Estimating Value of Lost Load (VoLL)

Final report to OFGEM

Prepared by

London Economics

5 July 2011

About London Economics

London Economics is one of Europe's leading specialist economics and policy consultancies and has its head office in London. We also have offices in Brussels, Dublin, Cardiff and Budapest, and associated offices in Paris and Valletta.

We advise clients in both the public and private sectors on economic and financial analysis, policy development and evaluation, business strategy, and regulatory and competition policy. Our consultants are highly-qualified economists with experience in applying a wide variety of analytical techniques to assist our work, including cost-benefit analysis, multi-criteria analysis, policy simulation, scenario building, statistical analysis and mathematical modelling. We are also experienced in using a wide range of data collection techniques including literature reviews, survey questionnaires, interviews and focus groups.

Head Office: 11-15 Betterton Street, London, WC2H 9BP, United Kingdom.
w: www.londecon.co.uk e: info@londecon.co.uk
t: +44 (0)20 7866 8185 f: +44 (0)20 7866 8186

Acknowledgements

We would like to acknowledge the useful guidance and feedback provided by Ofgem throughout this research. Ofgem provided us with key figures to help us determine attribute levels and convert WTP and WTA estimates to a per therm basis. Ofgem also provided input data for the estimation for industrial and commercial consumers. The research also benefited at a number of stages from suggestions by Professor Iain Fraser, Kent University and expert advice from Brian Little, Nexant. Others also provided helpful feedback on some of the methodological issues at an early stage in the research. We would also like to thank OMB Research and YouGov for key inputs in the survey development and administration stages. Responsibility for the contents of this report remains with London Economics.

Contents

Page

Executive summary vi

1 Introduction 1

1.1 Background for the study 1
1.2 Purpose and scope of this study 1

2 VoLL for domestic and SME gas users 3

2.1 Methodological approach 3
2.2 Designing the choice experiment 3
2.3 Valuation survey and sample 8
2.4 Domestic and SME gas usage 10
2.5 Estimating WTP and WTA 16
2.6 VoLL estimates for domestic gas users 22
2.7 VoLL estimates for SME gas users 39
2.8 Assessment of current compensation levels 52

3 VoLL estimates for industrial and commercial users 57

3.1 VoLL for I&Cs – general considerations 57
3.2 VoLL for electricity producers 57
3.3 VoLLs for non-electricity I&Cs 66

4 Conclusions 77

Annex 1 Literature review 78

Annex 2 Representativeness of domestic on-line sample 86

Annex 3 Representativeness of SME sample 92

Annex 4 Linear models for WTP and WTA for SME and domestic gas users 94

Annex 5 Validity and quality of responses to choice experiments 97

Annex 6 Observations and confidence interval for VoLL estimates by domestic consumers' characteristics 98

Annex 7 Observations and confidence interval for VoLL estimates by SME and interview characteristics 102

Annex 8 Discussion of gas critical production by industry 104

Annex 9 Iron and Steel detailed analysis 108

Annex 10 Chemical detailed analysis 113

Annex 11 Petroleum refining detailed analysis 115

Annex 12 Details of the spark spread method 119

Tables, Figures & boxes

Page

Table 1: Daily VoLL estimates for domestic and SME customers for outages in the winter occuring once in 20 years (p/therm) vi

Table 2: VoLL estimates for I&C customers (range p/therm) viii

Table 3: Selected attributes and attribute levels for non-price attributes 5

Table 4: Selected attributes and attribute levels for price attributes 6

Table 5: Survey completion mode used 10

Table 6: Gas usage by household having responded to the survey (% of total number of households having participated in the survey) (multiple responses possible) 11

Table 7: Availability of alternatives to gas (% of total number of households having participated in the survey) (multiple responses possible) 11

Table 8: Share with 'low' and 'high' impact of gas outages by number of main applications for gas 12

Table 9: Shares of households reporting a 'low' or 'high' impact of gas outages by gas usage (heating, cooking and hot water) and availability of an an alternative to gas 13

Table 10: Type of gas usage by the SMEs having particicpated in the survey (mutilple responses were possible) 13

Table 11: Availability of alternatives to gas forthe SMEs having particicpated in the survey 14

Table 12: Availability of alternatives to gas for different gas usage by the SMEs having participated in the survey (multiple responses were possible) 15

Table 13: Annual gas bill and impact of outages for SMEs 16

Table 14: Declining long term discount rates 25

Table 15: Impact of gas outages and average annual gas bill 30

Table 16: Share with 'low' and 'high' impact of gas outages by whether they stay at home 31

Table 17: Share with 'low' and 'high' impact of gas outages by whether they have children 31

Table 18: Average valuation of fair compensation per day of outage - domestic consumers 36

Table 19: Average willingness to pay per year for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers 38

Table 20: Fair compensation and willingness to pay valuations based on contingent valuation responses from the face-to-face sample 38

Table 21: Average size of annual gas bill for SMEs (in £) 42

Table 22: Sector and impact of gas outages 47

Table 23: SME size and impact of gas outages 47

Table 24: SME interview mode by size, sector and impact of gas outages 48

Table 25: Average valuation of fair compensation per day of outage - SMEs 50

Table 26: Average willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – SMEs 52

Table 27: Average UK spark spreads baseload power prices 61

Table 28: Average spreads peak power prices 63

Table 29: Baseload and peakload spark spread VoLL estimates p/therm 64

Table 30: Energy Use in Industry % of industry total, UK 2009 68

Table 31: Gas Use in UK Industry 2004 to 2009 69

Table 32: Gas Consumption including autogeneration estimates, 2007 70

Tables, Figures & Boxes

Page

Table 33: Gas-critical Factors and Potential lost GVA 71
Table 34: VoLL Estimates range p/therm 72
Table 35: Loss of refinery production and recover times 73
Table 36: Use of WTP or WTA to estimate the value of secure energy supply in previous studies 82
Table 37: Price information provided in monetary value or as percentage of energy bill 83
Table 38: Non-price attributes included in previous choice experiments analysing the value of secure energy supply 84
Table 39: Comparing population and sample characteristics for the on-line sample 86
Table 40: Age of household member having responded to the survey (% of total number of households having participated in the survey) 87
Table 41: Type of housing tenure of household having responded to the survey (% of total number of households having participated in the survey) 87
Table 42: Members of household member having a long-term disability (% of total number of households having participated in the survey) 88
Table 43: Incone of household having responded to the survey (% of total number of households having participated in the survey) 88
Table 44: Gender of household member having responded to the survey (% of total number of households having participated in the survey) 88
Table 45: Labour force status of survey respondent and socio-economic characteristics of households – on-line survey only 90
Table 46: Distribution (in %) of households by number of household members– on-line survey only 91
Table 47: Comparing population and sample characteristics for the SME sample 92
Table 48: Estimate of SME gas user population characteristics based on call outcomes for the first 306 completed interviews 92
Table 49: Industrial sector of the SMEs having particicpated in the survey 93
Table 50: Regional distribution of the SMEs having particicpated in the survey 93
Table 51: Choice experiment answering patterns (% of total) 97
Table 52: Choice experiment answering patterns by WTA and WTP (% of total) 97
Table 53: Number of respondents in WTA sub-analyses 99
Table 54: Number of respondents in WTP sub-analyses 99
Table 55: WTA a one month outage once in 20 years in the winter – domestic consumers 100
Table 56: WTP to avoid a one month outage once in 20 years in the winter – domestic consumers 101
Table 57: Number of respondents in WTA sub-analyses 102
Table 58: Number of respondents in WTP sub-analyses 102
Table 59: WTA for a one-month outage once in 20 years in the winter - SMEs 103
Table 60: WTP for a one-month outage once in 20 years in the winter – SMEs 103
Table 61: Refineries in the UK 115

Figure 1: Example of choice card 8
Figure 2: Impact of a gas supply outage of two months in winter (% of total number of households having participated in the survey) 12

Tables, Figures & boxes

Page

Figure 3: Annual spend on natural gas (% of SMEs having participated in the survey) 14
Figure 4: Impact of a gas outage lasting for two months and occurring during the winter would have on the business (% of SMEs having participated in the survey) 15
Figure 5: Illustration of non-linear duration effect 20
Figure 6: Baseline estimation results of the model for willingness to accept (on-line survey) 23
Figure 7: Baseline estimation results of the model for willingness to pay (on-line survey) 23
Figure 8: Estimates of WTA in £ per outage in different circumstances, figures not normalised to a per day basis – households (on-line survey) 24
Figure 9: Estimates of WTP in £ per year in different circumstances, figures not normalised to a per day basis – households (on-line survey) 25
Figure 10: Upper bound VoLL in £ per day of outage - based on WTA per day for an outage occurring at the beginning of the period 26
Figure 11: Lower bound VoLL in £ per day of outage - based on WTA per day for an outage occuring at the end of the period 26
Figure 12: VoLL in £ per day of outage - based on WTA per day using discounted payments 27
Figure 13: VoLL in £ per day of outage - based on WTP per day with discounted annual payments 27
Figure 14: VoLL per therm estimate - based on WTA per day using discounted payments 28
Figure 15: VoLL per therm estimate - based on WTP per day with discounted annual payments 28
Figure 16: WTA a one-month outage once in 20 years in the winter – various groupings of domestic consumers 30
Figure 17: WTP for a one month outage once in 20 years in the winter – domestic consumers 33
Figure 18: Valuation of fair compensation per day of outage - domestic consumers (frequency) 34
Figure 19: Valuation of fair compensation per day of outage - domestic consumers (bands) 35
Figure 20: Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers (frequency) 37
Figure 21: Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers (bands) 37
Figure 22: Baseline estimation results of the model for willingness to accept (SME survey) 39
Figure 23: Baseline estimation results of the model for willingness to pay (SME survey) 40
Figure 24: Estimates of WTA in £ per outage in different circumstances, figures not normalised to a per day basis – SMEs 40
Figure 25: Estimates of WTP in £ per year as a percentage of the annual bill in different circumstances– SMEs 41
Figure 26: Estimates of WTP in £ per year in different circumstances, figures not normalised to a per day basis – SMEs 42
Figure 27: Upper bound VoLL in £ per day of outage - based on WTA per day for an outage occurring at the beginning of the period 43
Figure 28: Lower bound VoLL in £ per day of outage - based on WTA per day for an outage occuring at the end of the period 43
Figure 29: VoLL in £ per day of outage - based on WTA per day using discounted payments 43
Figure 30: VoLL in £ per day of outage - based on WTP per day with discounted annual payments 44
Figure 31: SME: VoLL in £ per therm upper and lower estimates - based on WTA per day using discounted payments 44

Tables, Figures & Boxes

Page

Figure 32: SME: VoLL in £ per therm upper and lower estimates - based on WTP per day with discounted annual payments 45
Figure 33: SME: average VoLL in £ per therm - based on WTA per day using discounted payments 45
Figure 34: SME: average VoLL in £ per therm upper and lower estimates - based on WTP per day with discounted annual payments 45
Figure 35: WTA a one-month outage once in 20 years in the winter - SMEs 46
Figure 36: WTP for a one-month outage once in 20 years in the winter – SMEs 49
Figure 37: Valuation of fair compensation per day of outage - SMEs 50
Figure 38: Reported fair amount of compensation per day of gas outage in winter by quartile of SMEs (grouped by the reported level of compensation) 51
Figure 39: Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – SMEs 51
Figure 40: Knowledge about entitlement to compensation in the case of a gas outage (% of households having participated in the survey) 53
Figure 41: Knowledge about entitlement to compensation in the case of a gas outage (% of SMEs having participated in the survey) 54
Figure 42: Per day compensation requirements - based on WTA per day with no discounting 56
Figure 43: Time series of UK baseload clean spark spread p/therm 60
Figure 44: Time series of UK peakload clean spark spread p/therm 62
Figure 45: Households views' on whether they are able to keep their home heated to a comfortable level (% of households having participated in the survey) 89
Figure 46: Households' annual spending on gas and electricity (% of households having participated in the survey) 89
Figure 47: Regional distribution of households having participated in the on-line survey (% of total) 90
Figure 48: Linear estimation results WTA for domestic consumers (on-line sample) 94
Figure 49: Linear estimation results WTP for domestic consumers (on-line sample) 95
Figure 50: Linear estimation results WTA for SME consumers 95
Figure 51: Linear estimation results WTP for SME consumers 96

Executive summary

This report provides Value of Lost Load (VoLL) estimates for domestic, SME and industrial and commercial gas consumers. VoLL represents the value that gas users attribute to security of gas supply and the estimates could be used to provide a price signal about the adequate level of security of supply.

Domestic and SME gas users

The value of secure gas supply to SMEs and domestic consumers is generally difficult to measure because little data is available on the costs that these gas users incur in the case of an interruption of supply. Therefore, this study uses stated preference surveys to elicit VoLL estimates for SME and domestic consumers. Using choice experiments, we estimate VoLL using both willingness-to-pay (WTP) and willingness-to-accept (WTA) framing of the experiment, and we derive VoLL estimates for different frequencies, seasons and durations of interruptions.

Regardless of the methodology, we find that VoLL for outages in the summer is lower than VoLL for outages in the winter and, in most cases, estimates of VoLL for one day or one week outages in the summer are not statistically different from zero. We also find that estimates of VoLL per day decrease with the length of the outage, possibly because gas users face some initial costs (i.e., fixed costs) when implementing alternatives to their gas usage and such costs are not dependent on the duration of the interruption.

Based on the WTA methodology, we also estimate that VoLL per day is larger the more frequent the interruption. However, this is not mirrored in the estimates based on the WTP methodology which also generally results in larger VoLL estimates than the WTA methodology, especially for very infrequent events. We conjecture that this is because respondents do not properly take into account the total amount that would be payable per day of outage for very infrequent interruptions in the WTP experiment.

Table 1: Daily VoLL estimates for domestic and SME customers for outages in the winter occuring once in 20 years (p/therm)

Sector	WTA methodology	WTP methodology
Domestic (1 day duration)	2,260	4,800
Domestic (1 week duration)	1,940	4,380
Domestic (1 month duration)	690	2,750
SME (1 day duration)	84	3,753
SME (1 week duration)	71	3,356
SME (1 month duration)	19	1,834

Source: London Economics

We also find that VoLL varies depending on the characteristics of the gas user. VoLL is relatively low for SMEs with fewer than 10 employees and for businesses that expect a low impact of outages. For households, we find a lower VoLL for vulnerable groups and for domestic consumers with low gas usage.

Our analysis suggests that while the £50/day compensation levels for businesses more than satisfies the compensation requirements of the average SME, the £30/day compensation for domestic consumers is not adequate for all types of interruptions. In particular, our results show that the average domestic consumer requires more compensation per day for outages lasting one week or one day and taking place in the winter and there may be an argument for reducing or removing compensation to domestic consumers for summer outages.

Industrial and commercial gas users

The costs associated with a gas supply interruption are more directly measureable for large industrial and commercial consumers where gas is an important input in the production process. For these consumers a gas interruption may have very direct and measureable impact on revenue and costs.

We use a real options approach to estimate VoLL for electricity producers for baseload and peaking units and a value-at-risk method for other industrial users.

For gas-fired electricity generation, the value of lost load is found to be larger for baseload units than for peaking units because starting costs are less important for peaking units. We also conclude that the value of lost load for typical electricity producers also depends on the duration of the outage with VoLL per therm decreasing with the length of the outage. This is because the fixed start costs are spread over more units of gas lost and, as a result, the difference between peaking units and baseload units decreases with the duration of the outage. Moreover, when adjusting for the additional volatility in peak prices, using the options based approach, the two VoLLs (peak and baseload) are rather similar.

A value-at-risk methodology is used to calculate the Value of Lost Load for selected other industrial and commercial sector gas users. The value-at-risk methodology depends on the critical assumption that a loss of gas supply would result in total loss of production in each sector and hence loss of 100% of the gross value-added (GVA) for that sector. To soften the implications of this assumption, we introduce the concept of 'gas-critical' production — the % of production that would be lost in the event of an outage. The percentage of GVA that might be lost in a gas disruption is assessed as a range for each subsector.

A second modification of the value-at-risk method is that the gas consumption figures have been modified to include an assessment of gas used to generate electricity on site[1]. While best efforts have been made to estimate VoLLs by I&C sector that adjust for factors such as gas critical production, storability, and capacity, it should be noted that these estimates are reasonably preliminary, and more robust estimates would require additional work and resources. More robust estimates would most likely require a range of additional work and methods, including cooperating directly with industry.

---

[1] It is difficult to assess whether it should be assumed that if gas for on-site electricity production is not available, then whether alternative electricity supply would also not be available.

Table 2: VoLL estimates for I&C customers (range p/therm)

Sector	Low	High
Electricity (1hr interruption)	108[2]	135[1]
Electricity (24hr interruption)	48[2]	59[1]
Non-Ferrous Metals	854	1,139
Iron and Steel	1,312	1,715
Chemicals	272	362
Petroleum Refineries	303	378
Agriculture	0	148
Mineral Products	425	638
Textiles, Leather etc	370	616
Other Industries	1,799	2,398
Food Beverages etc	681	1,021
Paper, printing etc	490	735
Vehicles	1,708	2,277
Electrical Engineering etc	824	1,099
Mechanical Engineering etc	1,122	1,870
Construction	0	923
Fertilisers	322	322

Note: 1) baseload units, 2) peak units.

Source: London Economics and Nexant

1 Introduction

This section provides a short background for the current study as well as a description of its scope.

1.1 Background for the study

Ofgem is considering introducing Value of Lost Load (VoLL) as part of the Gas Security of Supply Significant Code Review (Gas SCR) with VoLL representing the value that gas users attribute to security of gas supply. Since VoLL is the value of secure supply, it should provide a price signal about the adequate level of security of supply and Ofgem envisage that estimates of VoLL could be used to:

- cap cash-out in an emergency; and
- set the level of compensation payable if firm customers are disconnected.

Price signals about the appropriate level of security of supply are currently not available because gas prices are effectively frozen in the case of a gas deficit emergency and compensation is not required if firm load customers are disconnected. However, it should be noted that while currently no compensation is provided in the cases mentioned above, compensation is paid for gas supply interruptions which are the result of a failure of a gas transporter's network. The current levels are £30/day and £50/day for domestic and non-domestic customers respectively.

By using VoLL to extend the coverage of compensation requirements, price signals may be incorporated into the market more widely and gas suppliers would be expected to have greater incentives to invest in risk mitigation measures such as increased storage or longer term supply contracts to reduce the risk of gas outages.

Estimating VoLL may, however, not be straightforward because there is no market for 'the security of gas supply' from which one can directly infer the price. The problem is most pronounced for domestic consumers and SMEs for whom the most important costs may be the intangible costs of the inconvenience caused. In addition, little data about gas usage and potential revenue costs of gas outages is publicly available for domestic consumers and SMEs. For industrial and commercial (I&C) customers, it is easier to estimate the direct costs of a gas interruption and there exist established methodologies to estimate VoLL. For example, value at risk methodologies and inferred values from interruptible contract auctions can be used to infer estimates of VoLL. In comparison, little data exists to estimate VoLL for domestic and SME gas consumers.

1.2 Purpose and scope of this study

The purpose of the study is to undertake quantitative research to derive estimates of VoLL for domestic, SME and I&C gas users, respectively. The study provides:

- a review of consumer research undertaken to inform the guaranteed standard for supply interruptions set to compensate consumers in the event of network failure;
- estimates of VoLL for different consumer types (domestic consumers, SMEs, I&C);
- estimates of VoLL for different durations of outages (24 hours, 1 week, 1 month);
- estimates of VoLL for different seasons; and

- a review of whether current compensation levels are appropriate in the light of the gas VoLL estimates.

Estimates of VoLL for domestic consumers and SMEs are obtained using a non-market valuation survey with a choice experiment. VoLL for industrial and commercial (I&C) consumers is estimated using a real options approach.

2 VoLL for domestic and SME gas users

VoLL for domestic and SME gas users are elicited from a choice experiment. There are some small differences in the design of the choice experiment for domestic and SME gas users. But, the overall approach and considerations are similar in the two cases. This section discusses the overall methodological approach before presenting the VoLL estimates separately for domestic and SME gas users.

2.1 Methodological approach

This study uses stated preference techniques to estimate VoLL for domestic and SME gas users. The primary results are obtained using a choice experiment and a few contingent valuation questions are also included as a sense check of the results of the choice experiment.

Stated preference techniques are generally applied to estimate the economic value of goods for which no market exists and where the value therefore is not observable in the market. It is a survey based technique where respondents are presented with hypothetical scenarios. Such survey based methods are preferred to direct estimation methods when the economic value is not directly observable or cannot be estimated based on existing data. This is arguably the case for SME and domestic gas users. However, for industrial and commercial gas users where gas is a key input the value of secure supply may be estimated directly from existing data based on the value of lost revenue associated with an outage.

Stated preferences techniques are also particularly suitable when inconvenience and intangible costs are some of the main costs associated with loss of supply and when substitutes to gas are unlikely to be perfect substitutes from the point of view of the gas user. Most previous studies estimating the value of secure energy supply therefore use stated preference techniques and most used choice experiments. For a further discussion of existing literature see Annex 1.

In choice experiments survey respondents are asked to make a number of choices between alternative hypothetical scenarios and estimates of the value of secure supply are elicited from the results. In comparison, contingent valuations involve open-ended questions where survey respondents are asked to state how much money they would be willing to pay for a service improvement or how much compensation they would require for a given outage.

Compared to choice experiments, contingent valuation is more likely to suffer from problems with respondents refusing to 'play the game' and provide a valuation. In addition, choice experiments are preferred when valuations are required for a number of different attributes of the supply interruption. For example in this case VoLL estimates are required for different frequencies, durations and seasons.

2.2 Designing the choice experiment

This section describes the design of the choice experiment. In particular, attribute and attribute selection, generation of choice options and inclusion of a no-choice option are discussed.

2.2.1 Selection of attributes and attribute levels

The choice experiment in the present study uses the attributes listed in the BIS 2006 consultation and attributes similar to those used in previous studies of the value of secure energy supply (see Annex 1).

According to Hanley *et al.* (2001) the number of attributes that can be tested depends on the sample size. But, as a rule of thumb no more than 4 or 5 attributes should be tested. Our attribute selection fits within this recommendation.

The levels of the chosen attributes were determined after consulting Ofgem to be as realistic as possible and span the range over which respondents can be expected to have preferences. Since choice experiments are close-ended questions by nature, inappropriate attribute levels (whether set too high or too low) will bias the results. Levels can include policy targets and should include a "status quo" level and a range around the existing level in order to elicit VoLL.

The attributes and attribute levels selected for domestic and SME gas users are identical for the two groups of consumers with the exception of the price attributes. The selected attribute levels for non-price attributes are shown in Table 3.

We note there is a lot of uncertainty about the current level of security of supply in GB because interruptions are so rare that there is little data on which to base a judgement. So while no definitive judgment can be made as to which of the included scenarios is most representative of the current situation, the scenario of gas interruptions lasting one month, occurring in the winter and occurring once in 20 years may be considered the most realistic (future) scenario of those included in the choice experiment. It is widely acknowledged that an emergency is more likely to occur in the winter when demand for gas is high and that if a gas emergency was to occur it would be relatively long-lasting for domestic and SME customers who are not able to be isolated from the gas network .

Furthermore, EU regulation 944/210 talks of gas interruptions occurring once in 20 years and lasting for 30 days. The regulation specifies that the relevant national authorities must take measures to ensure gas supply to protected consumers for *'any period of at least 30 days of exceptionally high gas demand, occurring with a statistical probability of once in 20 years'*.[2]

---

[2] Regulation (EU) No 994/2010 of The European Parliament and of The Council of 20 October 2010 concerning measures to safeguard security of gas supply and repealing Council Directive 2004/67/EC.

Table 3: Selected attributes and attribute levels for non-price attributes

Attribute	Attribute levels
Duration of interruption	24 hours
	1 week
	1 month
Season of interruption	Summer
	Winter
Frequency of interruption	1 time in 5 years
	1 time in 20 years
	1 time in 50 years

Source: London Economics

With respect to the price attribute the choice experiment is designed to allow estimation of VoLL based on both stated willingness-to-pay (WTP) and stated willingness-to-accept (WTA).

Theoretically, the VoLL could be equal to both consumers' WTP to avoid gas interruptions and consumers' WTA compensation in the event of disconnection. However, in practice the WTP and the WTA are not identical when estimated using survey methodologies. In general, surveys find that the WTA is higher than the WTP. In other words, the maximum amount consumers are willing to pay to achieve a better service is less than the minimum amount they are willing to accept in compensation for poor service. In the case of utility supply, consumers generally feel that they have an entitlement to secure supply and many may be opposed to the idea of having to pay extra to secure their supply. Additionally, given the fact that gas supply is generally seen as very reliable, consumers may oppose having to pay more to ensure the same level of reliability in the future. Therefore, if we were to base our estimates only on WTP rather than also using WTA to estimate VoLL, we could underestimate VoLL. However, at the same time, we note that WTA may overestimate VoLL in choice experiments and WTP may be seen as a more conservative estimate.

We expect that the estimates of WTP will provide a lower bound estimate for VoLL whereas the WTA estimates will provide an upper bound estimate of VoLL. The WTA estimates will also facilitate an assessment of the appropriateness of the current compensation levels. By estimating WTP, we would not obtain a direct indication of whether consumers find the current compensation levels appropriate.

In order to estimate VoLL by both WTP and WTA, the sample was split in two halves; half of the respondents was given WTP questions and the other half was given WTA questions. The price attribute levels were set to be different for domestic and SME consumers respectively, because a higher VoLL was expected for SMEs who might miss out on business activity in the event of a gas interruption. The attribute levels for daily compensation include the current compensation levels for network interruptions of £30 per day for domestic consumers and £50 per day for business consumers.

The price attribute for WTP is framed as an increase in the annual bill and expressed in percentage terms for SME users and in monetary value for domestic users. The monetary values for domestic consumers correspond to approximately 1%, 4%, 8%, 12% and 15% of the average annual gas bill for household consumers of £608[3]. The advantage of converting WTP to a monetary value is that it gives the researcher more certainty about the amount the respondent has in mind when answering the question and it also overcomes problems of low awareness of current bill levels among consumers. A similar conversion to a pound value is not undertaken for SMEs because there is little data on average bill levels. At the same time, there is likely to be much more variation in annual bills for this group of consumers.

Table 4: Selected attributes and attribute levels for price attributes

Attribute	**Attribute levels**	
	Domestic gas users	**SME gas users**
WTP: Annual increase in gas bill	£5	1% of current bill
	£25	4% of current bill
	£50	8% of current bill
	£75	12% of current bill
	£100	15% of current bill
WTA: Daily compensation amount while the gas is interrupted	£5	£10
	£15	£25
	£30	£50
	£45	£75
	£60	£100

Source: London Economics

2.2.2 Generating choice cards for the experiment

Given the attributes and attribute levels selected, choice cards were designed for the WTP and WTA choice experiments separately. Each choice card was designed to consist of two alternative scenarios with one or more attributes varying across the two scenarios. For each of the WTP and WTA choice experiments there was a total of 90 different scenarios given the attributes and attribute levels selected. Each of the 90 scenarios could be paired with all the other 89 scenarios to create the complete set of choice cards.

However, a choice experiment with the total set of choice cards would not have been feasible because there is a limit to how many choice cards can be presented to each respondent without compromising the quality of the collected data. For this study, the number of choice cards presented to each respondent was set to 10 and the number of choice cards was reduced using fractional factorial design. The number of choice cards was reduced to 40 for each choice experiment (i.e. for each WTP and WTA experiment for domestic and SME consumers, respectively). As is standard in the literature, the statistical method employed to reduce the number of choice cards ensured that the reduced number of choice cards would still span the choice set and allow us to make inference about willingness to pay for different attributes.

---

[3] Estimate of average annual bill is taken from Ofgem (2011): Typical domestic energy consumption figures, factsheet 96, and based on medium annual domestic gas consumption.

As is also standard in choice experiments, most dominant strategies were subsequently modified because these choice cards are expected to reveal little information about WTP/WTA but may annoy respondents who could find it pointless to have to make obvious choices. A few dominant strategies were left in the experiment to check respondents' understanding of the task.

2.2.3 Including a no-choice, don't know or status-quo option

It is generally recommended that choice experiments also include a no-choice option. This could be in the form of a status-quo option or an option clearly labelled 'no choice' or 'don't know'. This ensures that respondents are not forced to make a choice and ensures better estimates of WTP and WTA.[4] However, a possible disadvantage of including a no-choice option is that no information about WTP or WTA is revealed by respondents who select the no-choice option. In the present study, however, results suggest that this problem is relatively limited and that consumers generally select one of the alternatives presented to them rather than the no-choice option.

