather I & II
Max Adjustment (%)	8.0%	4.8%	12.3%
Min Adjustment (%)	-11.0%	-7.6%	-26.1%
Avg Adjustment (%)	-0.21%	-0.13%	-1.10%

* *Tobit regression*

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Conclusions

- There is statistical significance between weather and cost and quality.
- The economic significance is small on average.
  - → Weather can have a significant impact on the economic efficiency in some models.
- U.K. weather does not vary enough to make a difference.
- DNO is not in a disadvantaged position in light of the impact brought by the weather conditions.
- Ofgem Model: Network length as output
  - → handling the effect on weather
- Weather composite variables: Better representation
  - → A mixed picture of individual weather parameters (Tobit regression)
  - → Individual weather parameters: insignificant with DEA scores

UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

Q & A

Thank you

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL