Institution: Newcastle University

Unit of Assessment: 10

Title of case study: Forecasting Gas Demand

Period when the underpinning research was undertaken: 2014-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Dr Sarah Heaps	Senior Lecturer in Statistics	2012-present
Dr Kevin Wilson	Senior Lecturer in Statistics	2015-present
Dr Malcolm Farrow	Senior Lecturer in Statistics	2005-2019

Period when the claimed impact occurred: 2015-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

A mathematical sciences research team at Newcastle University has developed and implemented an original Bayesian statistics forecasting solution for gas demand within Northern Gas Networks (NGN), **impacting upon 2.7 million homes and businesses.** The research has delivered economic, operational and educational impact over a large geographical scale within the gas distribution sector.

Specifically, the research has corroborated impact in:

i) **Reducing gas bookings by 16%**, resulting in **capacity savings of over £1M per annum**;
ii) Maintaining reputation and **avoiding charges of £1M per day** during extreme weather conditions;
iii) Optimising network inspection planning, **avoiding wasted expenditure**;
iv) **Mitigating gas storage errors**, maintaining system balance and supply;
v) **Increasing understanding and education** within the gas distribution sector.

2. Underpinning research (indicative maximum 500 words)

Background

NGN deliver gas to 2.7 million homes and businesses throughout Northumberland, Northern Cumbria, Tyne & Wear, County Durham, and Yorkshire. NGN supply gas from local sites (offtakes) connected to the national network. They have a requirement to accurately forecast gas demand annually, daily and hourly. The energy sector in the UK and globally is changing to accommodate greener technologies in line with growing economic, environmental and public health concerns. Operational efficiency and decision-making can be enhanced through the improved forecasting of gas demand – the core objective of this research project.

Historically, NGN used information from Xoserve, the central service data provider for the UK's gas market, to inform demand predictions. In 2014, NGN selected Newcastle University (NU) as a research collaborator and contributed funding [G1] **to deliver a more independent, robust, and specific solution and improve the accuracy of the predictions [E1].** NU was chosen for

their experience in delivering statistics-based solutions within the energy sector, and their academic expertise in modelling time-dependent data.

The research challenge

Gas demand is primarily influenced by weather and work-life patterns [P1]. There are annual and weekly periodic effects and there is a need to nest short term daily predictions within fixed annual forecasts. Public holidays have a pronounced effect on demand, typically leading to an increase in household usage but a decrease in business use. This effect often spreads into neighbouring days, referred to as a proximity effect. Traditionally, in gas demand modelling, the days over which the proximity effect occur are pre-specified in fixed windows around each holiday. This is an inflexible approach as it relies on an arbitrary decision about the existence, size and position of the windows.

[P1] describes the Newcastle development of a fully Bayesian approach to the forecasting problem. The modelling assumed a non-homogeneous hidden Markov model, whose states account for normal, holiday and prior- and post-holiday proximity effects, and a state-dependent vector autogression for demand, with seasonal and day-of-week terms and non-linear effects of a time-varying composite weather variable. Apart from holidays themselves, which are observed, duration in the other states is hidden. This was modelled as a Markov process with time-varying transition probabilities depending upon the time intervals from the most recent public holiday and to the next one, and also on the particular holiday type, with Christmas, Easter and other holidays allowed to have different effects. Time-varying precision matrices were modelled using the Cholesky decomposition approach developed for a related non-homogeneous hierarchical Markov model used by Heaps, Boys and Farrow for spatio-temporal rainfall prediction [P2]. Priors were given careful attention and Hamiltonian Monte Carlo applied for estimation. The model was calibrated using high dimensional daily demand data collected over 9 years from each of the two NGN sub-regions: the North and the North East.

Improved forecasting

An evaluation of model accuracy (predictions vs. actual data), pre-Newcastle University research and post-Newcastle University research, has demonstrated a **significant improvement in accuracy of 10%** (in the mean absolute daily forecast error) in the North East region and **13%** in the North region [E2]. Another improvement was that the posterior distribution for the states demonstrated different patterns in the identification of proximity days between different public holidays and across different types of customers. This highlights the advantage of not fixing (allowing uncertainty in) the identification of proximity days, superior to the traditional, inflexible approach described previously [P1][P3].

The Newcastle approach to forecasting provides probabilistic distributions. This provides quantifiable uncertainty (a probabilistic range) in the forecasts, rather than simple point forecasts which have limited value.

Another feature of the modelling is forecast stability, meaning that small changes in either input covariates or in parameter values do not lead to large changes in forecast distributions. This is important in long-term forecasting, where failure to enforce stability can lead to volatile or oscillating forecasts with ever-increasing variances.

Bi-annual research implementation

The modelling and data analysis produce parameter estimates which are used for future demand forecasting. These parameter values are now bi-annually updated by NGN and embedded within their operational processes to provide a more robust, ten-year prediction at a daily level.

3. References to the research (indicative maximum of six references)

Publications

[P1] Heaps, S.E., Farrow, M. and Wilson, K.J. (2020) *Identifying the effect of public holidays on daily demand for gas*. Journal of the Royal Statistical Society: Series A, 183(2), 471-492. doi.org/10.1111/rssa.12504

[P2] Heaps S.E., Boys R.J., Farrow M. (2015). *Bayesian modelling of rainfall data by using non-homogeneous hidden Markov models and latent Gaussian variables.* Journal of the Royal Statistical Society: Series C (Applied Statistics) 64(3), 543-568. doi.org/10.1111/rssc.12094

[P3] Wilson K.J., Heaps S.E. and Farrow M. (2016). *Demand forecasting over complex geographical networks: the case of Northern Gas Networks*. In: 26th European Safety and Reliability Conference. Glasgow: CRC Press. doi.org/10.1201/9781315374987-66

Grant

[G1] NGN funding to develop the research methodology (£42K).