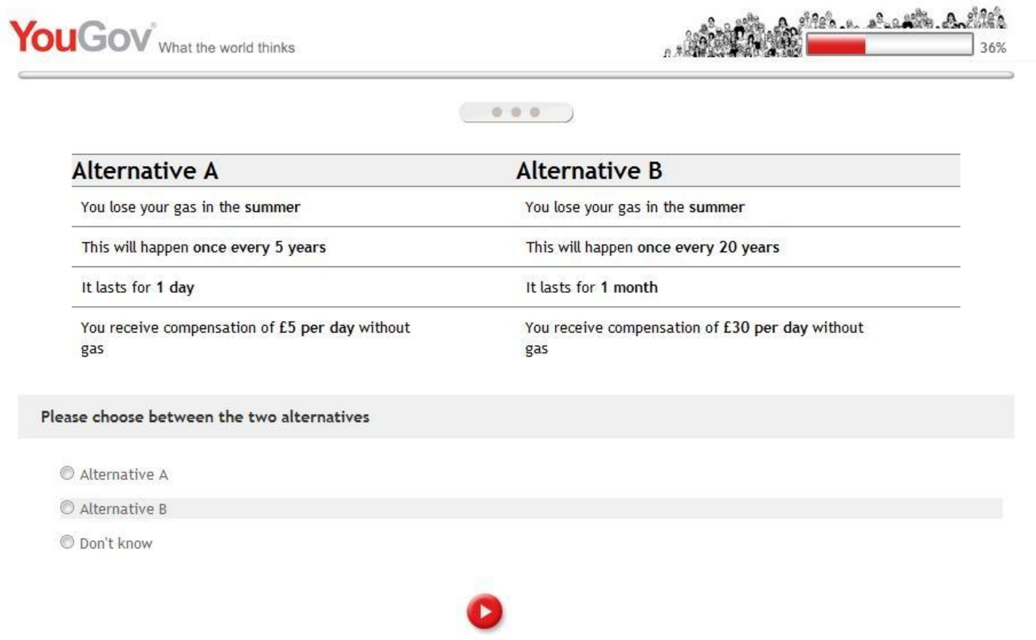
If a clearly defined status-quo exists, it may be desirable to include this option as a no-choice alternative on the choice card (i.e. a third alternative scenario). However, in the case of the present study, the definition of the characteristics of the status-quo scenario is not obvious. Consumer research undertaken for Ofgem in 2007, suggests that domestic consumers and small business consumers, generally, have low awareness of the current guaranteed standard for supply interruptions (12% and 17% respectively are aware they may be entitled to compensation if standards are not met) and due to the relatively low frequency of interruptions it is difficult to describe in accurate terms what the status-quo is.

In the absence of a clearly defined status-quo, the choice experiment includes a 'don't know' option. That is in addition to the two alternative scenarios presented on the choice card, respondents are given the option to say that they don't know which option they would prefer. An example of the choice cards presented to consumers is shown in Figure 1.

---

[4] If no 'no choice' option is included and respondents are forced to make a choice, the subsequent estimation of the results would be related to conditional utility concepts.

Figure 1: Example of choice card



Alternative A	Alternative B
You lose your gas in the summer	You lose your gas in the summer
This will happen **once every 5 years**	This will happen **once every 20 years**
It lasts for **1 day**	It lasts for **1 month**
You receive compensation of **£5 per day** without gas	You receive compensation of **£30 per day** without gas

Please choose between the two alternatives

○ Alternative A
○ Alternative B
○ Don't know

Source: YouGov

2.3 Valuation survey and sample

In addition to the choice experiment, the survey included a few background questions about:

- Gas usage characteristics such as what gas is used for (e.g., heating, hot water, cooking) and annual gas spend.
- Available substitutes to gas in the event of gas outage (e.g., an electrical cooker).
- Awareness of current compensation arrangements.
- Background questions about the respondent. In the household survey, this included age, gender and region. In the SME survey, this included sector, size, etc.

In addition, two contingent valuation questions were also included to provide a sense check of the results from the choice experiment. There was one contingent valuation question for WTP and one for WTA. These are listed below:

- WTA contingent valuation question: If your gas supplies were to be interrupted in the winter, how much do you think would be a fair amount of compensation per day without gas?
- WTP contingent valuation question: How much extra per year would you be willing to pay to reduce the likelihood of your gas supplies being interrupted from once in every 20 years to once in every 50 years?

These questions provide less information about the value of different attributes than the choice experiment because specific characteristics of the gas interruption had to be specified in the questions. For example the WTA question asks about compensation for an interruption in the winter time and the WTP question asks about the WTP for a service improvement with less frequent gas interruptions.

It should be noted that the contingent valuation questions were placed after the choice experiment to ensure that the responses would not bias the results of the choice experiment which was the main purpose of the survey. We acknowledge that, as a consequence of this decision, the results of the contingent valuation questions may have been influenced by the attribute levels set for the choice experiment.

2.3.1 Domestic survey

The domestic survey consisted of an on-line survey with 1,000 respondents and a face-to-face survey with 100 respondents. The respondents selected for the face-to-face survey were 'vulnerable consumers' with vulnerable consumers defined as consumers satisfying at least one of the following criteria:

- Pensioners (for practical purposes defined as women aged 60 or above and men aged 65 or above).
- Disabled or chronically ill (or someone else in the household disabled or chronically ill).
- Fuel poor[5] (for practical purposes defined as people with a gross annual household income of less than £15,000).

The sample for the on-line survey was drawn randomly from YouGov's 315,000 strong on-line panel of UK adults and quotas were set to ensure that the resulting sample was representative of the GB population in terms of age, gender and socio-economic characteristics. It should be noted that, since the on-line sample is a random sample, it also includes some vulnerable consumers. In addition, in order to be selected to participate in the survey, respondents had to meet the following 3 conditions:

- be connected to the mains gas network;
- be solely or jointly responsible for paying the households' gas bill; and
- if renting their home, paying for their gas separately from their rent.

In the on-line survey respondents were presented with 10 choice cards onscreen and in the face-to-face survey interviewers physically presented each respondent with 10 choice cards. This approach was selected in order to ensure a high level of data quality because it is much easier for respondents to choose between alternatives in a choice experiment if they can visually see the choice in front of them.

2.3.2 SME survey

An on-line survey approach is in general not feasible for businesses because on-line business surveys yield very low response rates. Therefore, the business survey was undertaken as a combined telephone-mail survey. Respondents were contacted over the phone and, when

---

[5] Ofgem defines fuel poor consumers as people spending more than 10% of their income on the fuel for heating, etc.

feasible, choice cards were e-mailed, posted or faxed to them so that they would be able to have the choice cards in front of them while making the choice.

A total of 500 SME respondents were drawn from Experian. Respondents were required to:

- be connected to the mains gas network; and
- pay for gas separately from the rent or service charge.

Quotas were set to ensure that the sample was representative of the population of GB SMEs in terms of region, size and sector. However, during the fieldwork it became evident that a smaller share of very small companies (0-9 employees) and companies in the construction sector use gas. The quotas were, therefore, adjusted to ensure that these groups would not be overrepresented in the final sample and that the final sample would be representative of SME gas users to the greatest extent possible. Annex 3 provides a comparison between sample and population characteristics for SMEs in GB.

In addition, a quota was set to ensure that no more than 25% of interviews were carried out over the telephone only or equivalently that at least 75% of respondents had the choice cards in front of them when completing the choice experiment. Table 5 summarises the survey completion modes actually used in the 500 interviews with SMEs.

Table 5: Survey completion mode used

	Interviews	% of interviews
Emailed choice cards	361	72%
Faxed choice cards	3	1%
Posted choice cards	20	4%
Telephone only	116	23%

Source: London Economics

2.4 Domestic and SME gas usage

This section provides details from the survey about SMEs and domestic consumers gas usage, the alternatives available to them in case of an outage and the impact they expect an outage will have on them given the available alternatives.

2.4.1 Domestic gas usage

The vast majority of domestic gas users use gas for central heating and heating water (more than 90% in both the on-line survey and in the face-to-face survey). The majority of gas users also use gas for cooking. In particular, 74% of respondents in the on-line survey used gas for central heating and 60% in the face-to-face interviews.

Table 6: Gas usage by household having responded to the survey (% of total number of households having participated in the survey) (multiple responses possible)

Type of gas usage	On-line survey (in %)	Face-to-face survey (in %)
Central heating	96	94
Cooking	74	60
Hot water	91	95
Other	2	3

Source: On-line and face-to-face domestic survey

Most consumers have at least some alternatives to gas but 8% of consumers in the on-line survey had no alternatives and 1% in the face-to-face interviews. At least 90% of consumers had a microwave suggesting that there may not be a great impact on consumers' ability to cook, although the quality of the cooking may be lower.

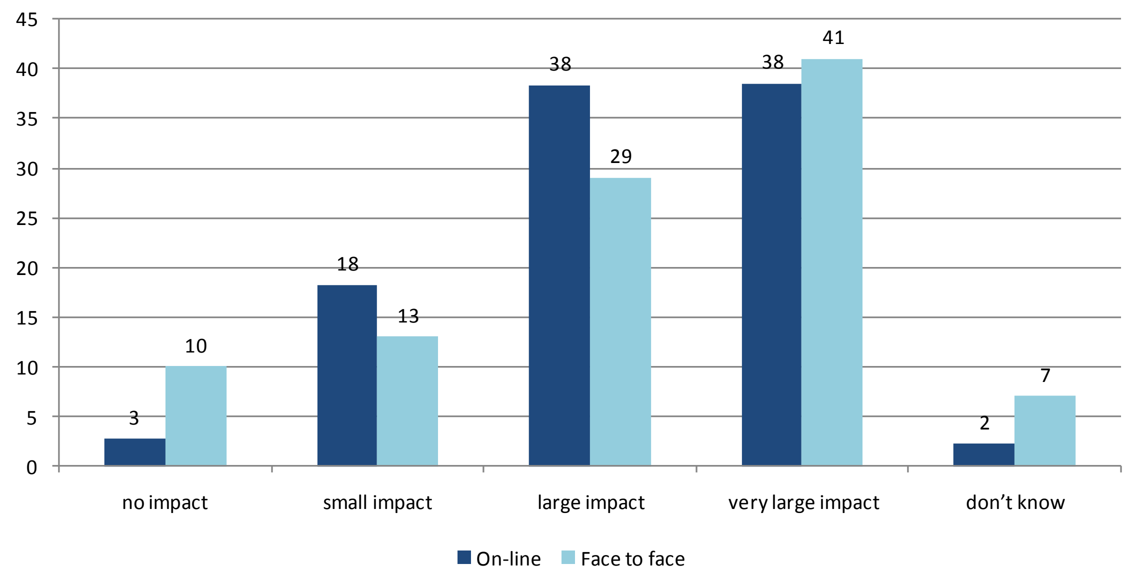
Table 7: Availability of alternatives to gas (% of total number of households having participated in the survey) (multiple responses possible)

Type of alternative	On-line survey (in %)	Face-to-face survey (in %)
One or more electric fan heaters or oil filled radiators	47	30
An electric fireplace	16	27
A solid fuel (coal or wood) burner	7	2
An electric oven / cooker	51	49
Calor gas / kerosene cooker	5	2
Electric shower	39	49
Electric immersion heater / water heater	27	19
Microwave	90	92
Other	5	4
None of the above	8	1

Source: On-line and face-to-face domestic survey

Most domestic consumers say that a two-month gas outage in the winter would have either a large or a very large impact on their household despite the alternatives they have. In particular, 76% of respondents in the on-line survey expected that a two-month outage in the winter would have a large or very large impact, while the corresponding figure for the face-to-face sample was 70%. Only 3% and 10% respectively reported that there would be no impact of a gas outage for their household.

Figure 2: Impact of a gas supply outage of two months in winter (% of total number of households having participated in the survey)



Source: On-line and face-to-face domestic survey

Separating consumers into three groups (those who use gas for all three applications; those who use gas for any two of the applications; and those who use gas for just one of the application), we provide in the table below information on the shares of respondents who report they would experience a high impact from a gas outage according to the number of applications they use gas for. There is little difference between those who use gas for two or three applications (Table 8). However, the share that would experience a high impact is lower for those who only use gas for one application.

Table 8: Share with 'low' and 'high' impact of gas outages by number of main applications for gas

	Low impact	High impact
Three applications	20%	80%
Two applications	19%	81%
One application	44%	56%

Note: 'High' impact defined as 'large' or 'very large' impact. 'Low' impact defined as 'no' or 'small' impact.
Source: London Economics analysis of on-line survey data.

The next table focuses on the relationship between the impact of an outage and whether consumers use gas for each application and also whether they have alternative for gas for each application. The impact is likely to be highest for those who use gas for hot water and do not have an alternative (88% of such consumers reported that they would experience a high impact) (Table 9).

Table 9: Shares of households reporting a 'low' or 'high' impact of gas outages by gas usage (heating, cooking and hot water) and availability of an an alternative to gas

Application	Use gas	Low impact	High impact
Heating:	Yes, with alternative	21%	79%
	Yes, without alternative	20%	80%
	No	36%	64%
Cooking:	Yes, with alternative	22%	79%
	Yes, without alternative	19%	80%
	No	24%	76%
Hot water:	Yes, with alternative	26%	74%
	Yes, without alternative	12%	88%
	No	39%	61%

Note: 'High' impact defined as 'large' or 'very large' impact. 'Low' impact defined as 'no' or 'small' impact.
Source: London Economics analysis of on-line survey data.

2.4.2 SME gas usage

The majority of SMEs use gas for central heating (91.6% of SME gas users) and/or for heating water (63.4%). The results of the survey also show that 38.4% of SME gas users use gas for cooking and 6.2% use gas in the manufacturing process.

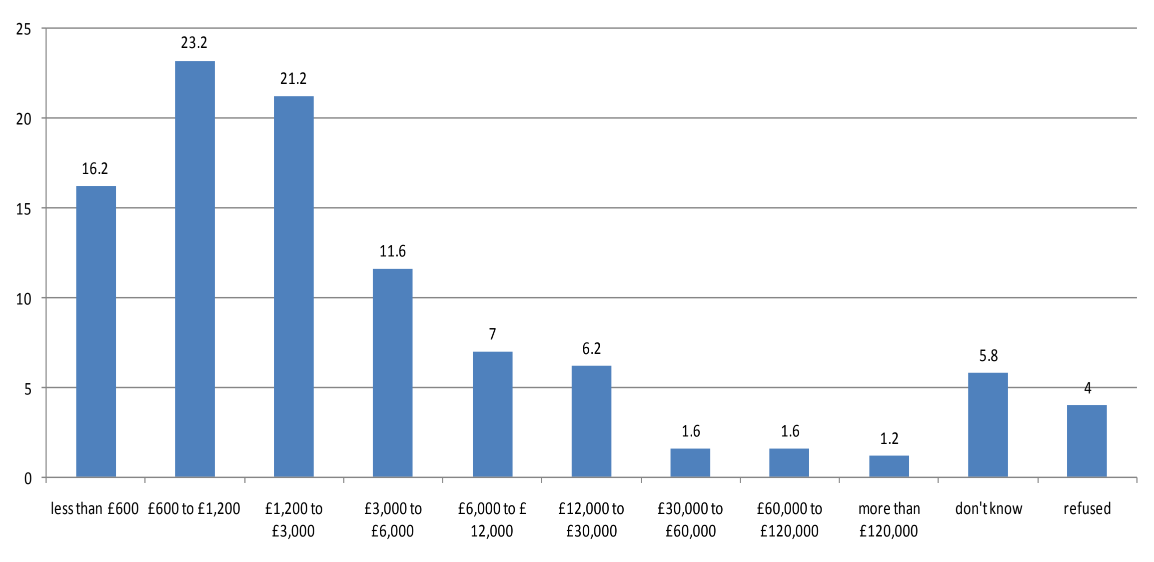
Table 10: Type of gas usage by the SMEs having particicpated in the survey (mutilple responses were possible)

Type of usage	Percentage of total sample
In the manufacturing or production process	6.2
For cooking	38.4
For central heating	91.6
For heating water	63.4
For anything else	4.2
Don't know	0.2

Source: SME survey

Figure 3 shows the distribution of the annual spend on natural gas for SME gas users in GB. The majority of SMEs spend less than £3,000 on gas per year. However, some businesses also spend considerably more. The maximum spend reported was £2,000,000. However, this seems to have been an outlier and excluding this observation we find that the average annual gas spend by SMEs is £7,287.

Figure 3: Annual spend on natural gas (% of SMEs having participated in the survey)



Source: SME survey

Most SMEs have at least one alternative to gas that could be used in the event of an outage. However, a sizable share of businesses (38.8%) does not have any alternatives to gas available and would potentially be particularly vulnerable to long lasting gas outages.

The results of the survey also show that 52.8% of businesses who use gas for central heating have alternatives available and approximately 44% of those who use gas for cooking or heating water have alternatives available. However, only 16.1% of SMEs who use gas in their manufacturing process have alternatives available making these businesses particularly vulnerable to gas outages.

Table 11: Availability of alternatives to gas forthe SMEs having particicpated in the survey

Alternatives available	Percentage of total sample
Alternative available	68.0
No alternative available	38.8
Don’t know	0.2

Source: SME survey

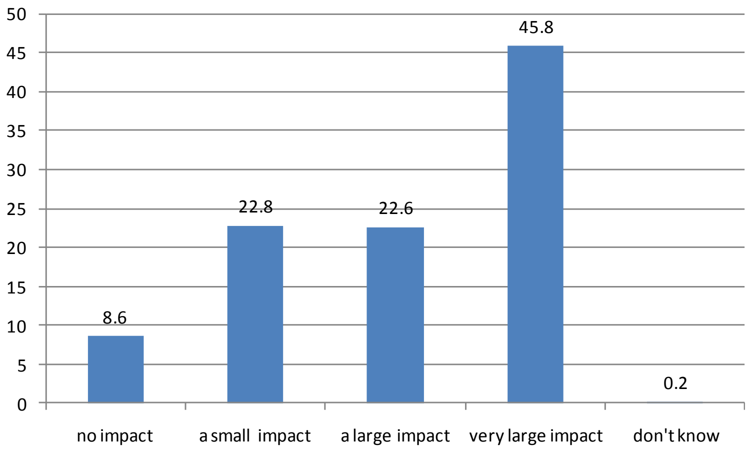
Table 12: Availability of alternatives to gas for different gas usage by the SMEs having participated in the survey (multiple responses were possible)

Alternative to gas available for	Percentage of SMEs using gas for particular usage
In the manufacturing or production process	16.1
For cooking	44.3
For central heating	52.8
For heating water	44.2

Source: SME survey

Sixty-eight per cent of SME gas users say that a gas outage lasting two months in the winter would have a large or very large impact on their business. Only 8.6% say that an outage would have no impact on their business.

Figure 4: Impact of a gas outage lasting for two months and occurring during the winter would have on the business (% of SMEs having participated in the survey)



Source: London Economics analysis of SME survey

There is generally a tendency that SMEs with a large annual gas bill expect that there will be a greater impact of gas outages than SMEs with a low annual gas bill (Table 13).

Table 13: Annual gas bill and impact of outages for SMEs

Bill	Low impact	High impact
less than £600	59%	41%
£600 to £1,200	34%	66%
£1,200 to £3,000	32%	68%
£3,000 to £6,000	26%	74%
£6,000 to £ 12,000	21%	79%
£12,000 to £30,000	0%	100%
£30,000 to £60,000*	17%	83%
£60,000 to £120,000*	0%	100%
more than £120,000*	0%	100%

Note: * Fewer than 30 firms in total

Source: London Economics analysis of SME survey

2.5 Estimating WTP and WTA

The heart of choice experiments is the basic neoclassical economic model of consumer behaviour and "utility". Typically, we assume that consumers[6] have a utility function, where they gain utility or satisfaction from goods and services. The approach then adds a random component, which can be interpreted as a random error, epsilon ε_i.

$$U_i = V_i + \varepsilon_i$$

For each consumer, the 'i-th' alternative (the subscript i indexes the alternatives) has its own utility level, and error, although we may make assumptions about the structure of the preference sets and the error structure.

Without choosing a functional form, we assume that the non-random portion of consumers' preferences can be represented or approximated by some functional form, and that this is often a function of attributes or the characteristics of the respondent.

$$V_i = \alpha_i + \beta_{1i} f(X_{1i}) \ldots \ldots + \beta_{Ni} f(X_{Ni})$$

Combining the two equations gives:

$$U_i = V_i = \alpha_i + \beta_{1i} f(X_{1i}) \ldots \ldots + \beta_{Ni} f(X_{Ni}) + \varepsilon_i$$

where alpha and beta are parameters to be estimated.

---

[6] We will use "consumers" to mean consumers of gas services. Our study will involve both domestic consumers and SMEs.

Data on the fundamental choice component in a choice experiment is discrete (we observe that the respondent has chosen choice A over choice B). Thus operationalising the utility model above involves the logical step that utility must be higher when a choice is observed or stated to be preferred, and is represented by the probability that the consumer chooses alternative i.

Rearranging from the previous equations after substitution, we see how the error component fits into the model, i.e. the difference between the non-random elements must exceed the difference between the random elements:

$$Prob_i = Prob[(\varepsilon_j - \varepsilon_i) \leq (V_i - V_j)] \; \forall \; j = 1 \ldots J \; (j \neq i)$$

The final step is to choose a distributional assumption for the error term and structure. A common assumption is an extreme value 1 exponential type distribution.

$$Prob(\varepsilon) = \exp\,(-\exp(-\varepsilon))$$

Independently identically distributed error terms (iid) is a common error structure assumption.

Then,

$$Prob_i = \frac{\exp\,(V_i)}{\sum_{j=1}^{J} \exp\,(V_i)}$$

The interpretation of the above is that for each alternative i, the probability that it is chosen is the ratio of the exponentials of the non-random V_i, to the sum over the utilities from the possible alternatives.

2.5.1 Choice of estimation method

The design of the choice experiment largely determines the choice of estimation method for this model. It is standard to estimate choice experiments with a no-choice option using a conditional logit model (also sometimes referred to as a multinominal logit model because the conditional logit model contains the multinominal logit model as a special case). This estimation method allows for attribute levels to vary between alternatives in an observable way (as in this case) and estimates the likelihood that a scenario is selected given the attributes of that alternative.[7]

The model is estimated with three alternative choices: the two scenarios A and B with specified attribute levels and the 'don't know' option. The attribute levels for the don't know options are set

---

[7] In comparison, in multinomial logit models attribute levels generally do not vary between alternatives and these models are generally used for problems where the characteristics of the alternatives are unimportant or unavailable.

to zero and a dummy equal to 1 for the 'don't know' option is included as suggested by Ryan *et al.* (2008), Vermeulen *et al.* (2005) and Haaijer *et al*. (2001)[8]. This approach ensures that information contained in the 'don't know' responses is not dropped from the analysis while ensuring that the parameter estimates are not biased by the inclusion of the 'don't know' option. If the dummy for the 'don't know' option was not included, the model would implicitly impose a utility level of zero in cases where the 'don't know' option was selected because all other attributes are set to zero. However, this choice might in fact not be associated with a utility level of zero and therefore had we imposed the restriction by excluding the dummy variable, this could have significantly biased the estimation results.

2.5.2 Choice of explanatory variables

In order to estimate WTP and WTA for different attribute levels, it is necessary to include both price and non-price attributes as explanatory variables in the regression.

While season can only be included as a dummy variable (equal to 1 if the outage occurs during the winter and 0 otherwise), frequency and duration can be included as either linear or nonlinear continuous explanatory variables.. In a linear model, the variables would be treated as continuous variables; the duration in number of days and the frequency expressed as the number of years between two interruptions. However, there may be non-linear effects. These could be accounted for either by including squared (and/or higher order) terms or by entering a dummy for each attribute level. For example, the effect of different frequencies could be captured by specifying the model with two dummies:

- a dummy equal to 1 if outages occur every 20 years and 0 otherwise; and
- a dummy equal to 1 if outages occur every 50 years and 0 otherwise.

In this example, outages occurring every 5 years would be the reference category and the estimation results would allow us to compare the effect of changing the frequency relative to the base of outages occurring every 5 years (in this example, this would amount to a service improvement with less frequent interruptions).

While a specification with dummy variables allows for the most flexible model specification (essentially allowing the relationship between the dependent variable and the explanatory variable to not depend on any specific functional form), it only allows us to analyse the effects of service improvements (or deteriorations) compared to the selected reference case and hence estimate WTP and WTA for service improvements (or deteriorations). It would not allow us to anchor the results and estimate VoLL (via WTP or WTA) for the selected reference case. In the example above, the dummy specification would allow us to estimate how much more consumers would be willing to pay (or how much less compensation they would be willing to accept) for a reduction in the frequency from once in 5 years to once in 20 and once in 50 years, respectively. This could give us an estimate of the *difference* between VoLL in situations with different frequencies, but it would not allow us to estimate the *level* of VoLL.

---

[8] Ryan, M., Gerard, K., and Amaya-Amaya, M. (2008), 'Using Discrete Choice Experiments to Value Health and Health Care', Springer; Vermeulen, B., Goos, P. and Vandebroek, M. 'Models and optimal designs for conjoint choice experiments including a no-choice option', Katholieke Universiteit Leuven; and Haaijer, R., Kamakura, W., and Wedel, M. (2001), 'The 'no-choice' alternative to conjoint choice experiments', *International Journal of Market Research*, Vol. 43(1).

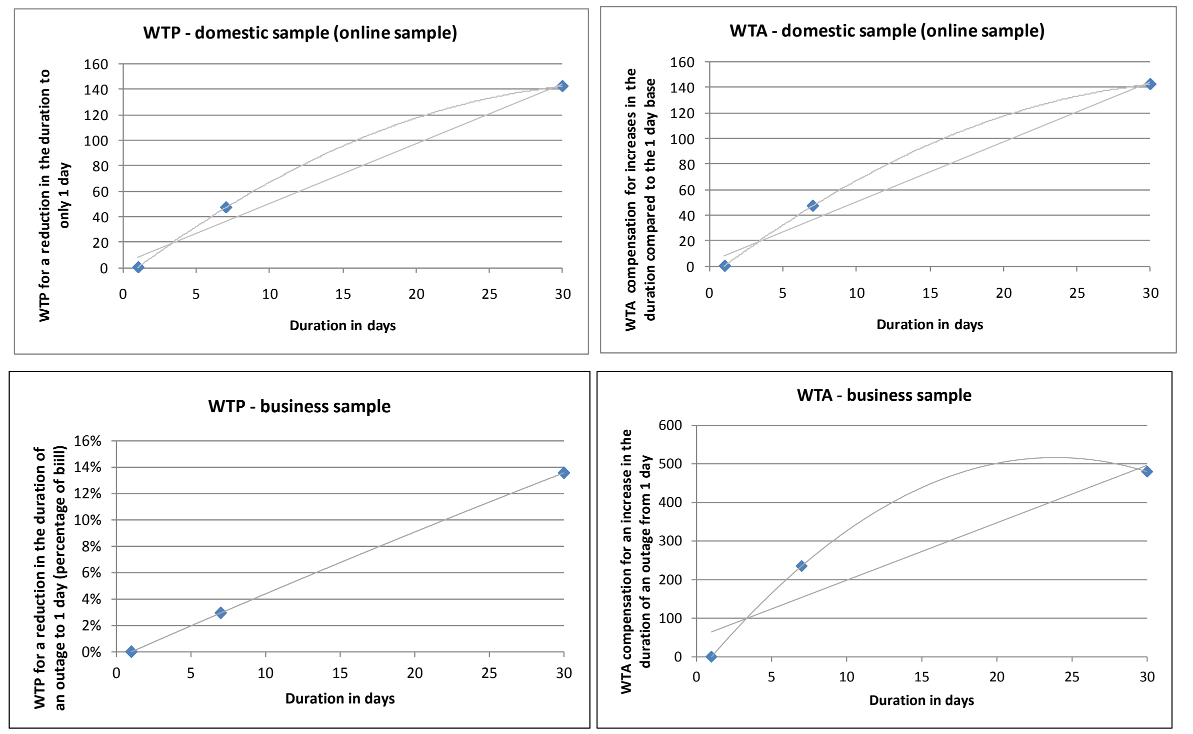
In order to estimate the level of VoLL it is necessary to include at least one variable as a continuous variable. We include frequency as a set of dummy variables and duration as a continuous variable. We allow for non-linearity in duration and include higher order terms for duration (and all interactions).

In addition to non-linearities, it is necessary to allow for interactions between the attributes. For example, it is important to take account of the fact that the inconvenience (i.e., loss of utility) suffered by a gas consumer as a result of a load loss of a given duration is likely to vary according to the season when the event occurs. Similarly, a loss of a given duration in a given season is likely to be judged differently depending on the expected frequency of the event. Therefore, in the estimation of the WTA and WTP, the variables “season” and “frequency of event” are entered in the model as dummies interacting with the “duration” variable rather than stand-alone variables.

2.5.3 Model selection procedure

An initial analysis using dummies for duration to estimate WTP and WTA for different changes in the duration parameters showed that a quadratic model would be more appreciate in three out of four cases for WTP and WTA and for the domestic sample and the SME sample (Figure 5). Only in the case of WTP for businesses might a linear model be more appropriate given the initial inspection of the data. Therefore, allowing for a quadratic model and then testing whether the quadratic terms are statistically significant in the models for each sub-sample was adopted as the most appropriate approach.

Figure 5: Illustration of non-linear duration effect



Note: Points estimated based on the model:

$\text{Choice}_i = \alpha + \beta1{*}\text{week}_i + \beta2{*}\text{month}_i + \beta3{*}(\text{Duration}_i{*}\text{Summer}_i) + \beta4{*}(\text{Duration}_i{*}\text{Frequency1/20}_i) + \beta7{*}(\text{Duration}_i{*}\text{Frequency1/50}_i) + \delta{*}\text{Monetary Value}_i + \varepsilon_i$

The reference category is a day outage in the winter occurring once every 5 years.

Week and Month are dummies equal to 1 if the outage lasted a week and a month respectively and 0 otherwise.

Linear and quadratic trend lines added to illustrate the non-linearity of the relationship.

Source: London Economics

Therefore, for both domestic and SME gas users and for both the WTP and the WTA analysis we use the same quadratic model to estimate the choice:

$$\text{Choice}_i = \alpha + \beta_1{*}\text{Duration}_i + \beta_2{*}\text{Duration}^2_i + \beta_3{*}(\text{Duration}_i{*}\text{Summer}_i) + \beta_4{*}(\text{Duration}^2_i{*}\text{Summer}_i) + \beta_5{*}(\text{Duration}_i{*}\text{Frequency1/20}_i) + \beta_6{*}(\text{Duration}^2_i{*}\text{Frequency1/20}_i) + \beta_7{*}(\text{Duration}_i{*}\text{Frequency1/50}_i) + \beta_8{*}(\text{Duration}^2\text{i}{*}\text{Frequency1/50}_i) + \delta{*}\text{Monetary Value}_i + \eta{*}\text{Don't know dummy} + \varepsilon_i$$

Where:

- "Duration" is a discrete variable taking the values 1, 7 and 30 days depending on the attribute level of the alternative.
- "Summer" is a dummy variable taking the value 1 if summer was one of the attributes and 0 otherwise.
- "Frequency1/20" is a dummy variable taking the value of 1 if, on the choice card, the event was specified to occur once every 20 years and a value of 0 otherwise.
- "Frequency1/50" is a dummy variable taking the value of 1 if, on the choice card, the event was specified to occur once every 50 years and a value of 0 otherwise.

- "Don't know dummy" is equal to one if the respondent answered 'Don't know'. This is included to avoid biases in the parameter estimates

We use the worst case scenario of outages every 5 years in the winter as the reference category for the estimation.

We note that variables with insignificant parameter estimates are not eliminated because this may in some cases imply that VoLL estimates for all attribute levels cannot be achieved. WTP and WTA estimates can be calculated although the parameter estimates are insignificant and insignificance of the parameter estimates does not necessarily lead to insignificance of the corresponding WTP and WTA estimates.

Estimation results for a linear model without the squared duration term and its interactions are presented in Annex 4. In addition, the model is run for different subgroups of respondents to examine how different respondents value security of supply.

2.5.4 Calculating WTP and WTA from the estimation results: transformation of parameter estimates

Once the model is estimated, the marginal WTA and WTP estimates are computed directly from the model specified. For example, the ratio of the following two coefficients yields the WTA (if there are no squared terms or interaction terms).:

$$WTA_{duration} = \frac{\beta_1}{\delta}$$

where β_1 indicates the parameter of the duration variable (if there had been no interaction or squared terms in the model). It is important to note that, if interaction effects/parameters and squared effects are included in the model, then these may impact the WTA, and the prediction should be for a given level of the other variable. In the estimated model we have interaction terms and squared terms. Therefore, to estimate the WTA compensation for a 1 day outage occurring in the winter and with a 5-year frequency, we apply the following formula:

$$WTA_{1\ day,winter,5\ years} = \frac{\beta_1 + \beta_2}{\delta}$$

Where β_1 indicates the parameter of "duration" while β_2 indicates the parameter of "duration^2". Recall that winter and 1 in 5 years is the reference category for the estimation as a result we do not need to account for interaction effects in this case. However, as another example, consider the case of a 1-day outage occurring in the summer. In this case, the following parameter transformation is required:

$$WTA_{1\ day,summer,5\ years} = \frac{\beta_1 + \beta_2 + \beta_3 + \beta_4}{\delta}$$

Where β$_3$ and β$_4$ are the parameters of the interaction terms between summer and the duration terms.

Standard errors and confidence intervals for the WTP and WTA estimates are calculated using the delta method[9] for parameter transformations used to generate WTP and WTA estimates. This means that the standard errors depend on the variance and covariance of the parameter estimates.[10]

2.6 VoLL estimates for domestic gas users

The on-line sample is largely representative of the GB population (see Annex 1 for a comparison between sample and population characteristics) and therefore we use this sample to obtain our baseline VoLL estimates for domestic gas users in GB. We note that, by adding the face-to-face results to the dataset, vulnerable groups would be overrepresented in the sample, unless the observations were to be reweighted and the weight given to vulnerable groups reduced to construct a representative sample. The data from the face-to-face interviews is used to analyse if the results are different for the face-to-face sample and if the results are different for vulnerable groups compared to non-vulnerable groups. Similar analysis is undertaken for other personal characteristics.

The summary estimation results for the quadratic model are provided for WTA and WTP in Figure 6 and Figure 7, respectively. The sign of the parameter indicates whether an attribute increases or decreases the likelihood that an alternative scenario is chosen by the respondent. These signs in both cases are as we would expect.

In both the WTP and WTA regressions it is the case that a longer duration of the outage reduces the likelihood that an alternative is chosen (hence resulting in a negative sign on the “duration”

---

[9] When parameter transformations are non-linear, as is the case when WTP and WTA are calculated, the delta method can be used to estimate the variance of the transformed variable.. The delta method expands the function used to transform the parameter estimates around its mean, usually with a one-step Taylor approximation, and then takes the variance. For example, in the simple case where WTA is estimated by:

$$WTA_{duration} = \frac{\beta_1}{\delta}$$

A first order Taylor expansion would yield:

$$WTA_{\text{duration}} = \frac{\beta_1}{\delta} \approx \frac{b_1}{d} + \frac{-b_1}{d^2}(\beta_1 - b_1) + \frac{1}{d}(\delta - \mathrm{d})$$

Where d is the estimate of δ and b$_1$is the estimate of β_1. Taking the variance of this expression yields an estimate of the variance of WTA:

$$Var(WTA_{\text{duration}}) \approx \frac{b_1^2}{d^4} Var(\beta_1) + \frac{1}{d^2} Var(\delta) - \frac{2\mathrm{b}_1}{\mathrm{d}^3} \mathrm{cov}(\beta_1, \delta)$$

[10] The delta method is implemented in Stata using the nlcom command.

variable) but this effect decreases with the length of the duration (shown by the positive sign on the squared term “duration2”). In both cases it is also the case that alternatives occurring in the summer are more likely to be chosen by respondents (a positive sign on “duration*summer”) as are alternatives occurring less frequency (positive signs on “duration*1 in 20” and “duration*1 in 50”). These effects all diminish as the duration increases.

The estimation results also show that respondents are more likely to choose an alternative if there is a high level of compensation associated with that alternative (Figure 6) and that they are less likely to choose an alternative if there is a high bill increase (price) associated with that alternative (Figure 7).

Figure 6: Baseline estimation results of the model for willingness to accept (on-line survey)

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.34552	0.01802	-19.17	0.000	-0.38084	-0.3102
Duration^2	0.008788	0.000648	13.57	0.000	0.007519	0.010057
Duration * Summer	0.254475	0.016552	15.37	0.000	0.222033	0.286917
Duration^2 * Summer	-0.00688	0.000571	-12.06	0.000	-0.008	-0.00576
Duration * 1 in 20	0.063464	0.021027	3.02	0.003	0.022252	0.104676
Duration^2 * 1 in 20	-0.00218	0.000753	-2.89	0.004	-0.00365	-0.0007
Duration * 1 in 50	0.10926	0.017293	6.32	0.000	0.075366	0.143154
Duration^2 * 1 in 50	-0.00364	0.000645	-5.64	0.000	-0.0049	-0.00237
Compensation	0.005608	0.001227	4.57	0.000	0.003202	0.008013
DK option	-3.29454	0.099572	-33.09	0.000	-3.4897	-3.09938

Source: London Economics analysis of the on-line household survey results

Figure 7: Baseline estimation results of the model for willingness to pay (on-line survey)

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.25713	0.015825	-16.25	0.0000	-0.28815	-0.22612
Duration^2	0.005429	0.000521	10.41	0.0000	0.004407	0.00645
Duration * Summer	0.121751	0.015277	7.97	0.0000	0.091809	0.151693
Duration^2 * Summer	-0.00281	0.000517	-5.43	0.0000	-0.00382	-0.00179
Duration * 1 in 20	0.141787	0.01878	7.55	0.0000	0.104979	0.178596
Duration^2 * 1 in 20	-0.00375	0.000653	-5.75	0.0000	-0.00503	-0.00247
Duration * 1 in 50	0.119009	0.017034	6.99	0.0000	0.085622	0.152395
Duration^2 * 1 in 50	-0.00301	0.000582	-5.18	0.0000	-0.00415	-0.00187
Price	-0.0218	0.000772	-28.25	0.0000	-0.02331	-0.02029
DK option	-3.94474	0.09881	-39.92	0.0000	-4.1384	-3.75107

Source: London Economics analysis of the on-line household survey results

For the derivation of the WTA and WTP under different circumstances, it is important to note that, for example:

- The estimated coefficient of the duration variable when it is winter and the event is likely to occur once every 5 years is given by the coefficient of “duration” plus the coefficient on squared term “duration^2” times the duration of the outage.

- In contrast, the estimated coefficient of the duration variable when it is summer and the event is likely to occur once every 5 years is given by the sum of the coefficients of “duration”, “duration^2”, “summer” and “duration*summer”.

Figure 8 gives estimates of domestic gas users WTA compensation of outages of different length (day, week and month), for different seasons (summer and winter) and for different frequencies (1 in 50 years, 1 in 20 years and 1 in 5 years). Confidence intervals for the estimates are also provided and estimates of WTA that are statistically different from £0 are in bold.

The figures in the table provide estimates of how much total compensation consumers would require in order to accept an outage of the specified duration, frequency and season. For example, for a one-day outage occurring in the summer once in 5 years, consumers would on average require compensation of £15.9. However, for a one-month outage occurring in the winter once in 5 years, consumers would on average require total compensation of £438.11 for the whole month (i.e. not per day) without gas.

The WTA ranges from estimates not statistically different from £0 (for 1 day and 1 week supply loss in summer time occurring at a frequency of 1 every 50 years or once every 20 years) to £438.11 (for a 30-day supply loss occurring in winter time at a frequency of 1 every 5 years). There is a clear tendency that domestic consumers require a higher total compensation for longer outages, for outages in the winter and for relatively frequent outages (i.e. outages occurring once every 5 years). The results also suggest that consumers require little or no compensation for outages in the summer that are relatively short and infrequent.

Figure 8: Estimates of WTA in £ per outage in different circumstances, figures not normalised to a per day basis – households (on-line survey)

	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
1 in 50	-2.94		**41.21**		-7.62		**249.91**		**181.02**		**437.24**	
Confidence interval:	-8.88	3.00	22.38	60.05	-41.70	26.46	136.71	363.11	77.92	284.12	248.97	625.51
1 in 20	4.97		**49.12**		36.79		**294.33**		**191.00**		**448.08**	
Confidence interval:	-3.45	13.38	27.03	71.20	-12.00	85.59	162.97	425.68	105.09	276.91	257.25	638.92
1 in 5	**15.90**		**60.05**		**96.99**		**354.52**		**180.15**		**438.11**	
Confidence interval:	6.64	25.16	34.54	85.55	41.93	152.04	203.75	505.29	95.79	264.52	232.53	643.68

Note: Confidence intervals are calculated based on standard errors derived using the delta method. Numbers in bold are statistically significant.

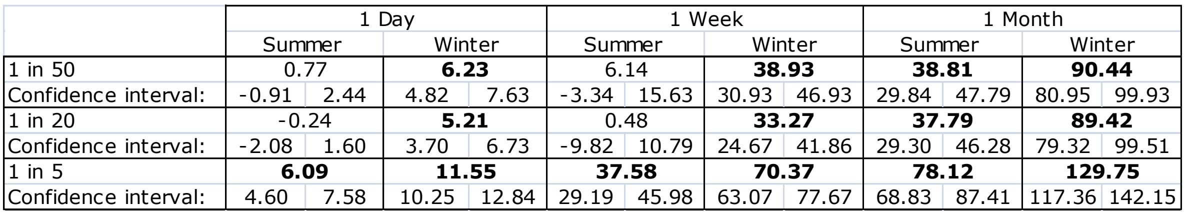
Source: London Economics analysis of the households on-line survey results

Figure 9 provides estimates of how much consumers would be prepared to pay to avoid gas outages of the specified duration, frequency and seasonal timing. For example, the estimates suggest that domestic consumers would be prepared to pay £6.09 per year to avoid a scenario where gas outages occur once in 5 years, in the summer and lasts one day. In contrast they would be willing to pay £129.75 to avoid a scenario where outages occur with the same frequency but in the winter and every time lasts for a month.

The WTP estimates of the value of secure supply in Figure 9 range from estimates not statistically different from £0 (one day or one week in summer at a frequency of 1 in 50 years or 1 in 20 years) to £129.75 (1 month in winter at a frequency of 1 in 5 years).

Largely, the same pattern is shown by WTA estimates, with estimates increasing with the duration as well as with the frequency and with higher estimates for winter outages than for summer outages. However, the pattern is less pronounced for WTP than for WTA and in particular estimates for frequencies of 1 in 50 years and 1 in 20 years are very similar (with confidence intervals overlapping) suggesting that respondents do not make a distinction between these two cases.

Figure 9: Estimates of WTP in £ per year in different circumstances, figures not normalised to a per day basis – households (on-line survey)



	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
1 in 50	0.77		**6.23**		6.14		**38.93**		**38.81**		**90.44**	
Confidence interval:	-0.91	2.44	4.82	7.63	-3.34	15.63	30.93	46.93	29.84	47.79	80.95	99.93
1 in 20	-0.24		**5.21**		0.48		**33.27**		**37.79**		**89.42**	
Confidence interval:	-2.08	1.60	3.70	6.73	-9.82	10.79	24.67	41.86	29.30	46.28	79.32	99.51
1 in 5	**6.09**		**11.55**		**37.58**		**70.37**		**78.12**		**129.75**	
Confidence interval:	4.60	7.58	10.25	12.84	29.19	45.98	63.07	77.67	68.83	87.41	117.36	142.15

Note: Confidence intervals are calculated based on standard errors derived using the delta method. Numbers in bold are statistically significant.

Source: London Economics analysis of the households on-line survey results

2.6.1 VoLL per day estimates

One should not conclude from the estimates reported in Figure 8 and Figure 9 that WTA is always higher than WTP because the WTA refers to a one-off payment following the occurrence of a supply interruption while the WTP implicitly refers to an annual payment to avoid an interruption. To compare the estimates it is useful to convert the results to a per-day-without-gas basis. All VoLL estimates presented in this section should therefore be interpreted as the value of one day's worth of gas supply loss in the specified scenarios.

Furthermore, in order to properly compare WTA and WTP, it is necessary to estimate the present value of both under different timings of the supply interruption. The payments under the WTP experiment will occur over a 5, 20 or 50 year period and therefore need to be discounted because to consumers the value of £1 paid today is higher than the value of £1 paid at some point in the future even disregarding the effect of inflation.

Similarly, a compensation payment of £1 today is worth more to the consumer than a compensation payment received of £1 received at some point in the future. So the value of the compensation to consumers depends on when the outage actually occurs over the period in question.

The HMT Green Book recommends using the real discount rates summarised in Table 14. It should be noted that discounting by these rates rightly does not account for inflation. It only accounts for the value individuals attaches to current, as opposed to future, consumption.

Table 14: Declining long term discount rates

Period of years	Discount rate
0-30 years	3.5%
31-75 years	3.0%

Source: HMT Green Book

VoLL per day based on the WTA estimates thus depends on when the outage occurs. The highest VoLL per day estimates are obtained if the compensation payment is received at the beginning of the period. For example, in the case of an outage occurring once in 50 years the maximum VoLL estimate is associated with an outage occurring in the first year of the 50 year period.

Using the same logic, lower bound VoLL per day estimates are based on outages that occur at the end of the period in which case the compensation payment is discounted to a present value estimate. Upper bound VoLL per day estimates based on WTA per day are provided in Figure 10 and lower bound VoLL per day estimates based on WTA are provided in Figure 11.

In both cases, the estimates of VoLL per day are higher in the winter than in the summer and for more frequent outages. It is worth noting that VoLL per day for long outages is lower than VoLL per day for shorter outages. This may reflect that consumers make alternative arrangements (such as purchasing an electric heater) in the case of a long outage. This may imply that consumers experience some initial fixed costs associated with an outage and as a result they may require less compensation per day once those alternative arrangements have been put into effect.

Figure 10:Upper bound VoLL in £ per day of outage - based on WTA per day for an outage occurring at the beginning of the period

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-2.9	**41.2**	-1.1	**35.7**	**6.0**	**14.6**
1 in 20	5.0	**49.1**	5.3	**42.0**	**6.4**	**14.9**
1 in 5	**15.9**	**60.0**	**13.9**	**50.6**	**6.0**	**14.6**

Note: Numbers in bold are statistically significant.
Source: London Economics

Figure 11: Lower bound VoLL in £ per day of outage - based on WTA per day for an outage occuring at the end of the period

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-0.6	**8.1**	-0.2	**7.0**	**1.2**	**2.9**
1 in 20	2.5	**24.7**	2.6	**21.1**	**3.2**	**7.5**
1 in 5	**13.4**	**50.6**	**11.7**	**42.6**	**5.1**	**12.3**

Note: Numbers in bold are statistically significant.
Source: London Economics

In between the upper and lower bound lies the expected value of the compensation over the period. In the case of an outage occurring every 5 years, the risk of an outage is 20% every year and hence the expected value of the compensation in each year in the 5 year period is 20% multiplied by the level of compensation provided. This stream of expected compensation payments is discounted to derive the present value of the expected compensation payments. This information is provided in Figure 12 and these estimates are clearly between the upper and lower bound estimates provided above.

As an example to illustrate the interpretation of the results, consider the case of outages occurring once in 5 years, in the summer and lasting for one day. The results suggest that VoLL per day i.e. consumers' valuation of one additional day of secure supply is £14.4 in this case. For one-month outages occurring every 5 years in the summer, the value of one additional day of secure supply is £5.4 according to the results of the WTA experiment.

Figure 12:VoLL in £ per day of outage - based on WTA per day using discounted payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-1.4	**19.5**	-0.5	**16.9**	**2.9**	**6.9**
1 in 20	3.5	**34.9**	3.7	**29.9**	**4.5**	**10.6**
1 in 5	**14.4**	**54.2**	**12.5**	**45.7**	**5.4**	**13.2**

Note: Numbers in bold are statistically significant.
Source: London Economics

To obtain VoLL per day of outage estimates based on the WTP estimates in Figure 9, the yearly payments must be discounted and summed over the 5, 20 and 50 year periods and then divided by the number of days of payment that will occur over that period. For example, in the case of a week-long outage occurring every 5 years, the annual payments over the 5 year period must be discounted, summed and divided by 7 days to obtain a VoLL-per-day estimate from the WTP experiment. These are provided in Figure 13.

Figure 13:VoLL in £ per day of outage - based on WTP per day with discounted annual payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	18.2	**147.5**	20.8	**131.8**	**30.7**	**71.4**
1 in 20	-3.4	**74.1**	1.0	**67.5**	**17.9**	**42.4**
1 in 5	**27.5**	**52.1**	**24.2**	**45.4**	**11.8**	**19.5**

Note: Numbers in bold are statistically significant.
Source: London Economics

It is interesting to compare the VoLL estimates obtained from the WTP experiment with the VoLL estimates obtained from the WTA experiment. Usually WTP estimates are lower than WTA estimates because respondents oppose the idea of having to pay for a secure supply (especially if they think they already have a secure supply). However, in this case, most of the WTP estimates of VoLL per day are larger than the WTA estimates of VoLL, the exception being 1-day and 1-week outages occurring in the winter where the estimates from the two experiments are almost identical.

The WTP estimates of VoLL per day are particularly large compared to the WTA estimates for outages occurring less often. There may be several reasons for this result. Firstly, it may reflect that consumers have difficulty forming preferences and hence responding to hypothetical scenarios that occur so infrequently.

Secondly, respondents may not have properly taken into account the total amount that would be payable per day of outage for very infrequent interruptions. For example, in the case of interruptions only occurring every 50 years, consumers would face the bill increase every year in that period but only experience an outage in one year. This may be because consumers have difficulties forming preferences over very long time periods or because it is more difficult for respondents to calculate the economic effects in the WTP experiment where payments are not as closely linked to the duration and occurrence of an outage as in the WTA experiment.

2.6.2 VoLL per therm estimates

Based on the VoLL per day estimates presented in the previous section it is straightforward to calculate estimates of VoLL per therm using an estimate of the number of therms used by domestic consumers per day. Ofgem estimates that the average domestic household uses 1.54 therms per day.[11]

VoLL per therm estimates are provided in Figure 14 and Figure 15 using the results from the WTA experiment and the WTP experiment, respectively.

Figure 14: VoLL per therm estimate - based on WTA per day using discounted payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-0.9	**12.7**	-0.3	**11.0**	**1.9**	**4.5**
1 in 20	2.3	**22.6**	2.4	**19.4**	**2.9**	**6.9**
1 in 5	**9.3**	**35.2**	**8.1**	**29.6**	**3.5**	**8.5**

Note: Numbers in bold are statistically significant.
Source: London Economics

Figure 15:VoLL per therm estimate - based on WTP per day with discounted annual payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	11.8	**95.6**	13.5	**85.4**	**19.9**	**46.3**
1 in 20	-2.2	**48.0**	0.6	**43.8**	**11.6**	**27.5**
1 in 5	**17.8**	**33.8**	**15.7**	**29.4**	**7.6**	**12.7**

Note: Numbers in bold are statistically significant.
Source: London Economics

2.6.3 WTA and WTP for different domestic consumer groups

This section analyses to what extent the WTA and WTP of domestic consumers vary according to their personal characteristics.

We present the results focusing on WTA and WTP for gas outages lasting one month and occurring once in 20 years in the winter time. This scenario is chosen as the basis for comparison because it may be considered the most realistic (future) scenario as discussed in further detail in section 2.2.1. Detailed results for other durations, frequencies and summer outages are included in Annex A as are exact definitions of the sub-samples being considered.

---

[11] According to Ofgem (2011): Typical domestic energy consumption figures, factsheet 96, medium annual domestic gas consumption equals approximately 16,500kWh. This amounts to 45.21 per day. Given that 1 therm = approximately 29.31 kWh, it follows that medium consumption households use approximately 1.54 therms per day.

WTA estimates

Figure 16 provides a graphical representation of the WTA estimates for an outage lasting one month and occurring one time in 20 years in the winter for different sub-samples compared to the baseline estimates presented in the previous subsections. We note that, as the comparison is for a given duration, frequency and season of outage, the estimates are WTA estimates that have not been converted in any way and represent undiscounted total WTA for the entire outage.

Interestingly, we observe that the level of compensation required by respondents in the face-to-face interviews, by vulnerable consumers (including vulnerable consumers from both the face-to-face survey and from the online survey) and by consumers who cannot keep their home heated to a comfortable level is lower than the level of compensation required by the average respondent (i.e., the baseline estimate).

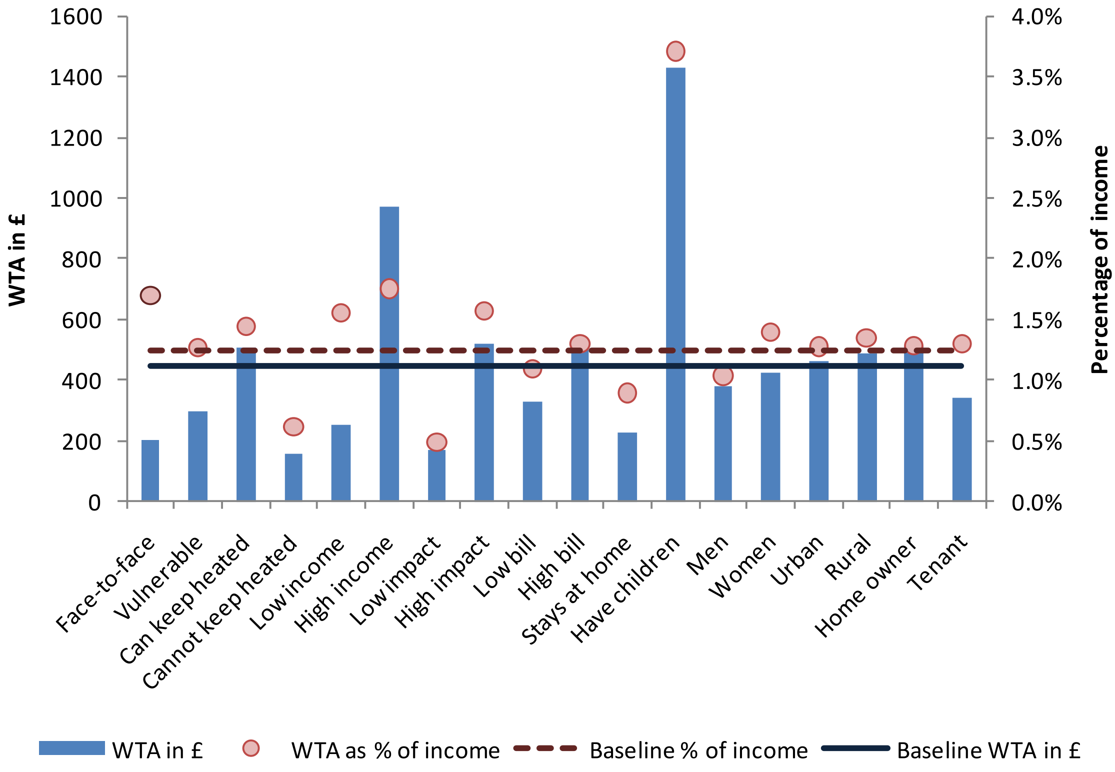
This appears to be partly due to an income effect whereby these individuals require less compensation because they also have a low income. When computing the WTA as a percentage of income, we find that vulnerable consumers require the same compensation as the average consumer in the baseline. While respondents participating in the face-to-face interviews require compensation that amounts to a higher percentage of their income, respondents who cannot keep their home heated to a comfortable level require less compensation, even when taken as a percentage of income.

In general, the analysis shows that consumers with low income state that they would require less compensation than consumers with a high income but the difference is less pronounced if compensation is expressed as a percentage of income.[12]

---

[12] We note that the WTA estimates as a percentage of income for low and high income respondents are both above the baseline estimate. There are a number of possible explanations for this result. Firstly, the estimates for the low and high income sub-samples are based on the combined on-line and face-to-face samples while the baseline estimate is only based on the on-line sample. Secondly, approximately 21% of the combined sample could not be included in the estimation of WTA for high- and low-income because they responded ‘don’t know’ or ‘prefer not to answer’ to the question about their income.