4. Details of the impact (indicative maximum 750 words)

The statistical research by Newcastle University has delivered economic, operational, and educational **impact on a large geographical scale**.

"There have been three implementations of the research within our systems in 2015, 2017 and 2019." [E1]. The next application is due in the first quarter of 2021. The bi-annual implementations have ***"…demonstrated a significant improvement in accuracy of 10% in the North East region and 13% in the North region"*** [E2], allowing the network to operate more efficiently and prevent costs [E1]. NGN documentation, outlining operating processes, includes details of the statistical methodology embedded within NGN's forecasting activities [E3, E4]

Impact on capacity bookings

The gas demand forecasts produced by the Newcastle University research team have impacted upon gas bookings. **NGN has reduced actual gas capacity bookings by 16%**, year-by-year, from 612 GWh/day to 514 GWh/day, to match the statistical forecasts [E1]. *"Avoiding paying for gas that is not used has resulted in **reduced capacity costs of over £1M**."* [E1]. This reduction has enabled NGN to release capacity back to National Grid which can then be allocated to other customers.

Impact during challenging periods including extreme weather

The research methodology has been robust during challenging periods, such as unseasonable weather, changeable weather and bank holiday weekends which **enables NGN to avoid charges of £1m per day** [E1].

In 2018, the effects of the "Beast from the East" https://www.bbc.co.uk/news/world-europe-43218229 were mitigated as a result of the statistical research. During the commencement of this unseasonable weather, NGN increased their maximum day forecast using the holiday factors. Failure to apply the increase would have resulted in NGN under-forecasting the North East local distribution zone maximum day estimate. The unadjusted forecast was 245 GWh/day, the increased maximum prediction using the holiday factors (Newcastle research) was 258 GWh/day. The actual gas demand on the 1st March 2018 was 254 GWh/day. NGN booked their gas capacity in line with the Newcastle research-estimated maximum day demand. If NGN had

not increased their estimated peak demand and gas capacity being allocated accordingly, overrun charges would have occurred.

"…we have used more accurate and precise forecasts to…ii) avoid charges during operationally challenging periods such as extreme weather e.g. ***overrun charges of £1M*** *could occur on one date alone if a repeat of the 2018 Beast from the East occurred under the new pricing structure".* [E1].

Impact on gas network inspection planning

The statistical research has had a direct influence on scheduling cost-effective pipeline inspection and *"…**avoiding wasted expenditure."*** [E1]. The research has allowed NGN to identify the optimum times of year to plan and launch pipeline inspections and conduct inline assessments. A more accurate understanding of the demand at a nuanced, daily level has allowed this to occur. Without accurate forecasts, inspection activities would be sub-optimally executed resulting in wasted expenditure - confidentiality prevents the presentation of financial cost savings.

Impact on gas storage errors

Through more accurate forecasts, the "…***research has mitigate(d) gas storage errors, maintaining system balance."*** [E1]. Over-forecasts and under-forecasts lead to problems within the regional storage system which can lead to detrimental impacts on the national UK storage position. This can result in less efficient systems, unavailability of resources, higher costs and reduced flexibility for the UK energy system. Underestimating or overestimating demand can impact upon the quantity of carbon gas entering the system from facilities such as bio-methane plants, and hydrogen blending facilities. The effects of over- and under-forecasting have been reduced by the Newcastle research, though it is difficult to estimate a direct quantitative improvement.

Impact on understanding & education: greater confidence and staff development

The research has had a significant impact on staff understanding and education within NGN. The research methodology allows NGN to make informed decisions and improve situational awareness. ***"Management now authorise new demand forecasts with increased confidence, knowing that prior authorisations based on the outputs of the research have been successful."*** [E2].
"The research has educated some NGN staff members in the field of Bayesian statistics and provided an opportunity for continued professional development." [E2].

Establishing UK wide gas distribution improvements

This research work resulted in the establishment of a UK-wide project in Autumn 2018 between all the UK gas distribution distributors (NGN, SGN, Cadent, Wales & West Utilities) and the School of Mathematics, Statistics and Physics at NU [E5]. The focus of this work was evaluating and improving the analysis of leakage at medium pressure across the UK gas distribution networks to ensure that the methods deployed are both accurate and cost-effective to the industry. The gas industry benefits from these statistical approaches in helping make the UK's energy infrastructure low-carbon, sustainable and secure [E6].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1] Testimonial from the Supply Strategy Manager at NGN. *Provides evidence of the financial impact and impact types.*

[E2] Testimonial from a Strategy Analyst at NGN. *Provides evidence of the accuracy improvement, understanding and education impact.*

[E3] NGN procedure for daily demand profiling (see page 3). *Provides evidence of Newcastle University's research work embedded within NGN's demand profiling approach.*

[E4] NGN 2019 demand forecasting user-guide (see page 28). *Provides evidence of Newcastle University's research work embedded within NGN's user guidelines.*

[E5] Testimonial from an asset officer at Wales and West Utilities. *Provides evidence of the UK-wide project involving all UK gas distributors.*

[E6] Networks article https://networks.online/ published in February 2019. *Provides evidence of the project and collaboration between NGN and Newcastle University.*