Figure 16:WTA a one-month outage once in 20 years in the winter – various groupings of domestic consumers



Source: London Economics

The amount of compensation required is also lower for consumers who say an outage would have a low impact on them given the alternatives to gas available to them compared to those who say an outage would have a large impact. This is a very intuitive result because the compensation required would be expected to increase with the impact of the outage. This holds even when compensation is expressed as a percentage of income.

Similar arguments hold for the relationship between the amount of compensation required and the size of the bill. A high bill is associated with high gas usage and the impact of an outage tends to be greater for consumers that use a large amount of gas (Table 15). We find that the level of compensation required is higher for consumers with a large gas bill than for consumers with a relatively low gas bill.

Table 15: Impact of gas outages and average annual gas bill

Impact of gas out age	Average annual gas bill
Low impact	£828.53
High impact	£928.34

Note: Average annual gas bill calculated using the mid-points of ranges shown to survey respondents. For the range ‘less than £250 per year’ £250 is used. For the range ‘more than £2,500 per year’ £2,500 is used. Respondents are defined as low impact if an outage would have ‘no impact’ or ‘a small impact’ on their household, and are defined as high impact if an outage would have ‘a large impact’ or ‘a very large impact’ on their household.

Source: London Economics analysis of on-line survey data.

It might be expected that people who stay at home during weekdays (i.e. do not work) are more affected by long-lasting gas outages than consumers who work. However, we do not find this to be the case and, in fact, survey results suggest that people who work say that there is a greater impact of gas outages than consumers who stay at home (Table 16). As a result, consumers who stay at home tend to state that they require less compensation in both monetary terms and as a percentage of income. However, the difference to the baseline is smaller when taken as a percentage of income because people who stay at home generally have a lower income.

Table 16: Share with 'low' and 'high' impact of gas outages by whether they stay at home

	Low impact	High impact
Staying at home	24%	76%
Working	21%	79%

Note: Respondents defined as 'staying at home' if their employment status is 'unemployed', 'retired' or 'looking after home/family'. Respondents defined as 'not staying at home' if their employment status is 'employed', 'student or 'other'.
Source: London Economics analysis of on-line survey data.

The survey also shows that consumers with children perceive a slightly greater impact of a gas outage than consumers with no children (Table 17) and the estimate of WTA for consumers with children is indeed very high. However, it should be noted that this estimate, while large, is not statistically different from zero because there is great variation in the results.

Table 17: Share with 'low' and 'high' impact of gas outages by whether they have children

	Low impact	High impact
Children	20%	80%
No children	22%	78%

Source: London Economics analysis of on-line survey data.

The various WTA estimation results also suggest that women and men require almost the same level of compensation. Similarly, there is not a significant difference between WTA for consumers in rural and urban areas. Finally, we find that tenants require slightly less compensation in pounds than home owners but an equal value when expressed as a percentage of income.

It should be noted that some of the estimates presented are not statistically different from zero because of relatively large variation in the results within the subgroup. In particular, the estimates for high income consumers, consumers with children and consumers living in rural areas are not statistically significant. We note that the rural subgroup is very small (74 respondents) and this explains why there is less certainty around the WTA estimate.

For consumers with a high income and consumers with children, the regression results show a very strong duration effect and much less impact of compensation on their choices in the choice experiment (regression results included in the annexes). This suggests that duration is a very important attribute for these consumers and that they require a large compensation for long-duration outages.

WTP estimates

Figure 17 provides a graphical representation of the WTP estimates for an outage lasting one month and occurring once in 20 years in the winter for different sub-samples compared to the baseline estimates presented in the previous subsections. We note that, as the comparison is for a given duration, frequency and season of outage, the estimates are WTP estimates have not been converted in any way and represent undiscounted WTP per year.

Firstly, it is worth noting that there is far less variation in the WTP estimates for different sub-samples than there is in the WTA estimates. This is also reflected by the WTP estimates being statistically significant for all subgroups while there were some statistically insignificant WTA estimates.

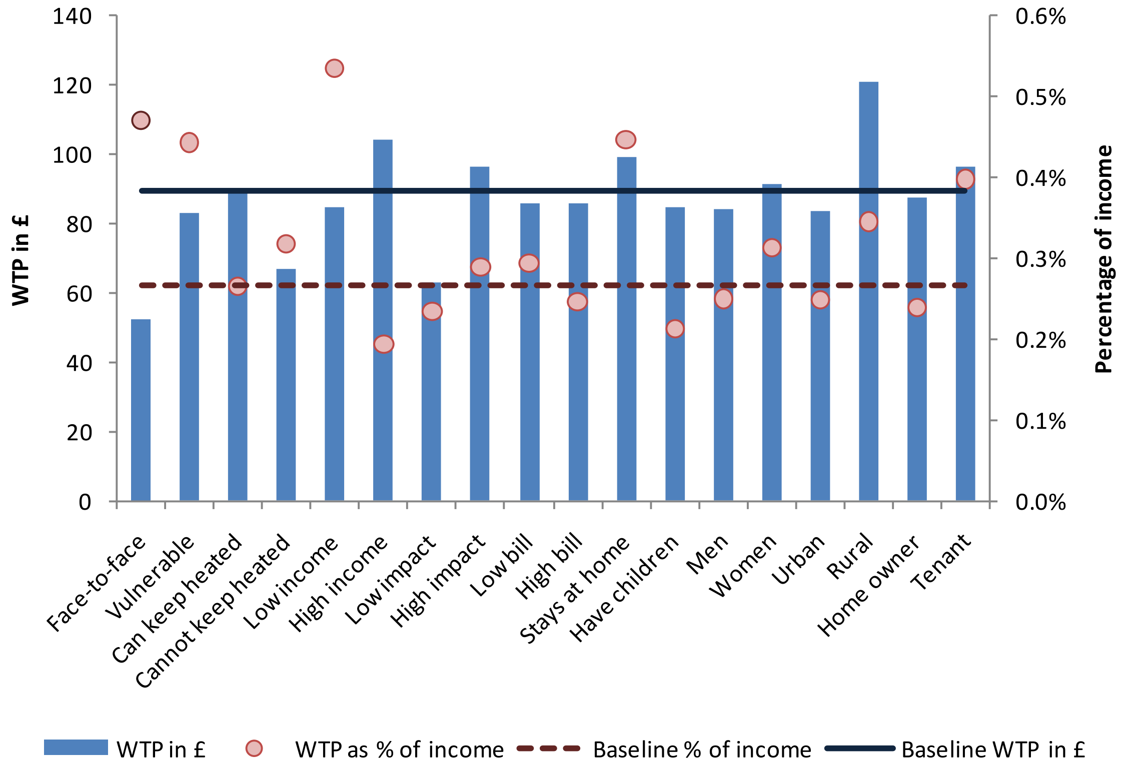
It is also worth noting that, like for WTA, we find that WTP estimates for the following groups are lower than the baseline estimates:

- the face-to-face sample;
- vulnerable consumers;
- consumers who cannot keep their home heated to a comfortable level;
- consumers with low income;
- consumers who think a gas outage will have a relatively low impact on them; and
- consumers with a low gas bill.

When expressing WTP as a percentage of income, the results of the WTP calculations show that face-to-face respondents, vulnerable consumers and consumers with a low income have a higher WTP relative to their income than the average consumer (illustrated by the baseline case). All of these groups have a relatively low income and the results could indicate that they overestimate their ability to pay for service improvements. Alternatively, it could indicate that these groups are relatively more adversely hit by outages and, therefore, actually are willing to pay more as a percentage of income than the average consumer. We note that we also found WTA as a percentage of income to be larger than the baseline for these groups.

As in the case of the estimation of the WTA, we also find that WTP estimates for consumers with a high income and consumers who think an outage lasting 2 months will have a high impact are higher than the baseline WTP estimates. While those who think there will be a high impact of an outage also have a high WTP as a proportion of their income, consumers with a high income have a relatively low WTP as a proportion of their income. As a result, we find that consumers with a high income have a relatively lower willingness to pay for service improvements than consumers with a low income. This latter result is contrary to the WTA analysis where which showed that consumers with low income required less compensation as a proportion of their income than consumers with a high income.

Figure 17:WTP for a one month outage once in 20 years in the winter – domestic consumers



Source: London Economics

As for WTA, the WTP estimates for men, women, consumers in urban areas, homeowners and consumers who feel that they can keep their home heated to a comfortable level are close to the baseline estimates.

However, the results of the WTP estimations also suggest that the size of the annual gas and electricity bill has much less impact on WTP than it did on WTA, and the WTP estimates for these groups are quite close to the baseline estimates.

The WTP analysis also suggests a higher WTP among consumers who do not work (i.e., stay at home during workdays) than for the average consumers as represented by the baseline case. This conclusion holds both in monetary value and when expressed as a percentage of income. This may be related to the fact that this group also report a lower household income and, as already discussed, it may be the case that consumers with low income overestimate their willingness (or ability) to pay.

The results suggest also suggest that people with children have a slightly lower WTP than the baseline. This is contrary to the WTA results which suggested that this group had a much higher valuation of secure supply than the average consumer. However, the WTA estimate for consumers with children was statistically insignificant (although large) and the WTA estimate should therefore be treated with extra care.

Finally, the analysis suggests that WTP for rural consumers and tenants is higher than the baseline, both in monetary values and as a percentage of income. Both groups have relatively low incomes and, as explained above, this may explain part of the effect.

However, in the WTA analysis rural consumers had a WTA comparable to the baseline and the WTA for tenants was below the baseline. We note that the WTA estimate for rural consumers was statistically insignificant and this may explain at least part of the difference for rural consumers.

2.6.4 VoLL estimates using a contingent valuation methodology

This section presents the results of the contingent valuation questions for domestic consumers and the results are related to the results of the choice experiment.

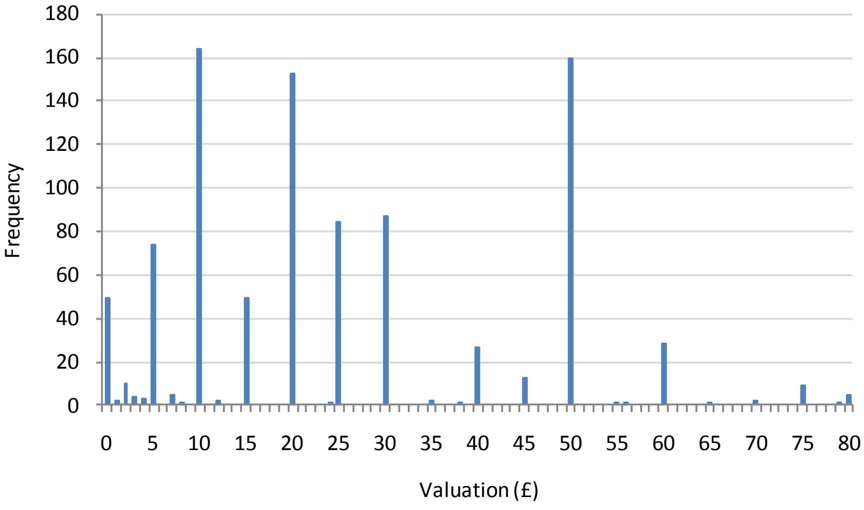
The estimates and analysis are primarily based on the on-line sample in order to ensure that the estimates are based on a representative sample. Results for the face-to-face interview are presented separately at the end of this section and compared to the main results.

WTA estimates

Survey respondents were asked to specify the amount of compensation *per day* they would consider fair for a gas outage occurring in the winter. It should be noted that no frequency or duration was specified in the question.

Consumers' responses to the contingent valuation questions asking respondents to state what they believe to be a fair amount of compensation per day without gas in winter are clustered around particular values. In particular, responses were clustered around valuations of multiples of £5 (Figure 18). It is a general finding in the relevant literature that when using open ended questions such of those used in the survey, respondents have a tendency to choose 'nice' looking numbers and for example are more likely to respond £25 than £24.

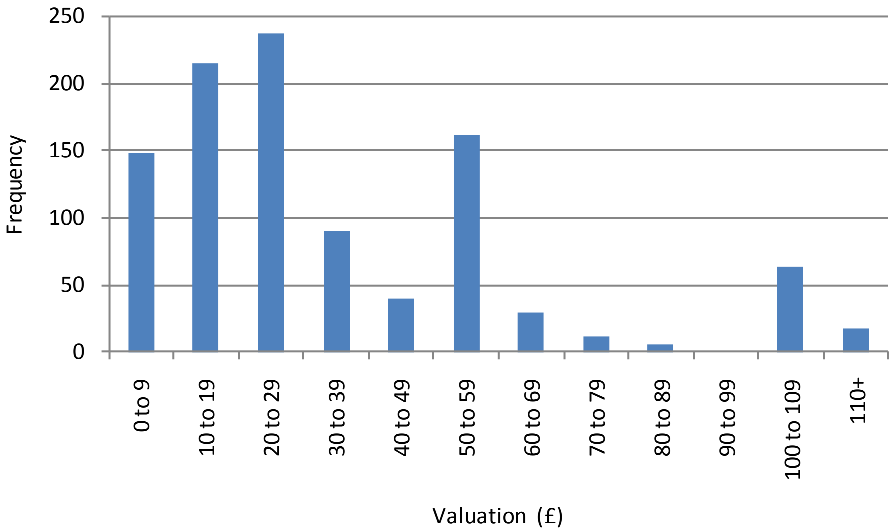
Figure 18: Valuation of fair compensation per day of outage - domestic consumers (frequency)



Note: Only responses in the range £0-£80 are shown. This is to show the clustering of responses.
Source: London Economics analysis of on-line survey data.

Therefore, it is useful to group the responses into different bands. When the data are banded, we see that the frequency rises at the lower end of the scale and peaks in the £20-to-£29 band, before dropping quickly (Figure 19). However, there are two further peaks: in the £50-to-£59 band and £100-to-£109 band. These are caused by respondents clustering around the values of £50 and £100.

Figure 19:Valuation of fair compensation per day of outage - domestic consumers (bands)



Source: London Economics analysis of on-line survey data.

On average, consumers think that a fair amount of compensation would be £38.76 per day[13] of outage in the winter. However, a few respondents think that compensation should be very high with the maximum being £1,500 per day. Table 18 shows how the average changes as more and more of the upper tail of the distribution is excluded. Although the average decreases as observations in the upper tail are removed, there is not a sharp decline. We note that most respondents require less than the average of £38.76 per day with the median being just £20 per day. We also note that when only non-zero responses are included the average compensation required is £40.72 per day and the median is £25 per day.

The average of £38.76 compares well with the results of the WTA choice experiment. The results of the analysis showed that consumers required compensation of between £14.6 per day and £60.0 per day for outages occurring in the winter (with no discounting i.e. as presented in Figure 10). As discussed previously, the required daily amount according to the choice experiment is less for longer lasting outages and for less frequent outages. The £38.76 per day compares particularly well with the per-day compensation requirements for:

- One day outages in the winter once in 50 years (WTA = £41.2 per day).
- One week outages in the winter once in 50 years (WTA = £35.7 per day).

---

[13] All averages calculated based on contingent valuation responses include both zero value responses and non-zero responses unless otherwise stated.

- One week outages in the winter once in 20 years (WTA = £42.0 per day).

The WTA estimates from the choice experiment for more frequent outages are higher and the WTA estimates for longer lasting outages are lower.

It should be noted that the reason why the contingent valuation results compare so well with the choice experiment results may be that the choice experiment preceded the contingent valuation questions and therefore may have set an expectation of a fair level of compensation in the minds of the respondents.

Table 18: Average valuation of fair compensation per day of outage - domestic consumers

Sample	Average (£)	Median (£)	Max. (£)	Min. (£)	Std. Dev.	Sample %[1]
Full sample	38.76	20	1,500	0	89.13	100%
Limited sample: Mean +/-2 std. dev.	30.75	20	200	0	27.81	99%
Limited sample: Mean +/-1 std. dev.	29.88	20	100	0	25.47	98%
Limited sample: Mean +/-0.5 std. dev.	25.10	20	80	0	18.30	92%
Excluding zero responses	40.72	25	1,500	1	90.92	95%

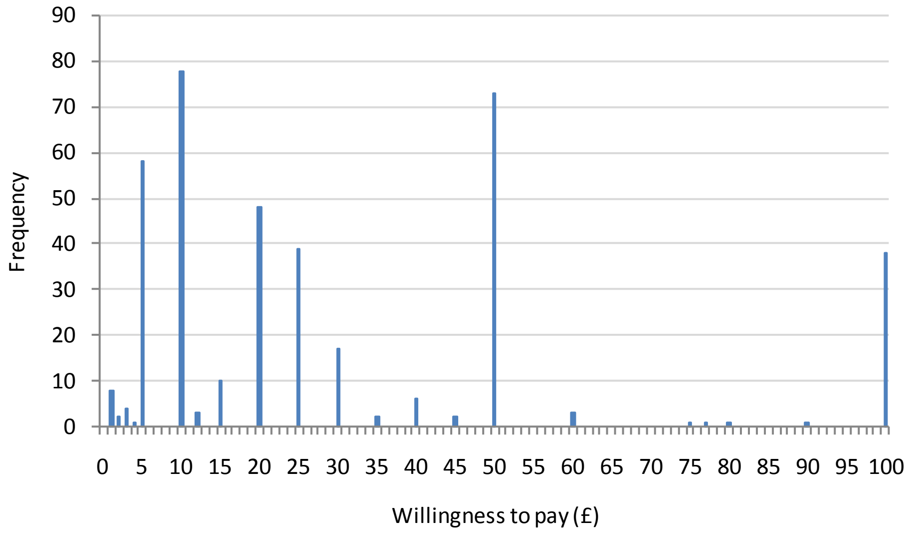
Note: 1. Refers to the number of observations in the sample as a share of the full sample.
Source: London Economics analysis of on-line survey data.

Willingness to pay

The most common response to the contingent valuation question about, what consumers' would be willing to pay for a reduction in the frequency of gas interruptions, is zero. Not surprisingly this suggests that there is a general unwillingness to pay more. This is a known disadvantage of contingent valuation methodologies.

Focusing on positive value responses in the range from £1 to £100, we observe clustering in the responses as we did for WTA (Figure 20). The clustering is again around multiples of £5.

Figure 20:Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers (frequency)

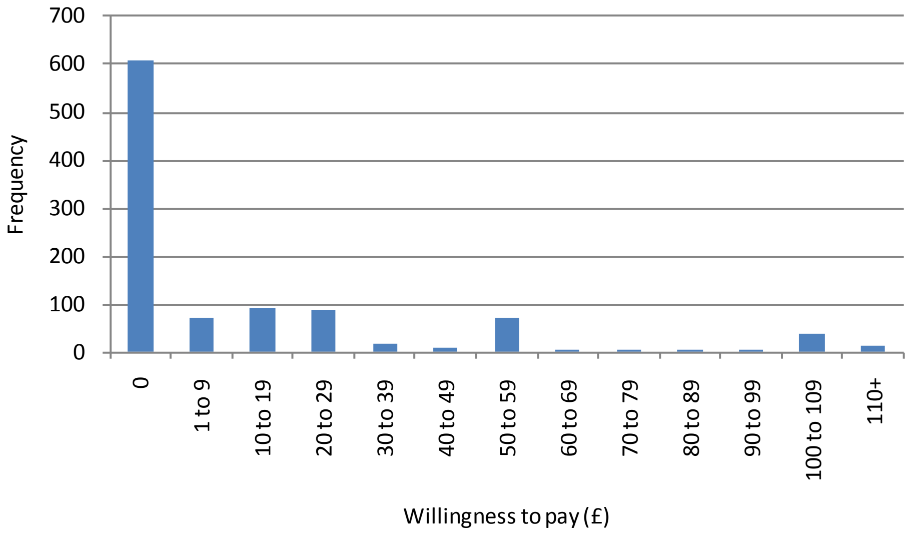


Note: Only responses in the range £1-£100 are shown.

Source: London Economics analysis of survey data.

Grouping the responses into bands shows that generally the WTP is low with very few respondents wanting to pay more than £60 per year (Figure 21).

Figure 21:Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers (bands)



Source: London Economics analysis of survey data.

On average, using the contingent valuation method, consumers are willing to pay £18.33 per year for a reduction in the frequency of gas outages from once in 20 years to once in 50 years. This is somewhat biased by a few very high responses with the maximum WTP being £2,000. When the responses which are greater than the average plus two times the standard deviations are removed from the sample, the average drops to £12.49 per year (see Table 19). The median is £0 per year because 60% of domestic consumers have no WTP for the service improvement. Excluding zero responses the average WTP is £45.54 per year and the median is £20 per year.

Table 19: Average willingness to pay per year for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – domestic consumers

Sample	Average (£)	Median (£)	Max. (£)	Min. (£)	Std. Dev.	Sample %[1]
Full sample	18.33	0	2,000	0	82.64	100%
Limited sample: Mean +/-2 std. dev.	12.49	0	200	0	24.41	99%
Limited sample: Mean +/-1 std. dev.	12.01	0	150	0	23.21	99%
Limited sample: Mean +/-0.5 std. dev.	8.09	0	100	0	14.67	94%
Excluding zero responses	45.54	20	2,000	1	125.49	40%

Note: 1. Refers to the number of observations in the sample as a share of the full sample.
Source: London Economics analysis of survey data.

This average willingness to pay for an improvement in service from the contingent valuation questions is somewhat high compared to the implications of the WTP estimates from the choice experiment. In fact, the choice experiment suggested that consumers did not differentiate between very infrequent events and consumers would not be willing to pay more for a reduction in the frequency from once in 20 years to once in 50 years.

Comparison of face-to-face contingent valuation results with the on-line sample

As observed for the on-line sample, valuations of fair compensation cluster around multiples of £5, especially £5, £10 (the mode), £20, £30 and £50.

Overall the average is £28.65 which is slightly less than the estimate for the on-line sample. This corresponds well with the finding from the choice experiment that vulnerable consumers and consumers in the face-to-face interview require less compensation for outages than the average consumer. As already mentioned, this is likely to be the case because a £1 of compensation is worth more to consumers with a low income (such as vulnerable consumers) than it is to consumers with a high income.

Table 20: Fair compensation and willingness to pay valuations based on contingent valuation responses from the face-to-face sample

	Mean(£)	Med. (£)	Max. (£)	Min. (£)	Std. Dev.
Fair compensation	28.65	20	150	0	27.70
Willingness to pay	3.43	0	50	0	9.68

Source: London Economics analysis of face-to-face survey data.

For willingness to pay for a reduction in the frequency of interruptions, the most common response is zero (83 out of 100 respondents), and the average is only £3.43. This is significantly less than for the representative on-line sample and again supports the finding from the WTP choice experiment that respondents participating in the face-to-face interviews have a lower WTP for secure supply than the average consumer.

2.7 VoLL estimates for SME gas users

This section provides results for estimated WTA and WTP for SME gas users. Estimation results for quadratic models of WTA and WTP are provided in Figure 22 and Figure 23.

The results show that as outage duration increases the likelihood that the alternative is chosen decreases (shown by the negative coefficient on the duration variable). However, the positive coefficient on the duration-squared term shows that this effect decreases as duration increases. Like households, SMEs are more likely to choose summer outages than winter outages.

The results also show that SMEs are more likely to choose alternatives with a high level of compensation (Figure 2), and that SMEs are less likely to choose an alternative if there is a high bill increase (price) associated with that alternative (Figure 2).

Including the variable *'Duration^2 * 1 in 50'* in the WTP model noticeably alters the estimated coefficients of other variables in the model, and results in statistically significant negative estimates of WTP for short outages, suggesting some misspecification in the model. Hence this variable is dropped from the baseline WTP model for SMEs.

Figure 22:Baseline estimation results of the model for willingness to accept (SME survey)

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.23067	0.025092	-9.19	0.000	-0.27985	-0.18149
Duration^2	0.005895	0.000797	7.39	0.000	0.004332	0.007457
Duration * Summer	0.207402	0.021304	9.74	0.000	0.165647	0.249157
Duration^2 * Summer	-0.00615	0.000726	-8.47	0.000	-0.00757	-0.00473
Duration * 1 in 20	0.023452	0.02847	0.82	0.410	-0.03235	0.079253
Duration^2 * 1 in 20	-0.00051	0.00099	-0.51	0.610	-0.00244	0.001435
Duration * 1 in 50	0.058922	0.025425	2.32	0.020	0.009091	0.108754
Duration^2 * 1 in 50	-0.00144	0.000845	-1.7	0.089	-0.00309	0.00022
Compensation	0.005782	0.001288	4.49	0.000	0.003257	0.008307
DK option	-4.08859	0.202394	-20.2	0.000	-4.48528	-3.69191

Source: London Economics analysis of SME survey results

Figure 23:Baseline estimation results of the model for willingness to pay (SME survey)

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.10933	0.023584	-4.64	0.000	-0.15555	-0.06311
Duration^2	0.001627	0.000706	2.3	0.021	0.000244	0.003011
Duration * Summer	0.139379	0.021004	6.64	0.000	0.098211	0.180547
Duration^2 * Summer	-0.00343	0.000715	-4.81	0.000	-0.00483	-0.00203
Duration * 1 in 20	-0.01693	0.025686	-0.66	0.510	-0.06728	0.03341
Duration^2 * 1 in 20	0.00056	0.000889	0.63	0.529	-0.00118	0.002302
Duration * 1 in 50	0.00942	0.00387	2.43	0.015	0.001834	0.017005
Price	-11.6277	0.818278	-14.21	0.000	-13.2315	-10.0239
DK option	-4.41531	0.177879	-24.82	0.000	-4.76394	-4.06667

Source: London Economics analysis of SME survey results

Estimates of WTA and WTP for SMEs are derived in the same way as for households in the previous section (i.e. adding the appropriate estimated coefficients). Figure 24 provides estimates of SMEs WTA compensation for outages of different length, in different seasons, and for different frequencies. WTA estimates that are statistically different from £0 are in bold, and the 95% confidence interval for each estimate is provided.

WTA for SMEs ranges from levels not statistically different from £0 (in the cases of one day or one week outages in summer), to £279.26 for an outage of 30 days occurring in winter at a frequency of 1 in 5 years. As would be expected, SMEs require higher overall compensation for longer outages, winter outages and more frequent outages. The compensation required by SMEs for summer outages is only statistically different from zero for longer outages.

As an example of the interpretation of the estimates, consider the case of one-month outages occurring once in 5 years and in the winter. The estimates suggest that SMEs on average require £279.26 compensation in total for the duration of the outage (i.e. not per day) in order to accept such an interruption.

Figure 24:Estimates of WTA in £ per outage in different circumstances, figures not normalised to a per day basis – SMEs

	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
1 in 50	-5.87		**28.93**		-28.83		**170.14**		**78.27**		**197.17**	
Confidence interval:	-15.34	3.59	14.06	43.80	-82.06	24.39	83.34	256.94	17.77	138.77	99.11	295.23
1 in 20	0.10		**34.91**		6.21		**205.18**		**117.27**		**236.18**	
Confidence interval:	-8.38	8.58	16.10	53.71	-42.13	54.55	97.11	313.26	58.53	176.02	140.43	331.92
1 in 5	4.07		**38.87**		30.32		**229.30**		**160.35**		**279.26**	
Confidence interval:	-4.23	12.37	21.90	55.85	-16.93	77.58	130.24	328.36	86.02	234.69	165.97	392.54

Source: London Economics analysis of SME survey results

The WTP estimates for SMEs range from not statistically different from 0% for one day or one week outages in summer, to 15.61% of the annual gas bill for an outage of 30 days in winter at a 1 in 5 year frequency.

Largely the same pattern arises as for WTA estimates with estimates increasing with the duration as well as with the frequency and with higher estimates for winter outages than for summer outages. However, the pattern is less pronounced for WTP than for WTA and in particular estimates for frequencies of 1 in 5 years and 1 in 20 years are very similar (with confidence intervals overlapping) suggesting that respondents do not distinguish at these frequencies.

The WTP estimates increase with the duration and are higher for winter outages than summer outages. There is little difference between the WTP estimates for different frequencies of outages for one day and one week outages: the confidence intervals for these WTP estimates overlap.

As an example of the interpretation of the estimates, consider the case of one-month outages occurring once in 5 years and in the winter. The estimates suggest that SMEs on average would be willing to pay what amounts to 15.61% of their annual bill per year to avoid this scenario.

Figure 25:Estimates of WTP in £ per year as a percentage of the annual bill in different circumstances– SMEs

	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
1 in 50	-0.32%		**0.85%**		-1.62%		**5.33%**		**3.80%**		**13.18%**	
Confidence interval:	-0.76%	0.11%	0.49%	1.20%	-4.07%	0.84%	3.28%	7.38%	1.84%	5.75%	10.88%	15.49%
1 in 20	-0.10%		**1.07%**		-0.26%		**6.68%**		**6.26%**		**15.65%**	
Confidence interval:	-0.49%	0.28%	0.65%	1.49%	-2.43%	1.91%	4.32%	9.03%	4.04%	8.48%	12.54%	18.75%
1 in 5	-0.24%		**0.93%**		-1.05%		**5.90%**		**6.23%**		**15.61%**	
Confidence interval:	-0.67%	0.19%	0.57%	1.29%	-3.47%	1.38%	3.84%	7.95%	4.21%	8.24%	13.12%	18.11%

Source: London Economics analysis of SME survey results

In order to make the figures comparable with the WTA estimates and to be able to calculate WTP per therm for SMEs it is necessary to convert these figures to monetary values based on estimates of the average size of SMEs' annual gas bill.

As part of the survey, SME respondents were asked to state the size of their annual gas bill. The majority of the respondents (451 out of 500) provided an estimate of their annual gas bill and using the full sample the average annual gas bill was £11,705. However, one respondent stated that the business had a gas bill of £2 million per year. This appears to be a clear outlier and is much higher than any other value provided. Excluding this outlier the average is £7,286.59.

We use this estimate to convert WTP to a monetary value but we note that there is a large variation around this estimate and that it is not obvious if more observations, particularly at the high end of the distribution, should be excluded when calculating the average annual bill for gas users. However, we note that the £2 million value is the most obvious outlier.

Table 21 illustrates how the average changes as more observations are excluded from the estimation of the average annual gas bill for SMEs. We note that the largest decrease (38%) in the average value occurs when the main outlier is excluded.

Finally, we note that as an alternative to the average, the median could have been used. While this could arguably provide a better conversion for the typical user, due to the large variation it would provide a serious underestimate for some SMEs.

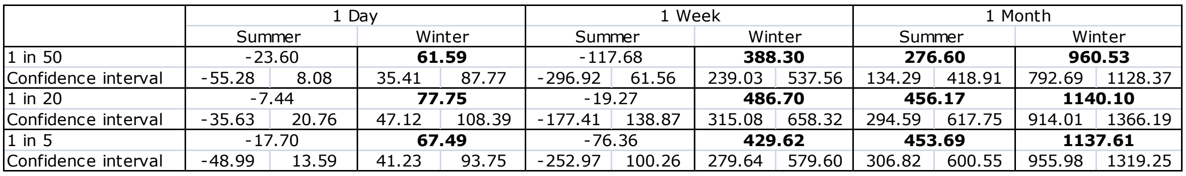
Table 21: Average size of annual gas bill for SMEs (in £)

Sample	Avg. (£)	Med. (£)	Max. (£)	Min. (£)	Std. Dev.	Sample %[1]
Full sample	11,705	1,500	2,000,000	80	97,409	100%
Full sample excluding main outlier	7,287	1,500	350,000	80	26,180	<99%
Limited sample: Mean +/-3 std. dev.	6,523	1,500	300,000	80	20,596	<99%
Limited sample: Mean +/-2 std. dev.	5,868	1,500	140,000	80	15,233	99%
Limited sample: Mean +/-1 std. dev.	5,054	1,500	90,000	80	11,564	99%
Limited sample: Mean +/-0.5 std. dev.	4,029	1,400	60,000	80	7,527	97%

Note: 1. Refers to the number of observations in the sample as a share of the full sample.
Source: London Economics analysis of survey data.

Based on the average annual gas bill estimate of £7286.59, the WTP estimates can be converted to a monetary value. The estimates range from not significantly different from zero to £1,137.

Figure 26:Estimates of WTP in £ per year in different circumstances, figures not normalised to a per day basis – SMEs



	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
1 in 50	-23.60		**61.59**		-117.68		**388.30**		**276.60**		**960.53**	
Confidence interval	-55.28	8.08	35.41	87.77	-296.92	61.56	239.03	537.56	134.29	418.91	792.69	1128.37
1 in 20	-7.44		**77.75**		-19.27		**486.70**		**456.17**		**1140.10**	
Confidence interval	-35.63	20.76	47.12	108.39	-177.41	138.87	315.08	658.32	294.59	617.75	914.01	1366.19
1 in 5	-17.70		**67.49**		-76.36		**429.62**		**453.69**		**1137.61**	
Confidence interval	-48.99	13.59	41.23	93.75	-252.97	100.26	279.64	579.60	306.82	600.55	955.98	1319.25

Source: London Economics analysis of SME survey results

2.7.1 VoLL per day estimates

In order to compare the WTP and WTA estimates we transform and discount[14] the estimates as we did for domestic consumers. Upper and lower bound WTA estimates are calculated in the same fashion as for households, by calculating the discounted WTA if compensation is paid at the end of the period in order to get the lower bound, and taking the non-discounted figure as the upper bound.

In both cases, the estimates of VoLL per day based on WTA estimates are higher in the winter than in the summer and for relatively frequent outages (Figure 27 and Figure 28). As for households, VoLL per day is lower for long outages.

---

[14] We note that discounting is not intended to account for inflation (all calculations are in current prices) but account for the fact that businesses and society place more value on consumption today than on consumption tomorrow.

Figure 27:Upper bound VoLL in £ per day of outage - based on WTA per day for an outage occurring at the beginning of the period

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-5.87	**28.93**	-4.12	**24.31**	**2.61**	**6.57**
1 in 20	0.10	**34.91**	0.89	**29.31**	**3.91**	**7.87**
1 in 5	4.07	**38.87**	4.33	**32.76**	**5.35**	**9.31**

Source: London Economics

Figure 28:Lower bound VoLL in £ per day of outage - based on WTA per day for an outage occuring at the end of the period

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-1.16	**5.71**	-0.81	**4.79**	**0.51**	**1.30**
1 in 20	0.05	**17.54**	0.45	**14.73**	**1.96**	**3.96**
1 in 5	3.42	**32.73**	3.65	**27.58**	**4.50**	**7.84**

Source: London Economics

In between the upper and lower bound lies the expected value of the compensation over the period. This information is provided in Figure 29 and these estimates are clearly between the upper and lower bound estimates provided above.

The estimates suggest that, for example, consumers value an additional day of secure supply at £8.41 in a scenario where outages occur once in 5 years, in the winter and last for one month.

Figure 29:VoLL in £ per day of outage - based on WTA per day using discounted payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-2.78	**13.71**	-1.95	**11.52**	**1.24**	**3.11**
1 in 20	0.07	**24.80**	0.63	**20.83**	**2.78**	**5.59**
1 in 5	3.67	**35.10**	3.91	**29.58**	**4.83**	**8.41**

Note: Numbers in bold are statistically significant.
Source: London Economics

VoLL per day of outage estimates based on the WTP estimates are calculated by taking the sum of discounted WTP over the 5, 20 and 50 year periods, and then dividing by the number of days of outage. These estimates are shown in Figure 30.

Similar to the results for households, VoLL per day estimates based on WTP for SMEs are larger for short outages and lower frequencies. We also note that there are very large differences between the WTP per day and WTA per day estimates. There are likely to be several reasons for this.

Firstly, like domestic respondents, it seems that respondents have not properly taken into account that their bill would increase in all future years when they accept price increases. Hence the results suggest that SMEs have similar difficulties as consumers when it comes to forming preferences over very long time periods.

Secondly, some of the difference may be due to the fact that in the WTA experiment compensation payments were stated in absolute monetary values whereas in the WTP experiment price was stated as a percentage of the annual gas bill. This was done to account for the fact that there is huge variation in SMEs gas usage. However, to compare with WTA estimates it is necessary to convert the results using the average bill size estimate from the survey. There is by definition some uncertainly related to the accuracy of this estimate and the large WTP estimates may to some extent reflect the large dispersion in gas usage.

Figure 30:VoLL in £ per day of outage - based on WTP per day with discounted annual payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-559.19	**1459.21**	-398.30	**1314.25**	**218.45**	**758.58**
1 in 20	-105.71	**1105.07**	-39.13	**988.18**	**216.11**	**540.12**
1 in 5	-79.91	**304.73**	-49.25	**277.11**	**68.28**	**171.21**

Source: London Economics

2.7.2 VoLL per therm estimates

Based on the VoLL-per-day estimates presented in the previous section, estimates of VoLL per therm can be calculated provided that an estimate of the number of therms used by SMEs per day is available.

However, information about gas usage for SMEs is not readily available and, compared to domestic consumers, SMEs are likely to have a much more variable gas usage. A range for VoLL per therm is therefore provided for each duration, frequency and season estimate.

As an upper limit of gas usage we use a definition of SMEs provided by Ofgem which defines SMEs as businesses that use less than 1.5GWH per year. This is equivalent to 140.22 therms per day. As a lower bound for SME gas usage we use Ofgem's estimate of the average domestic household gas consumption i.e. 1.54 therms per day.

Upper and lower bound VoLL per therm estimates are provided in Figure 31 and Figure 32 using the results from the WTA experiment and the WTP experiment, respectively.

Figure 31: SME: VoLL in £ per therm upper and lower estimates - based on WTA per day using discounted payments

	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1 in 50	-1.80	-0.02	**8.89**	**0.10**	-1.27	-0.01	**7.47**	**0.08**	**0.80**	**0.01**	**2.02**	**0.02**
1 in 20	0.05	0.00	**16.08**	**0.18**	0.41	0.00	**13.50**	**0.15**	**1.80**	**0.02**	**3.63**	**0.04**
1 in 5	2.38	0.03	**22.76**	**0.25**	2.54	0.03	**19.18**	**0.21**	**3.13**	**0.03**	**5.45**	**0.06**

Note: Numbers in bold are statistically significant.

Source: London Economics

Figure 32: SME: VoLL in £ per therm upper and lower estimates - based on WTP per day with discounted annual payments

	1 Day				1 Week				1 Month			
	Summer		Winter		Summer		Winter		Summer		Winter	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1 in 50	-362.53	-3.99	**946.02**	**10.41**	-258.22	-2.84	**852.05**	**9.37**	**141.62**	**1.56**	**491.80**	**5.41**
1 in 20	-68.54	-0.75	**716.43**	**7.88**	-25.37	-0.28	**640.65**	**7.05**	**140.11**	**1.54**	**350.17**	**3.85**
1 in 5	-51.81	-0.57	**197.56**	**2.17**	-31.93	-0.35	**179.65**	**1.98**	**44.27**	**0.49**	**111.00**	**1.22**

Note: Numbers in bold are statistically significant.
Source: London Economics

Based on the survey estimate of the average bill for SMEs it is also possible to make a rough estimate of average SME therm usage per day. Assuming that the bill structure for SMEs is similar to the bill structure for domestic consumers, approximately 65% of the bill is commodity charges and supply margin.[15] Assuming that the supply margin is 5% this implies that 60% of the value of the bill is the cost of the commodity i.e. gas. Using the estimate of the average annual bill for SMEs of £7,287, this implies that the average SME consume gas worth £4,299 each year.[16] It is reasonable to assume that the wholesale market price in 2010 was around £0.4 per therm. This implies that SMEs on average use approximately 29.45 therms per day[17]. Figure 33 and Figure 34 use this logic to obtain an estimate of average VoLL per therm for SME gas users.

Figure 33: SME: average VoLL in £ per therm - based on WTA per day using discounted payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-0.09	**0.47**	-0.07	**0.39**	**0.04**	**0.11**
1 in 20	0.00	**0.84**	0.02	**0.71**	**0.09**	**0.19**
1 in 5	0.12	**1.19**	0.13	**1.00**	**0.16**	**0.29**

Note: Numbers in bold are statistically significant.
Source: London Economics

Figure 34: SME: average VoLL in £ per therm upper and lower estimates - based on WTP per day with discounted annual payments

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-18.99	**49.56**	-13.53	**44.63**	**7.42**	**25.76**
1 in 20	-3.59	**37.53**	-1.33	**33.56**	**7.34**	**18.34**
1 in 5	-2.71	**10.35**	-1.67	**9.41**	**2.32**	**5.81**

Note: Numbers in bold are statistically significant.
Source: London Economics

---

[15] Ofgem (2011). 'Updated Household energy bills explained', Factsheet 97.

[16] 60% x £7287 = £4,299 per year.

[17] (£4299 per year/ £0.4 per therm)/365 = 29.45 therms per day

2.7.3 VoLL for different SME groups

This section analyses to what extent the WTA and WTP of SME gas users vary depending on the characteristics of the firm and the interviewing process.

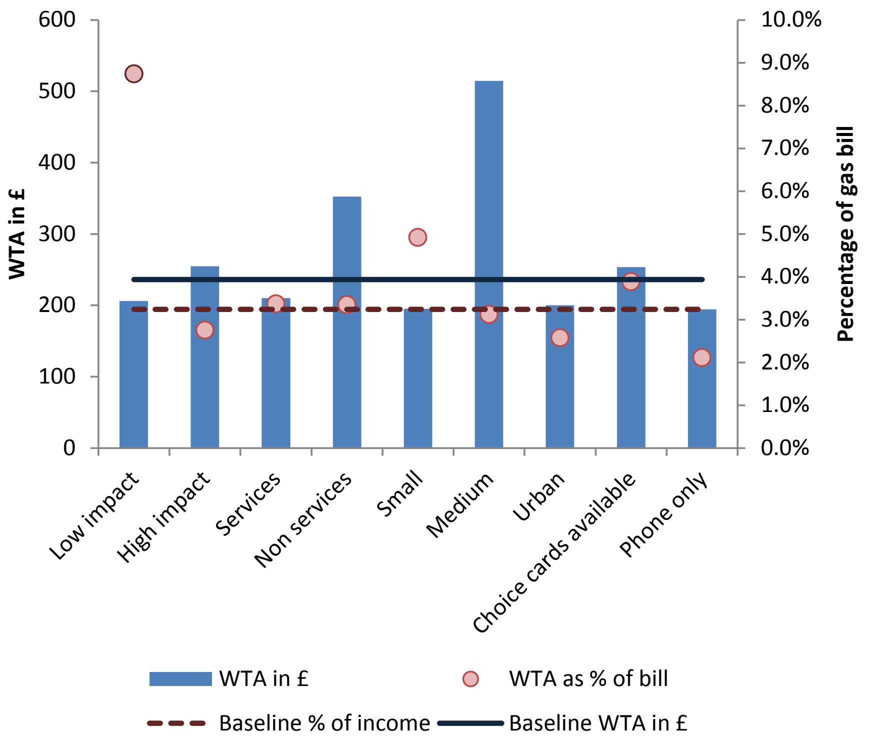
We present the results focusing on WTA and WTP for gas outages lasting one month and occurring once in 20 years in the winter time. This scenario is chosen as the basis for comparison because it may be considered to be the most realistic scenario. Detailed results for other durations, frequencies and summer outages are included as a separate annex in Annex B as are exact definitions of the sub-samples being considered.

WTA estimates

Figure 35 provides WTA estimates for different types of SMEs and interview processes. The estimates are for the entire one month duration and have not been normalised to a per-day basis or discounted to account for the fact that the outage may not occur immediately in the 20 year period. However, because we are focusing on estimates for a specific season, duration and frequency, the estimates are comparable.

As in the case of households, there is clearly a tendency that SMEs reporting that a gas outage would have a large impact on their business require more compensation. However, when expressed as a percentage of the gas bill, this conclusion does not hold.

Figure 35:WTA a one-month outage once in 20 years in the winter - SMEs



Source: London Economics

There is also a tendency that non-service businesses, i.e., businesses in construction, primary industries and production, require more compensation for a gas outage. This does not seem to be because these businesses expect an outage to have a greater impact on their business than businesses in the service sector (Table 22).

Table 22: Sector and impact of gas outages

SME size	Low impact	High impact
Services	29%	71%
Non services	45%	55%

Source: London Economics analysis of SME survey

The results also show that small firms with fewer than 10 employees require less compensation than SMEs with 10 or more employees but that, as a percentage of the gas and electricity bill, larger SMEs require less compensation. We note that this may simply reflect that SMEs with 10 or more employees use more gas, but these firms are not necessarily more dependent on gas usage in the production and/or provision of their services than the very small firms. We find that small SMEs generally report a lower expected impact of outages than larger SMEs.

Table 23: SME size and impact of gas outages

SME size	Low impact	High impact
SMEs with fewer than 10 employees	34%	66%
SMEs with 10 employees or more	25%	75%

Source: London Economics analysis of SME survey

There is also a tendency that SMEs in urban areas require a lower compensation than the baseline both in monetary terms and as a percentage of the bill.

We note that results also suggest that rural firms require much more compensation on average than any other firms but these results are statistically insignificant. This may partly be because the number of interviewed firms in rural areas is very small (the sample includes 41 SMEs in rural areas). We also note that the estimate for SMEs with more than 10 employees and the estimate for businesses in non-service sectors are also insignificant. This may also be partly attributable to a low number of observations in these areas.

We also note that the level of compensation required is slightly smaller for interviews undertaken only over the phone. This may be because there is a tendency that a higher proportion of small SMEs with fewer than 10 employees than SMEs with 10 employees or more were given the choice experiment options over the phone (Table 24).

We note that the share of services sector respondents who were given the options over the phone was around the same as the share of non-services sector respondents. The same applies for high and low impact respondents.

Table 24: SME interview mode by size, sector and impact of gas outages

	Copy of options provided	Options described over phone
All respondents	78.0%	22.0%
SMEs with fewer than 10 employees	75.6%	24.4%
SMEs with 10 employees or more	84.2%	15.8%
Services sector	78.0%	22.0%
Non-services sector	77.9%	22.1%
Low impact of outage	77.7%	22.3%
High impact of outage	78.1%	21.9%

Note: Small SMEs are defined as those with fewerr than 10 employees.
Source: London Economics analysis of SME survey

WTP estimates

Figure 36 provides a graphical representation of the WTP estimates for an outage lasting one month and occurring once in 20 years in the winter for different sub-samples compared to the baseline estimates presented in the previous subsections. We note that, as the comparison is for a given duration, frequency and season of outage, the WTP estimates have not been converted in any way and represent undiscounted WTP per year.

We note that whereas the WTA experiment (and the WTP experiment for domestic consumers) expressed compensation in a monetary value with WTA estimates subsequently being converted to the percentage of the bill, the WTP experiment for SMEs expressed WTP as a percentage of the bill. Subsequently, these percentages have been converted to monetary values based on the estimated average gas bill from the survey. For the baseline results we have used the average bill of the entire sample. For the sub-samples we have used the average bill of the relevant sub-sample in the WTP experiment.

We observe some of the same differences in the valuation of secure gas supply for different sub-samples as we did using the WTA estimates:

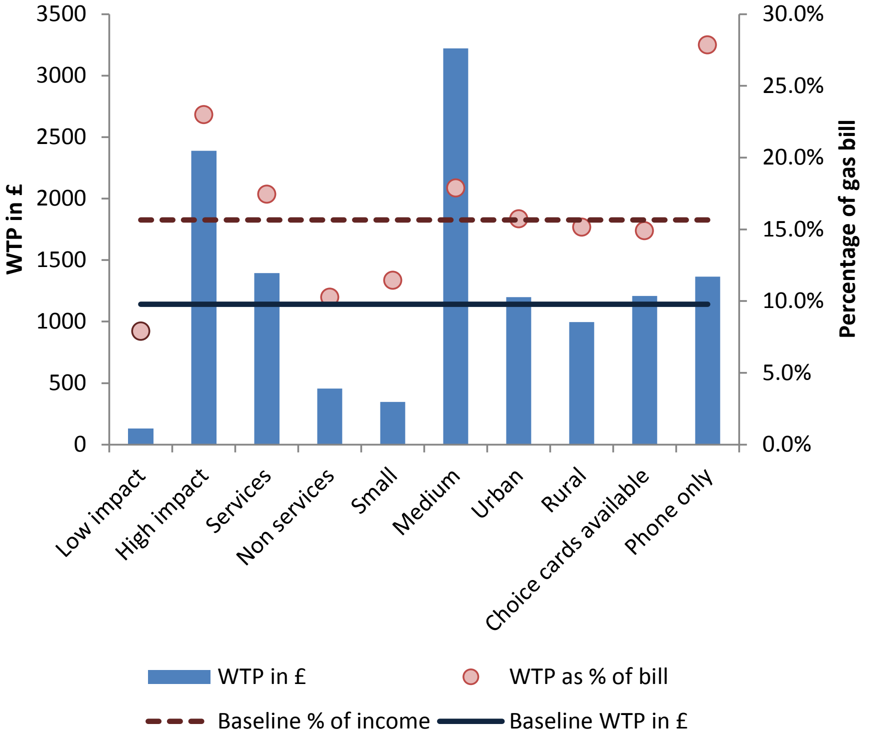
- SMEs for which outages have a low impact, value secure gas supply lower than SMEs for which outages have a large impact. For WTP, this holds both in percentage terms and in monetary terms. But, for WTA, it was not the case when compensation was expressed as a percentage of the bill.
- SMEs with fewer than 10 employees value secure gas supply lower than SMEs with 10 employees or more. Again for WTP this holds both in percentage terms and in monetary terms but for WTA it was not the case when compensation was expressed as a percentage of the bill.
- Respondents who had the choice cards for the experiment in front of them chose slightly differently than respondents who did not.

We also note that some of the differences in WTP valuations appear contrary to the differences in the WTA valuations discussed above:

- The results suggest that businesses in non-service sectors are willing to pay less for secure gas supply than businesses in service sectors. This suggests that the service sector value secure supply more than non-service sectors and is contrary to the conclusion based on WTA estimates.

- Similarly, the WTP estimates suggest that businesses in urban areas value secure supply lower than businesses located in rural areas. This is again contrary to the conclusions suggested by the WTA estimates. However, we note that the WTA estimate for rural consumers was statistically insignificant, although large.

Figure 36:WTP for a one-month outage once in 20 years in the winter – SMEs



Source: London Economics

2.7.4 VoLL estimates for SMEs using a contingent valuation methodology

This section presents the results of the contingent valuation questions for SME gas users and compares the results to those of the choice experiment.

WTA estimates

SME responses to the contingent valuation questions asking respondents to state what they believe to be a fair amount of compensation per day without gas in winter are distributed over a very large range from just £0 to £40,000.

This reflects the large heterogeneity in SMEs and their reliance on gas for revenue generation. However, most require much less compensation and 75% of respondents think that a compensation of £130 or less would be sufficient (Figure 38).

On average, the fair amount of compensation is stated to be £688 per day but when the top 2% of the sample are excluded the average drops to £370 per day. This is much higher than the WTA estimates achieved from the choice experiment where the maximum amount required per day was £38.87 per day for a one-day outage occurring in the winter once in 5 years (based on daily non discounted WTA estimates provided in Figure 27). However, excluding the top 2%, the median compensation required based on the contingent valuation question is £67.5 per day which is much closer to the result from the WTA experiment (although still significantly higher).

Including only non-zero responses the average is £724 per day and the median is £100 per day.

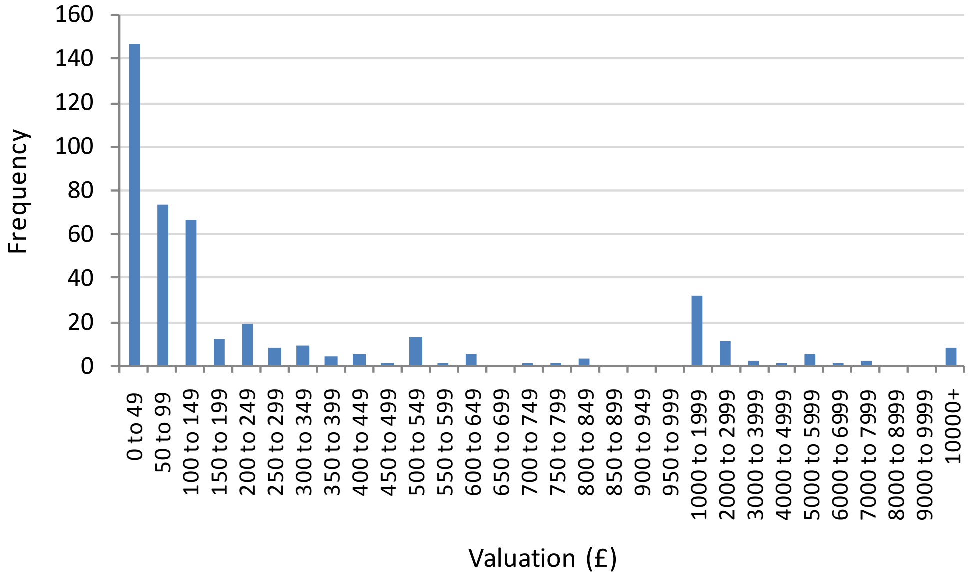
Table 25: Average valuation of fair compensation per day of outage - SMEs

Sample	Mean (£)	Med. (£)	Max. (£)	Min. (£)	Std. Dev.	Sample %[1]
Full sample	687.58	75	40,000	0	2,832.23	100%
Limited sample: Mean +/-3 std. dev.	370.37	67.5	7,000	0	913.98	98%
Limited sample: Mean +/-2 std. dev.	324.31	60	5,000	0	735.15	97%
Limited sample: Mean +/-1 std. dev.	259.12	50	3,500	0	497.35	96%
Limited sample: Mean +/-0.5 std. dev.	217.00	50	2,000	0	379.31	94%
Excluding zero responses	724.48	100	40,000	1	2,902.80	95%

Note: 1. Refers to the number of observations in the sample as a share of the full sample.

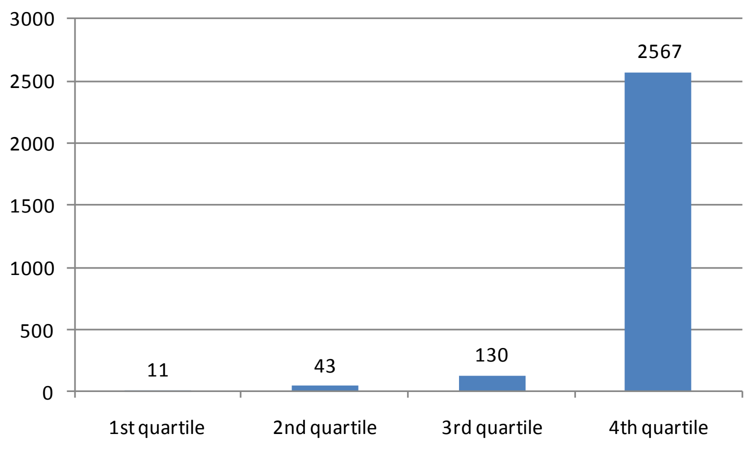
Source: London Economics analysis of survey data.

Figure 37:Valuation of fair compensation per day of outage - SMEs



Source: London Economics analysis of survey data.

Figure 38: Reported fair amount of compensation per day of gas outage in winter by quartile of SMEs (grouped by the reported level of compensation)

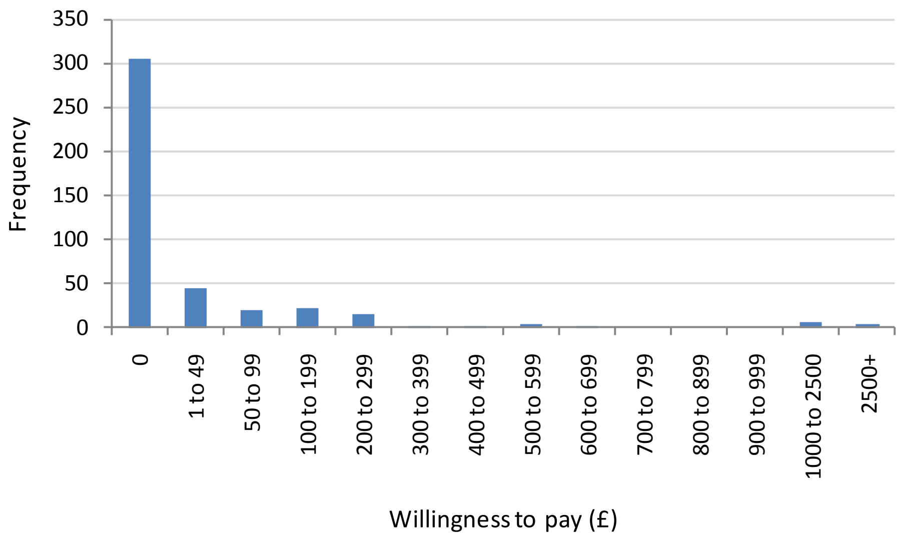


Source: London Economics analysis of survey data.

Willingness to pay

As observed for households and as estimated by the choice experiment, most SMEs have no willingness to pay for a reduction in the frequency from once in 20 years to once in 50 years. Out of the 426 SMEs providing a specific figure, 305 stated they are not willing to pay anything at all.

Figure 39:Willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – SMEs



Source: London Economics analysis of survey data.

The maximum WTP for the service improvement is £5,000 per year and for the full sample of respondents who provided a number the average is £81.63 per year. Reducing the sample to exclude the most extreme outliers the average drops to £36.61 per year.

Only 28% of SME respondent provided a non-zero response. Including only non-zero responses the average WTP using the contingent valuation methodology is £284 per year and the median is £75 per year.

Table 26: Average willingness to pay for a reduction in the frequency of outages from 1-in-20 to 1-in-50 years based on contingent valuation – SMEs

Sample	Mean (£)	Med. (£)	Max. (£)	Min. (£)	Std. Dev.	Sample %[1]
Full sample	81.63	0	5,000	0	432.52	100%
Limited sample: Mean +/-3 std. dev.	36.61	0	1,000	0	122.85	99%
Limited sample: Mean +/-2 std. dev.	27.34	0	600	0	78.77	98%
Limited sample: Mean +/-1 std. dev.	24.58	0	500	0	68.12	97%
Limited sample: Mean +/-0.5 std. dev.	18.69	0	250	0	47.06	96%
Excluding zero responses	284.40	75	5,000	1	776.49	28%

Note: 1. Refers to the number of observations in the sample as a share of the full sample.
Source: London Economics analysis of survey data.

In order to compare the estimates reported above with the results of the choice experiment, the difference between WTP valuations of outages occurring once in 20 years and once in 50 years are calculated (based on the non-discounted per year estimates provided in Figure 26. The choice experiment thus implies the following WTP for a reduction in the frequency of outages from once in 50 years to once in 20 years depending on the other characteristics of the outage:

- One day outage in the winter: £16.2 per year
- One week outage in the winter: £98.4 per year
- One month outage (both winter and summer): £179.6 per year

The contingent valuation results thus compare well with the results of the choice experiment in this respect and the average contingent valuation response is within the range of the results of the choice experiment.

2.8 Assessment of current compensation levels

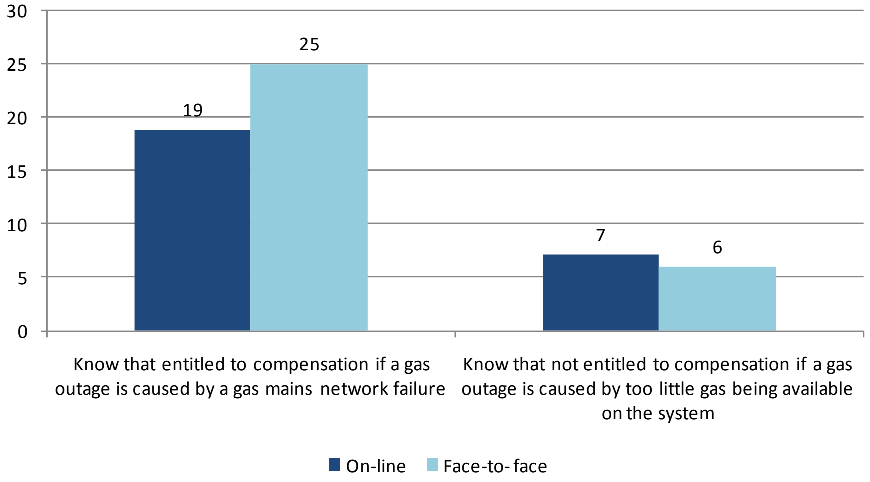
This section assesses the appropriateness of current compensation levels for domestic and SME consumers in the light of the findings of the study with respect to their WTA compensation.

First, however, we note that there is generally a poor awareness of current compensation arrangements among both domestic and SME gas users. Nineteen per cent of respondents in the on-line domestic sample and 25% of respondents in the face-to-face interviews knew that they would be entitled to compensation if a gas interruption is caused by a network failure (Figure 40). Among businesses 28% of SME gas users were aware of this (Figure 41).

Consumer research undertaken for Ofgem in 2007, also suggested that domestic consumers and small business consumers, generally, had low awareness of the guaranteed standard for supply interruptions with 12% and 17% respectively being aware they may be entitled to compensation if standards are not met.[18] Compared to these figures there are signs of a slight improvement in awareness.

The survey also reveals a poorer knowledge of compensation arrangements, or the lack thereof, for interruptions caused by gas emergency deficits. In all samples, 6-8% of respondents were aware that they would not get compensation in case of a gas emergency deficit.

Figure 40: Knowledge about entitlement to compensation in the case of a gas outage (% of households having participated in the survey)

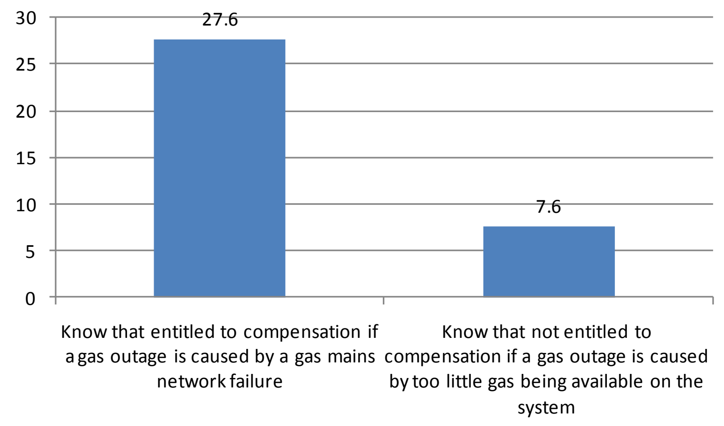


Source: London Economics based on the on-line and face-to-face domestic survey.

---

[18] Ofgem (2007) 'Gas distribution price control review: Consumer research. Prepared by FDS International for Ofgem.

Figure 41: Knowledge about entitlement to compensation in the case of a gas outage (% of SMEs having participated in the survey)



Source: London Economics based on the SME survey.

The 2007 survey showed that, although respondents had little awareness of compensation arrangements, they did feel that some compensation would be appropriate. These findings are mirrored in our study. The results of the WTA choice experiment clearly show that, in most cases, domestic and SME gas users require compensation for gas outages. Only in the case of short outages in the summer, are the estimated compensation levels not statistically significant. We note that this study does not suggest that there is any reason to suggest that consumers would want there to be no compensation if an outage is caused by a gas emergency deficit. On the contrary compensation for a gas outage seems appropriate from the point of view of the user no matter what the cause.

Current compensation levels for network failures are set in line with the results of the 2007 survey results which suggested that 80% of domestic consumers at that time found current compensation levels of £30/day very good or reasonably good. Among business consumers only 55% of respondents found compensation levels of £30/day very or reasonably good.[19]

The analysis in the present study shows that willingness to accept compensation requirements vary considerably depending on the duration, season and frequency of gas interruptions. In addition, the requirements vary according to other factors such as the characteristics of the household and the characteristics of the business. This means that different consumers find very different levels of compensation acceptable.

However, we acknowledge that it may be necessary to set daily compensation levels like those currently in place. To assess the appropriateness of current compensation levels we focus on the WTA results for the representative samples (i.e. the baseline models). We base our assessment of current compensation on the upper bound (non-discounted) per day compensation estimates

---

[19] Ofgem (2007) ‘Gas distribution price control review: Consumer research. Prepared by FDS International for Ofgem.

from the WTA experiment. Of the estimates provided in this report we believe that these give the best estimate of the compensation level required by consumers if an outage was to occur today.

The WTP experiment provides a less direct way of measuring this and as pointed out in previous sections, respondents appear to have had significant difficulties evaluating the alternative scenarios in the WTP experiment and hence do not appear to have taken into account the full payment stream. In addition, the WTP estimates for SMEs involve additional uncertainty because of the conversion from percentage estimates to monetary values using a survey estimate of the average bill.

We also note that while the results of the contingent valuation questions may also provide insights into the appropriate level of compensation, the survey was designed with the main purpose of creating unbiased estimates for the choice experiment. By placing the contingent valuation questions after the choice experiments the results of the contingent valuation analysis may be biased. In addition, we note that in the contingent valuation question asking respondents to state the amount of compensation they would consider fair, respondents faced no trade-off and if respondents expected that the outcome of the survey could be used to inform compensation levels in the future, respondents would have had an incentive to provide very high values.

For these reasons we primarily rely on the results of the WTA experiment for this analysis. The results of the WTA choice experiment in terms of compensation requirements on a per day basis are repeated in Figure 42.

The current compensation of £30/day is seen to fully meet average compensation requirements for domestic consumers for outages in the summer and for outages lasting one month. In fact there could be an argument for reducing or removing compensation to domestic consumers for outages occurring in the summer and lasting one month. However, on the other hand there seems to be a case for increasing compensation provided to domestic consumers for short outages occurring in the winter. This is also supported by the contingent valuation responses which suggested that consumers on average considered compensation of £38.79 per day a fair amount of compensation for outages occurring in the winter. The contingent valuation responses also suggested that most domestic respondents require less than the average of £38.76 per day with the median being just £20 per day.

We note that for compensation set as part of the guaranteed standards, 1 day and 1 week duration estimates are more relevant than the 1 month duration estimates. The separation between winter and summer outages is most prevalent for 1-day and 1-week outages, suggesting that in this case compensation in the summer should be decreased while compensation in the winter should be increased.

The current compensation level of £50/day for SMEs seems to fully live up to the expectations of the average business even for outages of short duration and for outages occurring in the winter. In fact, the results of the study suggest that businesses, on average, require less compensation per day than households.

However, we note that there is huge dispersion among businesses with respect to compensation requirements and the contingent valuation results suggest that SMEs on average require a much higher level of compensation of £370 (excluding the top 2%) with a median of £67.5 per day (excluding the top 2%). As noted previously, there may be reasons why this contingent valuation results overestimates actual compensation requirements.

Figure 42:Per day compensation requirements - based on WTA per day with no discounting

Domestic consumers

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-2.9	**41.2**	-1.1	**35.7**	**6.0**	**14.6**
1 in 20	5.0	**49.1**	5.3	**42.0**	**6.4**	**14.9**
1 in 5	**15.9**	**60.0**	**13.9**	**50.6**	**6.0**	**14.6**

SME consumers

	1 Day		1 Week		1 Month	
	Summer	Winter	Summer	Winter	Summer	Winter
1 in 50	-5.87	**28.93**	-4.12	**24.31**	**2.61**	**6.57**
1 in 20	0.10	**34.91**	0.89	**29.31**	**3.91**	**7.87**
1 in 5	4.07	**38.87**	4.33	**32.76**	**5.35**	**9.31**

Note: Numbers in bold are statistically significant.

Source: London Economics

3 VoLL estimates for industrial and commercial users

3.1 VoLL for I&Cs – general considerations

Fundamentally, the VoLL to any large Industrial and Commercial (I&C) customer is the lost gross profit from not producing, plus any starting or stopping costs to their industrial process. This value is given by the revenue less the value of variable costs (principally gas and other intermediate inputs). We say gross profit because the net revenue lost/value of production lost may include a margin to cover the cost of capital invested, and the idling of plant and equipment and labour that cannot quickly be adjusted during a load loss incident is properly counted in the cost or VoLL. Value added is the total sales value less the value of intermediate inputs. The basis of our VoLL estimates for I&C customers rest on this fundamental value in production approach.[20]

The cost of inputs which are storable, and do not depreciate, should not be included in the VoLL, as the only cost of idling these inputs is the cost of carry (interest-opportunity cost, cost of storage, less convenience yield). However, labour and capital, that is idled, represents an opportunity cost, which should be counted in the economic cost of an interruption.

A number of important factors will impact the VoLL for any I&C customer; among them, storability and load factor. If the commodity is storable, and if the load factor is not near 100%, then arguably, the VoLL is less than the average value of lost production less variable cost/gas cost, because the output has not been "lost". Its production timing must merely be shifted (ignoring start-up costs for the moment).

3.2 VoLL for electricity producers

3.2.1 Introduction: Extending to electricity

Electricity production represents an extreme case of non-storability; electricity cannot be stored economically on a large scale. There is the case of pumped storage, where water is pumped uphill at night/off-peak, but this is at a significant cost—roughly 15-34% energy loss—and the UK has rather limited pumped storage capacity relative to total capacity. Thus, for gas fired generators, any interruption in gas supply would necessarily mean that the electricity production is "lost" and cannot be made up at a later date by, for example, running an extra shift or overtime.

Electricity production thus is one of the more interesting cases from which to estimate VoLL. In addition to the non-storability factor, variable operations and maintenance costs are very small relative to gas and capital costs, and probably cannot be varied in the very short run, and so can be effectively or virtually ignored. Further, electricity prices, gas prices, thermal efficiencies of typical plants, and carbon emissions prices are all available and observable. Therefore, we can estimate the VoLL using actual market and publically available data.

---

[20] An alternative would have been to use interruptible contract price data.

A further nice feature of using electricity production to estimate the gas VoLL is that the outputs and the inputs are all in the same units – units of energy (MWh and therms).[21] Using electricity production to estimate VoLL for gas is not without challenges, however. One of the primary challenges is the fact that both electricity and gas prices tend to be quite volatile. They also exhibit potential trends and seasonal cycles. There is also the need to incorporate the cost of carbon and other factors.

A particularly interesting, but nonetheless surmountable, challenge is due to the interaction of plant flexibility (the ability to turn off and on quickly[22]) and volatile fuel and electricity prices. Our approach to this is to use the so-called real options spark spread approach, with some additional modifications to adjust for timing, time horizon, and potential empirical factors in the time-series such as mean reversion versus random walks.[23]

Our approach is thus to start with an intrinsic value approach based on recent historical averages. The intrinsic value looks simply at the historical average or most recent spark spreads with no option value or adjustments for flexibility in the face of volatility. This gives a per energy unit value of production for electricity generation.

In our approach, we look at both a typical baseload CCGT with assumed 55% thermal efficiency and an OCGT peaking plant with assumed 34% thermal efficiency.

We then estimate additional values for VoLL by adjusting for the optionality involved in running certain types of electricity plants. The rationale is that there is a distinct probability that electricity prices less gas prices/thermal efficiency, the so-called spark-spread, will be high when there is a gas outage.

We also then discuss adding in start and stopping costs.

3.2.2 Intrinsic value of spark spread for VoLL

Description of method

The starting point for VoLL for an electricity producer is the price of electricity per unit less the price of gas per unit divided by thermal efficiency – the so-called spark spread.

---

[21] In other industries, we believe that the estimation of VoLL on a per therm basis by using gross value added (GVA) and dividing by total therms (energy) may be in some cases misleading, because it isn't clear to what extent the gas used is critical to the actual production (our previous section addresses this). (The case of construction, showing a high VoLL under the GVA/therms method, comes to mind.) Electricity production has none of the problems associated with the GVA/therms method as the electricity produced must be proportional (adjusting for thermal efficiency) to the gas used due to the energy balance equation requirements (energy in must equal energy out, proportional to thermal efficiency).

[22] For our purposes, we are ignoring other more complex types of flexibility in thermal electricity generation, such as ability to part-load; provide load-following or TSO-automatic response, regulation, and other ancillary services, etc. Qualitatively, it would typically be assumed that these services are a higher value-added than mere electricity generation for the grid. Further, some plants would have the ability to produce some ancillary services simultaneously with electricity production. We merely say that incorporating them could be interesting but is beyond the scope of this paper.

[23] The standard approach to the value of an option, developed for financial products, assumes a random walk process for the price series of the underlying asset. This assumption is not likely to be valid for electricity prices, gas prices, or spark spreads over longer time horizons.

Equation 1:

$$\boldsymbol{\pi_t = \{p_t - VC_t\} = VoLL_t}$$

The VoLL is simply the value of production gross profit, π_t (price of electricity, p_t), in the time period t (t-subscript), less the variable cost VC_t. One can think of the variable cost as just the price of gas divided by thermal efficiency. However, with the advent of emissions trading for carbon and the system of tradable allowances to emit, the allowances can be saved and traded in the case they are not used. The difference between the electricity price and unit cost of gas and CO2 is the so-called *clean spark spread.* Thus, the cost of carbon should be included in the variable cost which is subtracted off. If one produces electricity (output), the allowance is 'used', but otherwise, it is 'saved'. Contrast this with capital cost. The service flows from the life of the plant and machinery are 'lost' when the production processes is idled. Thus they are included in the VoLL (not subtracted from the revenue per unit or electricity price).

Empirical estimates

We present our empirical estimates of the spark spread value in this section.

Data

We obtained data on electricity and gas prices from Bloomberg Professional. The data used were the daily closing prices for baseload and peakload electricity prices in £/MWh. These were daily assessment prices from the UK OTC and futures markets. For natural gas prices, the data was from ICE futures contracts data on NBP spot gas.

We collected forward and futures price data across the forward curve wherever available. In other words, on each trading day, electricity (baseload and peak) and gas (NBP) is traded for delivery, 1 month ahead, two months ahead,…,12months ahead, etc. There are also quarterly and seasonal contracts. For spot prices, there is NBP day-ahead data. For electricity, spot prices were taken to be the 'prompt month' or next-to-expire (one month ahead) contract data, and then continually rolled forward.

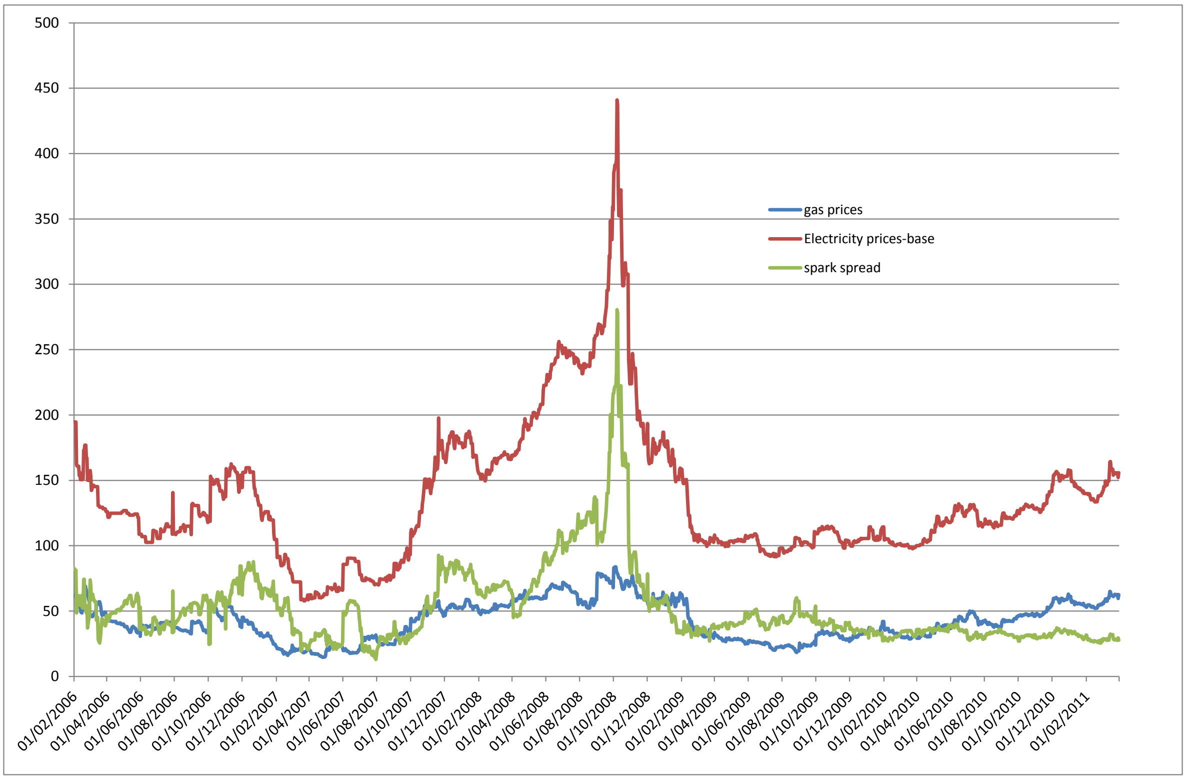
The data time period was from 1/1/2006 to 31/3/2011. This was the maximum time period for which the data for electricity prices was available. Prior to this period, the England and Wales electricity pricing and market functioned on the Pool market which preceded the NETTA and BETTA arrangements. Some prompt month gas contract data was missing for the first month only, and so we used the 2-month ahead contract prices, appropriately rolled back (i.e. for the same delivery period).

To implement the spark spread, from January 2007 when EU ETS trading started, we have also included carbon prices. These are exchange traded and traded daily closing prices of an EU ETS emissions allowance and also available from BB Professional. Data on EUR/GBP exchange rates are also used, daily closing exchange rates from BB Professional. The EU ETS prices are then converted from GBP to EUR.

Baseload prices and spreads graph

We first present the data graphically which will be informative as to the nature of the data. The full dataset time series for the baseload clean spark spread is presented below. The spark spread is the clean spread, but no additional value for gas transport or variable O&M have been subtracted from the power price.[24] The units are all in pence per therm (the electricity prices are baseload prices and have been converted). The data are the historical data on daily closing spot prices (prompt month for electricity and day ahead for gas, spot carbon and exchange rates).

Figure 43:Time series of UK baseload clean spark spread p/therm



Note: Bloomberg data

Source: London Economics

Observing the graphic, it should be noted that the commodity prices are not converted for CO2 and for thermal efficiency, so the *distance between* the two price series (red and blue lines) is not the clean spark spread itself.

A few observations are clearly in evidence and noteworthy from the visual inspection of the data. First, there is a large price spike in fall 2008 in electricity prices. The fact that the electricity price series and the spark spread seem to 'return to normal' indicates that the spark spread and the electricity prices, show mean-reversion. As a mean-reverting series, the two series clearly do not

---

[24] Presumably, if there was a gas outage, gas transport costs would not be paid. This indicates that it should be subtracted from the power price similar to the gas cost, but we assume these values are small.

follow a random walk-which would imply that all shocks or random impacts were permanent.[25] The gas price series only shows a small spike and so the empirical evidence on whether the gas price series follows a random walk or is mean reverting can probably not be decided by visual inspection, but should use an appropriate statistical test. As we will be interested only in the spark spread, we conclude that the spark spread is mean reverting. This importance of this will be discussed in greater detail when we implement the options-type models in the next subsection.

The second issue to note with the visual inspection is seasonality. Seasonality is often an issue with energy price data. There seems to be some apparent seasonality in gas, electricity and, to a lesser extent, the spark spread prior to the 2008 spike, but after the spike, there is no apparent seasonality in the spark spread. We did further empirical testing on the mean spread by quarter and did not find evidence of seasonality. This test was further complicated in that the overall seasonal average spread was driven by the 2008 spike. Thus with only 5 years data, and four seasonal parameters (e.g., a seasonal mean, or an overall mean and a seasonal proportional adjustment factor) it is difficult to estimate the seasonality factor. We conclude that seasonality does not appear to be significant for the spark spread in the most recent data.

It is an empirical question whether the spike should be included in the data. For now, we argue that it should be in the sense that if there is a gas outage when electricity prices are high, then this is exactly what we are interested in when estimating VoLL. Even though spikes tend to be one-off events, the probability of a once-off event of any number of types perhaps would be best included in our VoLL estimates, if we are perhaps more worried about underestimating VoLL than overestimating it.

Another point of note is to consider the flexibility of plant to shut down and avoid low price periods. To test this we estimated the average spread when taking the maximum over (spread, 0). Empirically, there is no difference (the graphical analysis also confirms this). Note that as there are apparently never negative spreads, and also, as baseload plant tend not to cycle (or shut down frequently), then the optionality of the plant in terms of shutting down or not, at least on a daily basis, is less important than a peaking plant.

The table below presents the average spark spread data across the full period and the most recent time periods. Overall the spread is about 43p/therm. Spreads have fallen from that average for 2010, down to about 26p/therm, however. Early 2011 data seems to indicate this fall in spreads continues. 2008 is showing a very high average, at about 60p/therm, but then this is being driven by the price spike.

Table 27: Average UK spark spreads baseload power prices

Time period	£/MWh-spread	p/therm-spread	p/therm E{Max[sprd,0]}
2006-3/31/2011	17.11	42.53	42.53
2008	24.91	60.16	60.16
2009	16.81	38.04	38.04
2010	12.90	26.04	26.04

---

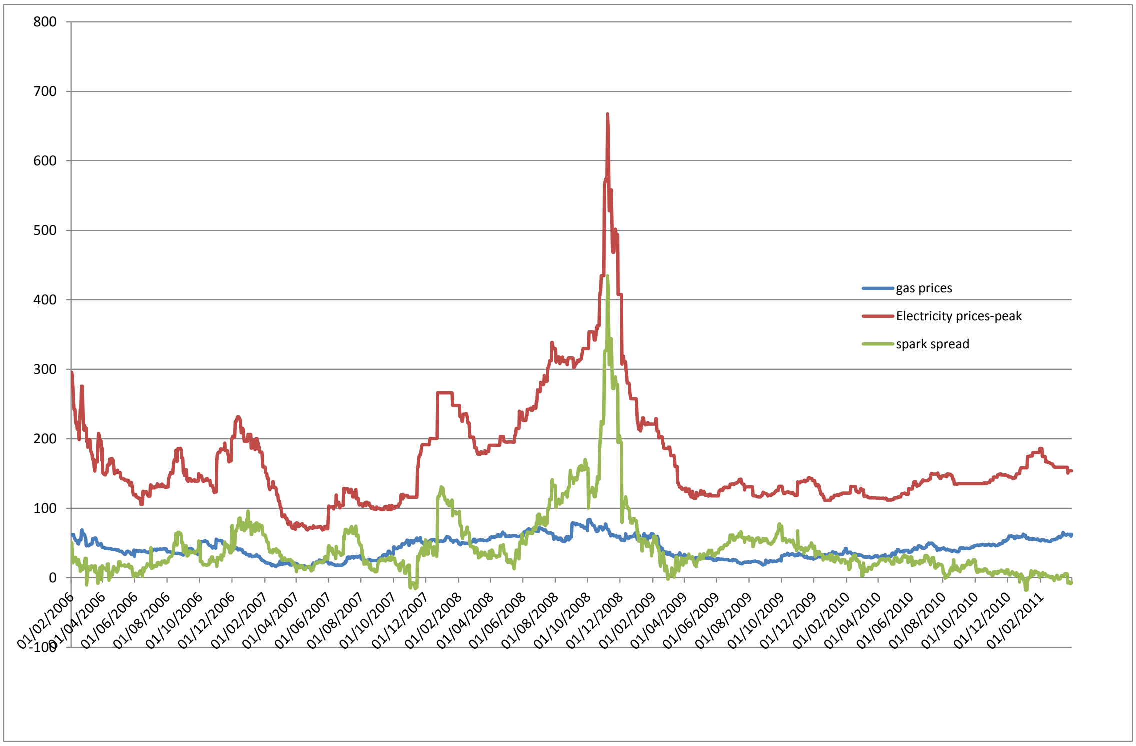
[25] This is the standard assumption and empirical finding with stock price data when trading is liquid on large public exchanges—the price returns follow a random walk with a trend, or geometric Brownian motion with drift. The derivative pricing models which were developed first for stock derivatives, thus often assume a random walk for the underlying price series.

Note: spot price data
Source: London Economics

Peak prices

We also present the same graphical analysis for peaking prices. The graphic is presented below. The gas price data are exactly the same as the baseload graphic. The adjustment is that the electricity price data is the peak-load price and the assumed thermal efficiency is akin to an OCGT or peaking/flexible/mid-merit plant, 34%.

Figure 44:Time series of UK peakload clean spark spread p/therm



Note: Bloomberg data
Source: London Economics

The same discussion, and conclusions, regarding the spike and evidence of mean reversion, as well as seasonality that was undertaken for the baseload prices also holds for the peak prices, especially for the clean spark spread. There is strong evidence of mean reversion and weak/little evidence of seasonality, especially in the recent three years.

One additional factor is also clearly in contrast to the baseload spreads. In the peak-spark spreads series, there are some times when the spread is negative. Thus, for some plants, it would not make sense to generate at this time for the assumed 34% efficient OCGT. Perhaps oil and coal will generate at these times. We should assume that the OCGT does not generate at these times and earn negative net operating revenues. Thus, we should adjust upwards the value of the spark spread on average, by excluding negative spread days. The table below presents the averages.

The third column is the average excluding negative spreads, i.e., using the formula:

Table 28: Average spreads peak power prices

Time period	£/MWh-spread	p/therm-spread	p/therm E{Max[sprd,0]}
2006-3/31/2011	6.22	18.24	20.41
2008	11.19	32.79	33.42
2009	8.34	24.44	25.07
2010	1.87	5.47	6.59

Note: spot price data
Source: London Economics analysis

The data on spark spreads for both baseload and peak periods show a wide range when looked at on an annual average basis. 2008 is showing a very high value, 100p/therm, for the peak spread. The average spread for 2010 is only 15.86p/therm for peak prices, and 32.49p/therm for baseload prices.

The choice of which time period is "correct" for our VoLL estimate is difficult. The answer depends in part on what one's view is of the spark spread time series drivers. If one believed the spark spread time series has some kind of long run equilibrium value, then we might take the long run average as the best estimate. If there are elements of "permanence" in shocks to the spread, then the spread average over the most recent and a shorter time period might be more representative of our best estimate. We discuss these and additional issues in the following sections.

The next sub-sections adjust our estimates for the probability that gas prices are high when electricity prices are high and also for the probability in shutting down. We further study the issue of a long-run trend and equilibrium value when prices (and the spread) are mean-reverting. We adjust for the mean reverting property of the underlying price series by using price data across the forward curve.

3.2.3 Real options approach

Estimating VoLL for large electricity customers should take account of the probability that electricity prices are likely to be high when gas prices are high. Further, when producers can shut down when prices are low, the average spark spread will be too low an estimate of VoLL. These factors suggest a real options-based approach. For this approach, we rely on market data on the UK spot prices of electric power, and UK NBP spot prices for gas. The value of production gross profit in any given hour in the future is given by the following formula:

$$\pi_t = E(\mathrm{Max}\{p_t - VC_t, 0\})e^{-rt}$$

where *E* is the expectations operator, p(t) is the spot price of power and VC(t) is the spot price of gas (in £/MWh), *e* is the exponential function and r is the risk free rate, and t is the time period.

The formula above illustrates that the production of electric power is like a European call option on the so-called "spark-spread", the difference between the value of the power and the value of the gas in equivalent units. This methodology has been applied to the valuation of gas contracts and peaking power plants (See Swinand, Rufin, and Sharma 2005)[26]. Additional details can be found in Deng (1999)[27].

As a European call option, the spark spread option value can be estimated as an option value using standard techniques, such as the well-known Black-Scholes-Merton (BSM) formula. The BSM formula requires estimates of underlying parameters, such as market prices of the power and gas, volatilities, and risk free rates, which all can be estimated from the available data.

As discussed in Deng et al (1999), some adjustments to the BSM formula are made to accommodate the spark spread option. The valuation formula is altered to change the variable of the underlying from the price (Log price) of a single security to the log of the ratio of prices {ln(p1/p2)}. The general intuition is the same, however, as the formula measures the probability that the option will be “in the money” (i.e., that the price of electricity exceeds its gas and carbon price of production) at some point in the future.

It is necessary, however, to review the parameters and assumptions of the model and make appropriate adjustments so as to make our VoLL estimate as realistic as possible. A discussion of each can be found in the annexes.

3.2.4 Results of spark spread estimates

The table below presents our estimates of VoLL and some of the underlying building blocks.

Table 29: Baseload and peakload spark spread VoLL estimates p/therm

Price/item	Baseload	Peak
Electricity price (P_e)	130.8	151.8
Gas price (P_g)	51.9	51.9
Variable cost (Pg+C)/H	106.5	172.3
Spark spread (Pe - (Pg+C)/H	24.3	-20.5
Option value VoLL	43.72	44.22
VoLL including start/stop costs (1hr)	135	108
VoLL including start/stop costs (24hr)	59	48

Note: forward curve prices April 2010 to March 2011.
Source: London Economics

The table shows the results of our estimates of the VoLL for large electricity users. Ignoring stop and starting costs, the VoLL for the CCGT or baseload plant is about 44p/therm. The option-value adjustment doesn’t make much difference, compared to the long run historical average spread of about 43p/therm, although it does increase the value relative to the most recent year’s price-based spreads: about 24p/therm.

---

[26] Gregory P. Swinand, Carlos Rufin, Chetan Sharma, “Valuing Assets Using Real Options: An Application to Deregulated Electricity Markets,” Journal of Applied Corporate Finance Volume 17, Issue 2, pages 55–67, Spring 2005.

[27] Deng, Johnson, and Sogomonian (1999), “Spark Spread Options and the Valuation of Electricity Generation Assets” Proceedings of the 32nd Hawaii International Conference on System Sciences – 1999.

For peak electricity prices, the difference is larger. The VoLL is estimated as 44p/therm still, but the average spread based on historical prices is only 20p/therm. Considering the most recent years' prices and forward curve data, the spread is negative -20p/therm. Adjustments for shutting down if the price is negative, the option value/volatility make the VoLL estimate higher; this accounts for the correlation between electricity and gas prices as well.

Adding the start/stop costs to the figures increases the estimates substantially. The value with the 1-hour baseload stop added raises the VoLL estimate to 135p/therm, while for peakload this estimate is 108p/therm. For the 24-hour stop the value of lost load value *per therm lost* falls because the start/stop costs are fixed relative to the duration of the outage, but the number of therms assumed lost rises in proportion to the hourly production gas used. Thus, for the 24-hour outage, the VoLL would be 59p/therm for baseload and 48p/therm for peakload. As the outage became very long, the added per-therm costs of the start and stop would become negligible, and the VoLL estimate would approach the opportunity cost.

3.2.5 Conclusions of estimation of VoLL for electricity generators

We conclude that the value of lost load for typical electricity producers for a one hour outage would range between 108p/therm (1hr peaking unit) and 135p/therm (1hr baseload unit). For a 24-hour outage, the values range from 48p/therm (24hr peaking unit) to 59p/therm (24hr baseload unit).

The reason for the wide range between the two types of units are multiple. The difference is due to the flexibility of the peaking unit. Since it is more flexible, and thus takes less gas/time to re-start, then the start and stop costs impact less on the peaking unit. This impact falls away as the outage gets longer (and thus the fixed start costs are spread over more units of gas 'lost'). Another driver of the difference between the peak and baseload units is the spark spread. The intrinsic value of the spread has been lower as of the last few years for the spread based on peak electricity prices versus baseload prices. However, when adjusting for the additional volatility in peak prices, i.e., using the options based approach, the two VoLLs (peak and baseload) are rather similar (both close to 44p/therm).

The intrinsic value of the VoLL based on the spark spread is smaller than the value per therm of gas itself in general. Gas prices of late have in general been above 50p/therm. There is no particular reason to expect that electricity as a commodity should cost less than gas, however. In equilibrium, electricity producers should earn no more than a fair rate of return on their capital. Naturally, the rate of return will fluctuate with the supply and demand balance and scarcity to indicate the need for more capacity. Nonetheless, in equilibrium, even as gas commodity prices rise (which again might be consistent with equilibrium and normal market pricing of a scarce and exhaustible commodity), it is thus quite conceivable that the spark spread would stay the same, all else equal.

In discussing our conclusions, caveats and cautions to our analysis are important to recognize. While our analysis has made every effort to give precise estimates of the VoLL, there are reasons to view the results carefully.

A first issue with our results is they are based on market commodity data from financial markets. An implicit assumption is that, because of liquid trading, the market daily closing price is the best estimate of the value of the commodity on the day for the given delivery period. Changes in the price from day-to-day are also typically assumed to be driven by changes in information about supply and demand, financial conditions, and other market fundamentals. If market trading is not liquid then other factors such as risk-aversion of traders, who is trading (and possibly their size and bargaining power) could drive prices too. On the whole, we suspect liquidity in electricity trading is a larger issue than with gas prices, as the futures markets for gas are exchange based and have been well established for years. Electricity pricing tends to be driven by over-the-counter trades.

Another issue to our results is the spark spread methodology. In general, however, we note that had we based our results on say, long-run historical average daily spark spreads, we might have come to a similar order of magnitude on our conclusions (the long run average for baseload was about 43p/therm versus 44p/therm). The larger difference is for peakload, where the long run average was about 20p/therm, but the options based method gave us 44p/therm.

The options methodology is known to be sensitive to a number of factors, but most significantly is the estimated volatility. Furthermore, the ‘correct’ volatility estimate would depend on the exact nature of the stochastic process driving the spark spread (or its underlying components, gas prices, electricity prices, and carbon prices in GBP). In principle, one would need to undertake rigorous statistical testing of the series to test for unit roots or jumps, and then testing of models to see how well they fit the data. Such modelling and testing would have added rapidly to the complexity and length of this report, and is beyond the scope of this project.

On the whole, our judgment is that our estimates are conservative, in the sense of not being too large. We note that the electricity values are smaller than many of the other I&C sectors. Sensitivity analysis could have been carried out on more of the parameters, but we do not think this would have altered our estimates or central expectations for the VoLL. Some factors that we ignored such as gas transport costs might have reduced the estimated VoLL values slightly had they been included. Similarly, flexing of certain parameter inputs, such as the assumed thermal efficiencies, would have lowered the estimated VoLLs if a lower efficiency was assumed, or raised them if a higher efficiency was assumed. Typically, the maximum thermal efficiency for a CCGT might be 59%-60%, and so our assumed 55% is not too far off the most efficient units. For peaking units there is much more variation in efficiencies, but newer units would be close to our assumed efficiency of 34%.

3.3 VoLLs for non-electricity I&Cs

3.3.1 Introduction

This sub-section presents VoLLs for non-electricity I&Cs, focusing on the Value-at-Risk methodology in particular.

Previous Value-at-risk calculations have assumed that that a gas disruption would result in a total shut down of each industry segment and consequent loss of 100% of the Gross Value Added generated by that segment. The present report challenges that assumption and attempts to investigate the extent to which gas is used for process critical applications and for less critical uses such as space heating, water heating and cooking in factories and offices. The approach has been limited to a desk top study but at least attempts to get beneath the level of macro GVA and gas consumption statistics to better understand the degree to which production is sensitive to gas supply availability.

3.3.2 Value-at-risk

Value-at-risk is one methodology that has been used to estimate the VoLL for gas load for UK industry. The VoLL for each industrial sector can be estimated as follows:

VoLL=GVA/GU *100 pence/therm

Where:

- VoLL = Value of Lost Load
- GVA = Gross Value Added (£million per year)
- GU = Gas Use (therms per year)

The Value-at-risk methodology has the useful feature of being readily calculated from existing ONS data. GVA data can be sourced from the Office of National Statics (ONS) and Gas Use can be sourced from the Digest UK Energy Statistics (DUKES).

The unadjusted calculations result in a very wide range of VoLL estimates values ranging from 211.47 p/therm for Non-ferrous metals to 24,686.04 p/therm for construction. The weighted average across all industrial sectors is 1,488.04 p/therm using the most recent data.

3.3.3 Discussion of value-at-risk

Energy and Gas Usage in Industry

The following table shows the structure of energy consumption by industry sector.

Gas is the largest contributor to final energy use in the UK industrial sector with a 37% share in total energy use (when excluding refineries and feedstocks), closely followed by electricity and heat with 35%. Solid fuels represent only 6% of final energy use and oil 20%. Including oil used in petroleum refinery furnaces (but excluding crude oil feedstock) and for non-energy uses, including petrochemical feedstock and lubricants, brings the oil share up to 44%. Gas is also used as a feedstock in petrochemicals but in much smaller quantities than oil.

Table 30: Energy Use in Industry % of industry total, UK 2009

Sector	Coal	Oil	Gas	Other	Electricity and Heat
Non-Ferrous Metals	2%	5%	26%	0%	67%
Iron and Steel	31%	5%	37%	0%	27%
Chemicals	1%	4%	50%	0%	45%
Agriculture	0%	32%	17%	15%	36%
Mineral Products	25%	7%	46%	0%	22%
Textiles, Leather etc.	6%	11%	53%	0%	30%
Other Industries	3%	39%	15%	0%	44%
Food Beverages etc.	1%	9%	59%	0%	31%
Paper, printing etc.	3%	3%	53%	0%	41%
Vehicles	3%	9%	52%	0%	37%
Electrical Engineering etc.	0%	5%	32%	0%	63%
Mechanical Engineering etc.	1%	7%	43%	0%	49%
Construction	1%	31%	40%	0%	28%
Unclassified	7%	80%	0%	13%	0%
Total	4%	44%	26%	1%	24%
Total Excluding Refineries and non – energy use	6%	20%	37%	1%	35%
Petroleum Refineries	0%	86%	6%	0%	8%
Non- Energy Use	0%	91%	9%	0%	0%
Total Including Refineries and feedstocks	4%	44%	26%	1%	24%

Source: Digest of UK Energy Statistics, 2010, Nexant analysis

Gas consumption in industry is summarised in Table 2.2 for the period 2004 to 2009. Industrial gas use declined by 8.4% between 2004 and 2008 and then by 17% in 2009 due to the effect of the recession. The chemicals sector is the largest gas consuming sector and accounts for 27% of industrial gas consumption in 2009 (including non-energy use). “Mineral Products” (12%), “Food Beverages etc.” and “Paper, printing, etc.”, are other major users.

Table 31: Gas Use in UK Industry 2004 to 2009

Sector	2004	2005	2006	2007	2008	2009
Non-Ferrous Metals	3199	3168	3106	2864	2989	2472
Iron and Steel	9715	8453	8391	7323	6920	5037
Chemicals	42002	36076	34334	30140	31182	25740
Petroleum Refineries	3076	5163	5161	5206	4971	3924
Agriculture	2355	2261	2013	1998	2161	1840
Mineral Products	13401	18302	17803	16878	18363	15042
Textiles, Leather etc.	7120	7031	6637	6078	6099	5164
Other Industries	10413	10400	9864	9229	9475	8040
Food Beverages etc.	28232	24921	23714	22973	24361	20057
Paper, printing etc.	13879	17689	16518	15511	16602	13857
Vehicles	10228	9959	9470	8523	8613	7210
Electrical Engineering etc.	4158	4134	3922	3736	3895	3249
Mechanical Engineering etc.	8611	8577	8180	7670	7704	6454
Construction	2931	2676	2555	2378	2482	2098
Non- Energy Use	10021	7913	7913	10228	9273	8979
Unclassified	65	55	47	40	34	29
Total	169341	166723	159581	150735	155090	129163

Source: DUKES 2009 (2004 data) and DUKES 2010 (all later years)

Industrial process applications include waste treatment and incineration, metals preheating (particularly for iron and steel), drying and dehumidification, glass melting, food processing, and fuelling industrial boilers. However, not all gas consumption classified as for industrial use is used for such industrial process application. Gas is also used for space heating, water heating and cooking within the industrial sector. Whilst data is not collected as regards to how much gas is used for process and other purposes, it is instructive to review the statistical definitions used to allocate consumption to standard industry codes in the Digest of UK Energy Statistics (DUKES).

The DUKES energy statistics are compiled on the basis of Standard Industry Codes and therefore reflect the main activity of companies consuming the energy rather than the application. The ONS guidelines on using the SIC codes requires that statistics are assigned to codes on the basis of the principle activity of a producing unit which is the activity which contributes most to the total value added of that unit. The principal activity does not necessarily account for 50 per cent or more of the unit’s total value added. Secondary activities include all other activities of the unit that produces goods or services suitable for delivery to third parties.

A further distinction is made between principal and secondary activities, on the one hand, and ancillary activities, on the other. Ancillary activities, such as accounting, transportation, storage, purchasing, sales promotion, repair and maintenance, etc. are those that exist solely to support the principal or secondary economic activities of a unit, by providing goods or services for the use of that unit only. It follows that the energy statistics compiled for each industrial sector will include an element of energy use for purposes other than industrial processes described above. Specifically they will include lighting, space heating, water heating and cooking uses at office buildings as well as at factories.

This is an important consideration of relevance to calculation of VoLL because gas used for non-process purposes is much less likely to impact production and therefore value added than will gas used in actual in processes critical to manufacturing output.

Electricity and Heat

The gas consumption figures included in Table 31 above do not include gas used on site to generate electricity and heat in CHP plants. These are classed as autogenerators in DUKES and the volume of gas supplied to such plant in 2009 was 30,146 GWh or about 8.5% of total gas use in the power sector. There is no data available of how this volume is distributed between end-user categories. However DUKES does contain a table detailing the breakdown of own generating plant capacity by undertakings in industrial and commercial sector.

An assessment has been made of gas purchases for autogeneration purposes based on the assumption purchased volumes are in proportion to the installed capacity which ignores differences in load factor of operation and in plant efficiency. The combined gas volumes for direct gas use and autogeneration are included in the following table.

Table 32: Gas Consumption including autogeneration estimates, 2007

Sector	Direct Gas Use Million Therms	Gas used in Autogen Million Therms	Total Gas Use Million Therms
Non-Ferrous Metals	98	0	98
Iron and Steel	250	438	688
Chemicals	1028	1772	2800
Petroleum Refineries	178	688	866
Agriculture	68	0	68
Mineral Products	576	0	576
Textiles, Leather etc	207	0	207
Other Industries	315	0	315
Food Beverages etc	784	574	1358
Paper, printing etc	529	1115	1645
Vehicles	291	0	291
Electrical Engineering etc	127	440	568
Mechanical Engineering etc	262	440	702
Construction	81	0	81
Fertilisers	349	0	349
Total	4794	5468	10262

Source: London Economics and Nexant

Note that purchases of electricity from Major Power Producers have not been included. Gas used in power generation by Major Power Producers is considered elsewhere in this study and so not included here to avoid the risk of double counting.

An important element of our methodology is the estimation of how much production in any industry is "gas critical". A discussion of this can be found in the annexes.

The following table is a tentative (best informed guess) assessment of the potential GVA that would be lost in a gas interruption for each industry subsector. For each sector we have included a subjective assessment of the range GVA percentages that might be lost as a result of an interruption in percentage terms based on the qualitative analysis set in Section 2.2.3. Given the uncertainties involved this is expressed as a range. The final column is the resulting range of GVA produced by multiplying total GVA by the upper and lower percentages.

Table 33: Gas-critical Factors and Potential lost GVA

Sector	Total GVA £/yr	Critical %	Potential GVA lost £m/yr
Non-Ferrous Metals	1391	60 to 80	835 to 1113
Iron and Steel	13887	65 to 85	9027 to 11804
Chemicals	16906	45 to 60	7608 to 10144
Petroleum Refineries	3276	80 to 100	2621 to 3276
Agriculture	2024	0 to 5	0 to 101
Mineral Products	6122	40 to 60	2449 to 3673
Textiles, Leather etc	2555	30 to 50	767 to 1278
Other Industries	18880	30 to 40	5664 to 7552
Food Beverages etc	23104	40 to 60	9242 to 13862
Paper, printing etc	20153	40 to 60	8061 to 12092
Vehicles	16557	30 to 40	4967 to 6623
Electrical Engineering etc	15598	30 to 40	4679 to 6239
Mechanical Engineering etc	26267	30 to 50	7880 to 13134
Construction	74860	0 to 1	0 to 749
Fertilisers	1123	100 to 100	1123 to 1123
Total	242703	27 to 38	64921 to 92762

Source: London Economics and Nexant

Value of Lost Load

The calculation of VoLL results from dividing the range of potential lost GVA in Table 33 by the consumption figures in Table 32. The calculation produces a range on VoLL for subsector which reflects the range of potential lost load. The VoLL results in p/therm are found below in Table 34. The overall weighted average range is 633 to 904 p/therm.

It should be stressed however, that the calculation is sensitive to the assessment of the proportion of GVA that would lost in the event of a gas disruption and this is an aspect that should be investigated in greater depth. It is also worth emphasising that the methodology takes no account of consequential costs arising from damage to equipment following an enforced shut down of production. These costs could be considerable as has been pointed out by many of the respondents the Ofgem consultation process.

Table 34: VoLL Estimates range p/therm

Sector	Low	High
Non-Ferrous Metals	854	1139
Iron and Steel	1312	1715
Chemicals	272	362
Petroleum Refineries	303	378
Agriculture	0	148
Mineral Products	425	638
Textiles, Leather etc	370	616
Other Industries	1799	2398
Food Beverages etc	681	1021
Paper, printing etc	490	735
Vehicles	1708	2277
Electrical Engineering etc	824	1099
Mechanical Engineering etc	1122	1870
Construction	0	923
Fertilisers	322	322
Total	633	904

Source: London Economics and Nexant

An additional uncertainty concerns the ability of industries to recover from short disruptions by making up for lost production once the gas supply has been restored. The ability to do so will depend on a number of factors including:

- The length of disruption and the cumulative loss of production
- The existence of spare capacity and the ability to ramp up to higher rates of production following the disruption
- The availability of storage for products and inventories held by producers and their customers
- The ability of customers to absorb higher rates of production post disruption
- The likelihood that lost production will be lost to competitors – e.g. imports or production from other UK units if the disruption is local

These issues are discussed in the next section.

Spare production Plant Capacity, Storage and other Mitigating Factors

Theoretically, if a production plant is operating at less than full capacity it could manage a temporary shutdown more easily than if it is operating at full capacity on a 365 day a year basis because spare capacity can be used to replace production lost during an interruption. In general and highly simplistic terms a plant running at x% load factor could still produce the same annual volume in 365*x/100 days.

In practice it is not easy to measure the spare capacity of an industry but one can gain some insight from looking at changes in production over time. Even this approach must be treated with considerable caution because some of the capacity used in the past may not be available in the future due to permanent plant closures, mothballing, and downsizing of the workforce. Furthermore, it would be unrealistic to assume that production could be stepped up to former levels immediately when the gas is turned on again.

Where sufficient stocks are held by producers, it may be possible to continue to supply customers for some time from those stocks and draw-downs of producers' stocks could be replenished by increased production. Equally, if customers draw down their own inventories there would be scope for increased production to replenish their own stocks. However, in the event of a disruption to supplies, it is to be expected that customers would seek alternative supplies either as imports or from other UK sources in the event a local disruption. (To the extent that customers are able to maintain stocks in this way, they may or may not have sufficient stocks on-hand to absorb a short-term interruption in supply from their suppliers).

These issues are illustrated with reference to the Petroleum Refineries, Iron and Steel and Chemicals sectors in the sub-section below.

Petroleum Refineries

Total UK refinery processing capacity as at end of 2009 was 87.5 million tonnes per annum, which excludes capacity at North Tees which is currently suspended. Production in 2009 was 75.3 million tonnes – a load factor of 86%. (Source: DUKES).

Production in 2009 was equivalent to 206 thousand tonnes per day compared to a daily capacity of 240 thousand tonnes per day so that operating at full capacity would produce an extra 34 thousand tonnes per day. Assuming 2 further days are needed to re-start the refinery a disruption of 1 day would result in lost production of 618 thousand tonnes and it would take 18 days of production at full capacity to recover this volume. Longer disruptions would require correspondingly longer recovery periods as the following table shows. A fifty-day interruption would take almost a year to recover production levels we estimate.

Table 35: Loss of refinery production and recover times

Outage days	Lost Production 000 tonnes	Days to recover lost Production
1	618	18
5	1442	42
10	2472	73
15	3502	103
20	4532	133
30	6592	194
40	8652	254
50	10712	315
60	12772	376
70	14832	436

Source: London Economics and Nexant

The above considers only the production side. An increase in production following the disruption must go either to storage or customers. The extent to which spare capacity can be used to mitigate a disruption in practice therefore depends on the availability and use of storage and also on the behaviour of customers.

During a short disruption at least storage held at refineries could be used smooth deliveries to customers. Inventories could be drawn down during the disruption and replaced from additional production after the gas supply was restored. Now, total storage of petroleum products in the UK was 7139 thousand tonnes in 2009 equivalent to about 35 days of production.

The UK holds emergency stocks of oil to help reduce the adverse impact on the UK of any disruptions of supplies of oil arising from domestic or international incidents. European Union (EU) legislation (EC Directive 2006/07) requires EU member states to hold oil stocks equivalent to 90 days' worth of average daily consumption calculated from the previous calendar year. These stocks are held to deal with oil supply emergencies, not to manage or affect prices. The UK, as a producer, receives a derogation of 25 per cent on its obligation and is only required to hold stocks equivalent to 67½ days of consumption.

The International Energy Agency (IEA) also requires its members to hold stocks for use in the event of global disruption. Until 2007, the UK as a net exporter was exempt from this requirement. However, in 2006 the UK became a net importer and so since 2007 has had an IEA obligation to hold stocks as well as its EU obligation. The same stocks count towards meeting both sets of obligations, and, as IEA obligations are based on net imports, we do not expect a significant net increase in total UK obligations until after 2016. The timing of this change depends on a range of factors, including the decline rate of indigenous oil production and the pattern of future UK oil product demand.

To meet these obligations, the UK Government requires companies supplying oil products into the UK market (production plus net imports) to maintain a certain level of emergency stocks of oil products as fuels. As part of this, oil companies are allowed to hold stocks in other EU countries subject to bilateral agreements between Governments, and count these stocks towards their stocking obligations.

However, it seems unlikely that the industry would simply let stocks run down to very low levels, without seeking alternative supplies including increased imports. The UK currently imports around 22.5 million tonnes of petroleum products and exports 25.7 million tonnes. Any increase in imports or reduction in exports would result in permanent loss of GVA from UK refineries to refineries in other countries.

To the extent that deliveries to customers were not maintained through use of storage or imports, there would be the possibility of un-met demand for oil during the period of the disruption. Whether this un-met demand would result in increased demand post disruption is difficult to assess. Most oil used in the transport sector is for personal and commercial travel. Shortage of fuel would no doubt lead to fewer trips being made during the disruption but the majority of those trips will be cancelled rather than postponed and some sales of fuel and the associated GVA will be lost permanently.

In conclusion the use of spare capacity and storage could be useful in mitigating a disruption of gas supply for a fairly short period of perhaps a few days. Beyond that refiners would most probably face permanent loss of GVA to a combination of imported products and permanent lost sales to customers.

Iron and Steel

Iron and steel production in UK has varied widely over recent years. Production in 2007 was 15 million tonnes, the highest since the start of the century. By 2009, production had fallen to 10.1 million tonnes following a number of plant closures and mothballing at Teesside, Tewksbury and Llanwern. Following fluctuations in both capacity and production over the last years we estimate that the load factor of Iron and Steel may be higher than the refineries sector and possibly 90-95%.

Certainly Tata has shown itself to be very responsive to changes in demand levels and an unwillingness to carry excess capacity.

Furthermore, the UK imports around 50% of steel and it is likely that production lost in gas disruption would be made up from increased imports.

Furthermore, shutting down and restarting blast furnaces is far from a simple matter because of the high temperatures and pressures inside of the blast furnace. Closing down precipitately could be hazardous, lead to harmful emission and potentially to damages to the lining of the blast furnace.

Chemicals

Production and capacity figures are not available on a consistent basis for the Chemical industries. However, the series for Chemicals and Man Made Fibres shows a decrease of 10 % between 2007 and 2010 which is a modest decline compared to other manufacturing. Over the same period, capacity in the bulk chemicals sector based on plant by plant analysis from Chemsystems Online shows a decrease in capacity 30%. Whilst these series are not strictly comparable, it does appear to suggest that that industry has contracted sharply as a result of the recession and spare capacity may have been squeezed out a result.

3.3.4 Conclusions

This section of our study has reviewed the value-at-risk methodology for calculating the Value of Lost Load in the Industrial and Commercial Sector.

The Value-at-risk methodology depends on the critical assumption that a loss of gas supply would result in total loss of production in each sector and hence loss of 100% of the GVA for that sector. This approach leads to some rather counter-intuitive results, especially for sectors where GVA is high and gas use is low. The most extreme sector is construction where the methodology yields a VoLL of almost £25,000.

In part at least, we believe the driver of these counter-intuitive results is that this key assumption stems from a possible misinterpretation in respect to the energy statistics and how consumption data provided by suppliers are allocated to SIC codes. In particular, the SIC codes are applied to an enterprise based on its main activity. This implies that a portion of gas consumption data allocated to industry use will in reality include gas used in heating offices and factory spaces, etc., as well as for production-critical process uses such as heating and drying.

A further point is that the broad industrial categories include a wide range of industrial activities carried out by thousands of companies. Gas will not be used uniformally across each sector and is likely to be concentrated into particular sub-sectors whilst other subsectors would be relatively unaffected by a gas disruption.

To address these concerns we develop the concept of ‘gas-critical’ production.

Given the diversity of the industrial sectors, it is difficult, based on statistics alone, to assess the breakdown of GVA to processes which will be gas-critical. Accordingly, the percentage of GVA that might be lost in a gas disruption is assessed as a range for each subsector. Even so, the range is highly subjective and should be treated with caution. An important lesson is that gas intensity is not necessarily a good measure of how critical gas is to industrial processes. For example, gas use in petroleum refineries is small compared other costs, notably crude oil and small even in relation to fuel oil used to fire furnaces but is absolutely critical to meeting quality specifications for the products, especially sulphur content.

A second modification of the value-at-risk method is that the gas consumption figures have been modified to include an assessment of gas used to generate electricity on site. The value-at-risk calculations figures included gas used to generate electricity which industry buys from the grid but these volumes have been excluded to avoid double counting with estimation of VoLL for the power sector.

The methodology yields a VoLL in the range of 633 to 904 p/therm compared with the previous range of 530-1488 p/therm based on the simple Value-at-risk methodology.

It should be noted that this valuation is purely in terms of lost Gross Value Added resulting directly from a gas disruption and consequent loss of production. There is no inclusion for potential damages to capital equipment which could be considerable in some cases, such as steelmaking.

The report also considered the impact of spare capacity and storage on mitigating lost GVA. Where the industry has access to both spare capacity and storage there is some scope, at least in theory, to recover lost production during a gas disruption by stepping up production in the period following gas reconnection. In practice, there is a risk that sales and hence GVA will be lost, if for instance customers turn to alternative suppliers including imports to replace lost output. This could then in fact impact the producer for a longer period of time than the time needed to make up the lost production with overtime or additional output.

While we have made our best efforts to estimate VoLLs by I&C sector that adjust for factors such as gas critical production, storability, and capacity, it should be noted that these estimates are reasonably preliminary, and more robust estimates would require additional work and resources. More robust estimates would most likely require cooperating directly with industry. In conclusion, we would recommend that Ofgem should work closely with industry to obtain a deeper understanding of how gas is actually used in and across each industrial sector, such that VoLL estimates could be adjusted with greater confidence and precision.

4 Conclusions

This report provides estimates of the value of lost gas load for three broad types of consumers:

- domestic gas users;
- SME gas users; and
- Industrial and commercial customers.

The result show large variations in the value of lost load depending on the type of gas user and, in the case of domestic and SME gas users, depending on the characteristics of the gas interruption. The estimates of industrial and commercial customers reveal huge variations depending on the sector, while VoLL for small SMEs and SMEs that expect a low impact of outages consistently are found to be lower than the average VoLL for SMEs. For household consumers we find a lower VoLL for vulnerable groups and for domestic consumers with low gas usage.

The results for domestic and SME gas users also show that VoLL estimates obtained using a WTP and a WTA methodology are quite different. Usually WTP estimates are lower than WTA estimates because respondents oppose to the idea of having to pay to secure supply. However, we find most WTP estimates of VoLL per day (or per therm) to be larger than the corresponding WTA estimates; the exceptions being 1 day and 1 week outages occurring in the winter where the estimates from the methodologies are almost identical. The WTP estimates of VoLL per day are particularly large compared to the WTA estimates for outages occurring with a low frequency. We conjecture that the reason for this, is that respondents may not have properly taken into account the total amount that would be payable per day of outage, for very infrequent interruptions in the WTP experiment.

The variation in VoLL estimates for different users and types of outages makes it difficult for regulators to set a uniform compensation level for gas outages, even if a distinction is made between businesses and non-businesses as is currently the case.

Our analysis suggests that while the £50/day compensation levels for businesses more than satisfies the compensation requirements of the average SME, the £30/day compensation for domestic consumers is not adequate for all types of interruptions. In particular, our results show that the average domestic consumer requires more compensation per day for outages lasting one week or one day and taking place in the winter. In contrast they require less or no compensation for outages in the summer and lasting one month.

Finally, we note that the results suggest that consumers do want compensation in most cases and that there is nothing to suggest that compensation requirements are different depending on the cause of the compensation, given the characteristics of the user and the outage.

Annex 1 Literature review

This annex contains a review of the literature of previous non-market valuations to estimate the value of secure supply. Firstly the annex provides a rationale for using a choice modelling approach to analyse VoLL for domestic consumers and SMEs. Secondly, the annex provides a review of key design features in previous studies. The literature review is used to inform the design of the choice experiment.

A1.1 Rationale for choice experiment method

There are two main ways of estimating the economic value of non-market goods. The first of these is a direct approach, which includes revealed preference techniques, where individuals or firms reveal their preferences through actual choices made and observed in the real world. Revealed preference estimates uses data on alternatives to gas which might be selected by consumers, for example, the direct cost to a residential consumer of a gas outage may include the cost of having to use an electric heater to heat their house while there is no gas supply.

The other commonly used approach for estimating the economic value of non-market goods such as VoLL is based on stated preference techniques. This is an indirect approach, in which a hypothetical market is constructed and consumers are asked hypothetical questions in order to ascertain the value that they attach to those goods and services.

Additional methods to estimate VoLL exist, such as case studies. Some studies estimate direct outage costs using case studies to estimate actual rather than hypothetical costs of energy outages. An important piece of work in this area is a study for the US Department of Energy on the consequences of the New York Blackout in 1977.[28] However, this approach suffers from the obvious disadvantages that gas outages in the UK are relatively rare and that data on the costs of such outages is hard to find, particularly for domestic consumers and SMEs.

A1.1.1 Advantages and disadvantages of revealed preference methods

Due to the nature of the effect of a gas outage on domestic consumers and SMEs, it is unlikely to be possible to value the burden they would bear using a direct approach and/or by looking purely at other goods and services that they buy as a substitute for gas supply.

This indirect VoLL estimation technique has been used in the past[29] and VoLL for electricity was estimated by summing the cost of averting behaviour. However, the use of revealed preferences in the present case seems a less accurate option than using stated preference techniques, as it could fail to account for the complete discomfort and inconvenience felt by individuals as a result of a gas outage, or it might overestimate the VoLL if purchases of other goods and services, that would

---

[28] SCI (1978): Impact Assessment of the 1977 New York City Blackout, SCI Project 5236-100, Final Report, Prepared for the U.S. Department of Energy, July

[29] See for example Kariuki and Allan (1996) 'Evaluation of Reliability Worth and Value of Lost Load', IEE Proceedings- Generation, Transmission and Distribution, Vol. 143, pp. 171-180, and Charles River Associates (2002), 'Assessment of the Value of Customer Reliability (VCR)'.

be useful in the case of a gas outage, could serve other purposes, and the estimates did not account for this.

For example, it is likely that, during a gas outage, people will be made less comfortable, but that they may do little about it. For instance, if there was to be a gas outage for a short period of time, many may feel that it is not worth purchasing additional household items, such as an electric heater, and would simply put up with the discomfort resulting from the outage. There may also be costs to consumers of an outage that cannot be mitigated because the alternatives available are not perfect substitutes of consumers' usual energy supply. For example, if consumers buy an electrical cooker to substitute for a gas cooker, the electrical heater purchased may be intended for temporary use only and, for instance, have a more limited capacity. So, while the consumer is able to cook during the outage, he or she may not be able to cook for as many people or cook very involved dishes. In this example, the electrical cooker is not a perfect substitute for the gas cooker and the consumer may derive less 'utility' or pleasure from using the electrical cooker than they would have from using the gas cooker. This case is just one source of potential bias from the revealed preference approach. In this case, this means that the estimates of the outage cost based on revealed preferences would be lower than the true cost felt by consumers. We note that in this case VoLL estimates based on a revealed preference methodology could provide a lower bound for the true VoLL.

The direct approach is much better suited to estimating the cost to I&C users of gas outages, as the outage is likely to affect their production and through that, their profits. Methods, such as the production function technique are likely to give a more accurate reflection of the true cost to these consumers of an outage, because it can be assumed that under profit maximisation lost production and thus lost gross profits are the cost to gas users of an outage.

A1.1.2 Stated preference methods: contingent valuation methods or choice experiments

Stated preference techniques are much better suited to the estimation of the VoLL for domestic consumers and SMEs, and is endorsed by the Council of European Energy Regulators (CEER).[30] Stated preference techniques are able to give a comprehensive measure of the VoLL, albeit from a hypothetical scenario, even when intangible costs such as inconvenience and discomfort are some of the main costs associated with an outage. Through the use of well-designed questionnaires the complete cost to individuals and small and medium sized businesses can be better uncovered.

Most studies estimating VoLL use either a contingent valuation method (CVM) or a discrete choice experiment (DCE) (also sometimes referred to as choice modelling). CVM seeks to measure willingness to pay (WTP) or willingness to accept (WTA) through direct questions such as "What are you willing to pay?", while DCE tries to secure rankings and ratings of alternatives from which WTP or WTA can be inferred.

Many of the VoLL studies from the USA have used techniques described in the Electric Power Research Institute's (EPRI) "Outage Cost Estimation Guidebook". This guidebook gives descriptions of the different techniques that can be used whilst also including three example contingent

---

[30] CERR Guidelines on Estimation of Costs due to electricity interruptions and voltage disruptions

valuation questionnaires. These questionnaires were the basis for a large number of estimations by utility companies in the States.[31]

However, contingent valuation suffers from several difficulties. Firstly, it is liable to suffer from the problem of “yes-saying”. This can occur for two reasons: either a respondent may try to please the interviewer by saying “yes”, when truthfully they should say “no”; or the individual may say “yes” to a much higher bid than his own valuation as they may feel it is in their own interest to do this, in the safe knowledge that that amount of money will not actually be collected from them. It is also possible that respondents could respond strategically if believe their response would influence the value placed on the object/good, if they are reasonably assured of not having to actually pay for it. This is called the incentive compatibility problem. Open-ended contingent valuation designs (e.g., how much are you willing to pay?) can avoid the “yes-saying” problem. However, experts tend to suggest that this causes the respondent to face a more difficult mental task.

A further problem with using contingent valuation in this context is that it is likely to cause some respondents to refuse to “play the game”, as some would be likely to refuse to pay more in order to maintain what they see as a currently very secure gas supply. Choice modelling can by-pass this problem by eliciting WTP indirectly through the use of statistical techniques rather than by asking for a direct monetary valuation.

Further, choice modelling is generally preferred for estimation of VoLL for different attributes (e.g. duration and season of outage)[32] and the methodology has also been used in many previous studies of security of supply valuations.

A1.2 Estimating the value of secure energy supply

There is not a great deal of literature analysing the value of security of gas supply. However, a choice experiment run in Switzerland in 2007[33] used a WTA approach to estimate the value of gas security. It found that residential gas consumers would require 28.3 CHF per year for one additional day without gas (approximately £12). The study also found that business consumers would require 312.2 CHF per year for one additional day without gas, which is approximately £136.

While there are few studies estimating VoLL for gas usage, there is a large amount of literature estimating the cost of interruptions to electricity supply and this literature may also inform our experiment design. We therefore include these studies in our review below.

A1.2.1 Willingness to pay or willingness to accept

Theoretically, the VoLL could be equal to both consumers’ WTP to avoid gas interruptions and consumers’ WTA compensation in the event of disconnection. However, in practice the WTP and

---

[31] Southern California Edison Company (1987 and 2000), Pacific Gas and Electric Company (1986, 1987, 1989, 1993, 1996), Southern Company (1987, 1999), Niagara Mohawk (1985), Duke Energy Company (1992, 1997), Bonneville Power Administration (1987), Salt River Project (2000), Puget Sound Energy (1999), Cinergy (1998)

[32] Economic Valuation with Stated Preference Techniques - Summary Guide (Pearce et al (2002) Department for Transport, Local Government and the Regions : London)

[33] Plaut Economics (2007),’Erdgasmarkt Schweiz: Ermittlung des Bedarfs einer Marktöffnung aus der Sicht der Akteure und Analyse der Marktöffnung in ausgewählten EU-Ländern’, a report prepared for Bundesamt für Energie BFE.

the WTA are not identical when estimated using survey methodologies. In general, surveys find that the WTA is higher than the WTP. In other words, the maximum amount consumers are willing to pay to achieve a better service is less than the minimum amount they are willing to accept in compensation for poor service. Experience suggests that the gap between surveyed willingness to pay and willingness to accept can be very large, particularly with open-ended questions in contingent valuations.

Therefore, this raises the question of whether to design the survey to estimate WTP or WTA. The choice depends on the specific research question. In the case of utility supply, consumers generally feel that they have an entitlement to secure supply and many may be opposed to the idea of having to pay extra to secure their supply. Additionally, given the fact that gas supply is generally seen as very reliable, consumers may oppose having to pay more to ensure the same level of reliability in the future. Therefore, if we were to base our estimates only on WTP rather than also using WTA to estimate VoLL, we could underestimate VoLL. However, at the same time, we note that WTA may overestimate VoLL in choice experiments and WTP may be seen as a more conservative estimate. Therefore, similar to Bliem (2009), MORI (1999) and Hartman *et al.* (1991), we include **both** WTP and WTA in our analysis. Table 36 summarises information on which studies estimate WTP or WTA. Most studies only estimate WTP or estimate both WTP and WTA. We note that Plaut Economics (2007) is the only study analysing VoLL for gas users and the study does so for Switzerland.

Table 36: Use of WTP or WTA to estimate the value of secure energy supply in previous studies

Study	WTP	WTA
Hartman et al. (1991) [34]	✓	✓
Beenstock (1996)	✓	✓
Energy Australia (1999) [35]	✓	
MORI (1999) [36]	✓	✓
Accent (2004) [37]	✓	✓
Layton and Moeltner (2004) [38]	✓	
Plaut Economics (2007)		✓
Carlsson and Martinsson (2008) [39]	✓	
Bliem (2009) [40]	✓	✓
Carlsson et al. (2009)[41]	✓	
Hoch and James (2010) [42]	✓	

Source: London Economics

A1.2.2 Presenting price and compensation levels

How WTP or WTA is reported varies across the literature (see Table 37). The price or compensation level is usually given as either a cash value for a given time period or as a proportional change in the energy bill.

In the Beenstock (1996)[43] study, 650 households were surveyed with results given for both domestic WTP to avoid, and WTA compensation for, for electricity outages in terms of a value per KWh. Results were reported for both WTP to avoid and WTA compensation for outages in terms of dollars per minute in Hartman et al. (1991). Whereas Carlsson and Martinsson (2008) reported results as a weighted average WTP to avoid outages, giving results for planned outages and unplanned outages.

---

[34] Hartman, R. S., M. J. Doane, and C.-K. Woo, 1991, Consumer rationality and the status quo, Quarterly Journal of Economics 106, 141-162.

[35] Energy Australia, (1999), Meeting Customer Requirements Under the Regulatory Framework, Discussion Paper prepared for Independent Pricing and Regulatory Tribunal (IPART), January, Sydney in Sayers, C. and Shields, D., (2001), Electricity Prices and Cost Factors, Staff research paper, Productivity Commission, Australia.

[36] MORI, (1999), Quality of Supply: Attitudes of Business and Domestic Electricity Customers, Research Study Conducted for Office of Electricity Regulation (OFFER), January – March, 1999.

[37] Accent Marketing and Research. (2004). Consumer Expectations of DNOs and WTP for Improvements in Service. London

[38] Layton, D & Moeltner, K (2004) "The Cost of Power Outages to Heterogeneous Households – An Application of the Mixed Gamma-Lognormal Distribution"

[39] Carlsson, F., and P. Martinsson. (2008). "Does it Matter when a Power Outage Occurs? – A Choice Experiment Study on the Willingness to Pay to Avoid Power Outages". Energy Economics

[40] Bliem, M (2009) "Economic Valuation of Electrical Service Reliability in Austria – A Choice Experiment Approach"

[41] Carlsson et al., 2009, The Effect of Power Outages and Cheap Talk on Willingness to Pay to Reduce Outages

[42] Hoch and James (2010). "Valuing Reliability in the National Electricity Market". Report for Australian Energy Market Operator

[43] Beenstock, M & Goldin, E (1996) "Priority pricing in electricity supply: An application for Israel"

An Australian study of business consumers by Energy Australia reported businesses' WTP to have no more than one electricity interruption per year. They found that 67% of small businesses would pay a fixed quarterly charge of $50 or more and did not give the results as a proportion of total bill that consumers would be willing to pay. This is not always the case in outage experiments, however, as many studies report both a cash value and a proportion of energy bill that represents the WTP to avoid outages.

For example, a 1999 study by MORI in the UK yielded businesses' WTP for an improved service as 1.5% of the bill and provided estimates of domestic consumers and business' WTA cash as compensation for more power cuts. The Accent study (2004) also gave values in terms of a cash payment to avoid outages of different lengths alongside results in terms of a proportion change in the energy bill. Bliem (2009) found that households in Austria require a 16.07% reduction in their current bill to accept a 4-hour power interruption.

Table 37: Price information provided in monetary value or as percentage of energy bill

Study	Monetary value	% of energy bill
Beenstock (1996)	✓	
Hartman et al. (1991)	✓	
Energy Australia (1999)	✓	
MORI (1999)		✓
Accent (2004)		✓
Layton and Moeltner (2004)	✓	
Plaut Economics (2007)	✓	
Carlsson and Martinsson (2008)	✓	
Bliem (2009)		✓
Carlsson et al. (2009)	✓	
Hoch and James (2010)		✓

Source: London Economics

A1.2.3 Attribute selection

Choice experiments allow for estimation of the marginal WTP or WTA for different attributes. That is, the results can be used to assess how much consumers would be willing to pay or how much less compensation they would require for improvement in services along different dimensions such as the frequency and duration of outages. Selection of attributes and attribute levels is therefore key to the design of choice experiments. It should be noted that while a price attribute for security of supply must be included in the choice experiment in order to derive an estimate of WTP or WTA[44], other attributes included vary from study to study.

Table 38 summarises the non-price attributes included in previous choice experiments analysing the value of secure energy supply.

---

[44] Hanley, N., Mourato, S. and Wright, R. E. (2001). Choice modelling approaches: a superior alternative for environmental valuation?. Journal of Economic Surveys, Vol. 15, pp. 435-462

Table 38: Non-price attributes included in previous choice experiments analysing the value of secure energy supply

Study	Frequency	Season	Timing (time of day or week)	Duration	Planned/ unplanned	Other attributes
Accent (2004)	✓[1]			✓		
Layton and Moeltner (2004)		✓	✓	✓		
Plaut Economics (2007)	✓					✓
Carlsson and Martinsson (2008)	✓[1]	✓	✓	✓		
Bliem (2009)	✓[1]		✓	✓	✓	
Hoch and James (2010)	✓[1, 3]	✓[3]	✓[3]	✓	✓[2]	

Note: 1) Specified as the number of outages over a fixed year period. 2) The study included two choice experiments; one in South Australia and one in New Zealand. This attribute was included in the South Australia experiment. 3) The study included two choice experiments; one in South Australia and one in New Zealand. This attribute was included in the New Zealand experiment.
Source: London Economics

Among the other attributes included in the studies, Accent (2004) included improvement in resilience, change in maximum time for restoring consumer power after a storm, change in information during a power cut, and commitment to undergrounding a proportion of the network. Hoch and James (2010) looked at 2 different choice experiments conducted in South Australia and New Zealand. The choice experiment in South Australia included attributes associated with information provided to consumers regarding unplanned outages, information provided regarding planned outages, voltage fluctuation, undergrounding and future power supply improvements. Plaut Economics (2007) included an attribute specifying whether the current supplier or a new supplier would be responsible for the supply of gas.

Most studies include attributes relating to the frequency, duration and timing of interruptions. It is worth noting that the duration and frequency of interruptions is quite different for gas and electricity outages. Electricity supply interruptions occur more frequently but last for a much shorter period of time. Therefore, Carlsson and Martinsson (2008), for example, allow for multiple outages over a 5-year period each with duration of 4, 8 or 24 hours when estimating marginal WTP for unplanned power interruptions in Sweden. Bliem (2009) even considers power cuts lasting 3 minutes and a frequency of up to 10 times per year.

In the context of gas interruptions (especially gas deficit emergencies) interruptions are expected to be longer and less frequent, for example, occurring only every 20 years but lasting for one or two months. Therefore, it may not be relevant to include an attribute specifying the time of day or time of week in the context of gas interruptions. It may be more important to include an attribute for the season.

The Department for Business, Innovation and Skills (BIS) (formerly the Department for Trade and Industry, (DTI)) 2006 consultation[45] lists the following factors as likely to affect consumers' WTP for improvements in the gas supply:

- season of interruption (Summer or Winter);
- duration of interruption;
- frequency of interruption; and
- price of security of supply.

---

[45] DTI (2006), 'Gas security of supply: the effectiveness of current gas security of supply arrangements. An energy review consultation'

Annex 2 Representativeness of domestic on-line sample

This annex provides a table comparing UK population characteristics with sample characteristics and additional details of sample characteristics based on the survey results.

It should be noted that the survey focused only on gas bill payers and the characteristics of gas bill payers may be slightly different from the characteristics of the population as a whole. This may explain why there is a higher share of owner-occupied tenures and employed in our sample, and slightly fewer 18-24 year olds.

It should also be noted that the survey focused on GB only while most population statistics only are available for the UK as a whole or for England and Wales.

Table 39: Comparing population and sample characteristics for the on-line sample

	Population	Population Source	Survey
Gender			
Male	49%	Mid-2009 Population Estimates: United Kingdom; estimated resident population by single year of age and sex, ONS	51%
Female	51%		49%
Age			
18-24	12%	Mid-2009 Population Estimates: United Kingdom; estimated resident population by single year of age and sex, ONS	7%
25-44	35%		41%
45-64	32%		35%
65+	21%		17%
Ethnicity			
White British	83%	Estimated resident population by ethnic group and sex, mid-2009 (England & Wales), ONS	74%
White Irish & Other	5%		3%
Black or minority Ethnic	12%		23%
SEG			
AB	26%	National Readership Survey, 2010	26%
C1	29%		33%
C2	21%		18%
DE	24%		24%
Rural vs. Urban			
Urban	81%	Higher Geographies Dataset, 2009, ONS	85%[1]
Rural	19%		15%
Tenure			
Owner Occupied	67%	Survey of English Housing, 2009, DCLG	71%
Social Rented	17%		11%
Private Rented	16%		17%
Fuel Poverty			
Yes	17.59%	OFGEM	14%[2]
No	82.41%		85%[2]
Employment status			
Employed	62%	Derived from the Integrated Household Survey, October 2009 - September 2010, ONS	62%
Unemployed	4%		3%

Table 39: Comparing population and sample characteristics for the on-line sample

	Population	Population Source	Survey
Inactive (retired, full-time student and not looking for work)	34%		30%[46]
Long term condition or disability			
Yes	26%	Life Opportunities Survey 2010, ONS	23%[3]
No	74%		77%

Note: 1) Includes town and fringe. 2) Based on survey question about whether consumers do not feel that they can keep their home heated to a comfortable level. 3) Either the respondent personally or someone else in the household.
Source: YouGov

A2.1 More detailed sample characteristics

The tables below provides detailed information on the socio-economic characteristics of the households having participated in the on-line or face-to-face surveys.

Table 40: Age of household member having responded to the survey (% of total number of households having participated in the survey)

Age group	On-line survey (in %)	Face-to-face survey (in %)
under 20	1	34
20 to less than 30	20	
30 to less than 40	18	
40 to less than 50	20	
50 to less than 60	16	6
60 to less than 70	15	27
70 to less than 75	6	13
more than 75	3	20
Total	100	100

Source : On-line and face-to-face domestic survey.

Table 41: Type of housing tenure of household having responded to the survey (% of total number of households having participated in the survey)

On-line survey		Face to face survey	
Type of tenure	**% of households**	**Type of tenure**	**% of households**
Owner occupied	72	Owned outright	31
Social rented	11	Buying with a mortgage/ loan	10
Private rented	17	Rented from local authority	34
		Rented from private landlord	14
		Rented from a housing association	11
Total	100	Total	100

Source : On-line and face-to-face domestic survey.

---

[46] An additional five per cent in the domestic survey marked ‘other’ for employment status

Table 42: Members of household member having a long-term disability (% of total number of households having participated in the survey)

Type of household member		On-line survey (in %)	Face-to-face survey (in %)
Survey respondent			
	Yes	15	53
	No	82	47
	Don’t know	2	0
	Refusal to respond	1	0
	Total	100	100
Other household member			
	Yes	13	10
	No	84	90
	Don’t know	2	0
	Refusal to respond	1	0
	Total	100	100

Source : On-line and face-to-face domestic survey.

Table 43: Incone of household having responded to the survey (% of total number of households having participated in the survey)

Income group	On-line survey (in %)	Face-to-face survey (in %)
under £5,000 per year	2	6
£5,000 to £9,999 per year	9	29
£10,000 to £14,999 per year	17	48
£15,000 to £19,999 per year	27	2
£20,000 to £29,999 per year	43	4
£30,000 to £39,999 per year	56	1
£40,000 to £49,999 per year	66	0
£50,000 to £99,999 per year	79	0
£100,000 and over	81	0
Don't know	3	3
Prefer not to answer	16	7
Total	100	100

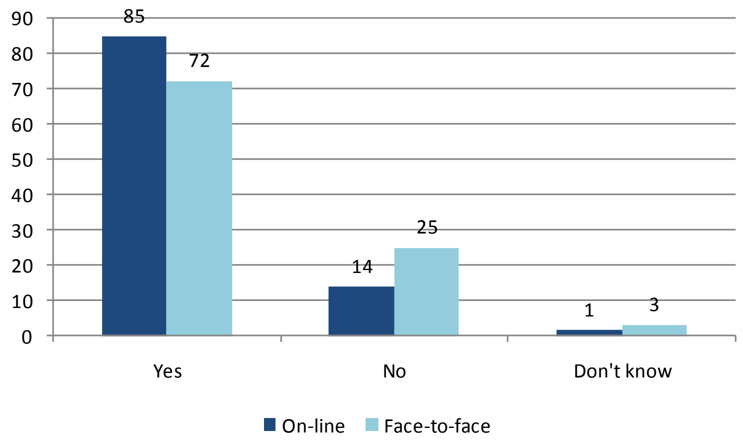
Source : On-line and face-to-face domestic survey.

Table 44: Gender of household member having responded to the survey (% of total number of households having participated in the survey)

Gender	On-line survey (in %)	Face-to-face survey (in %)
Male	51	36
Female	49	64
Total	100	100

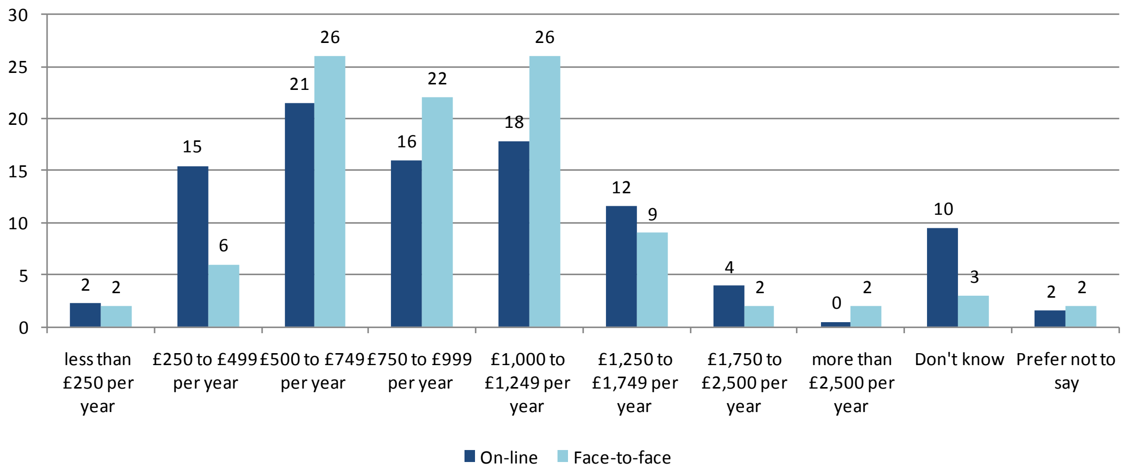
Source : On-line and face-to-face domestic survey.

Figure 45: Households views' on whether they are able to keep their home heated to a comfortable level (% of households having participated in the survey)



Source : On-line and face-to-face domestic survey.

Figure 46: Households' annual spending on gas and electricity (% of households having participated in the survey)



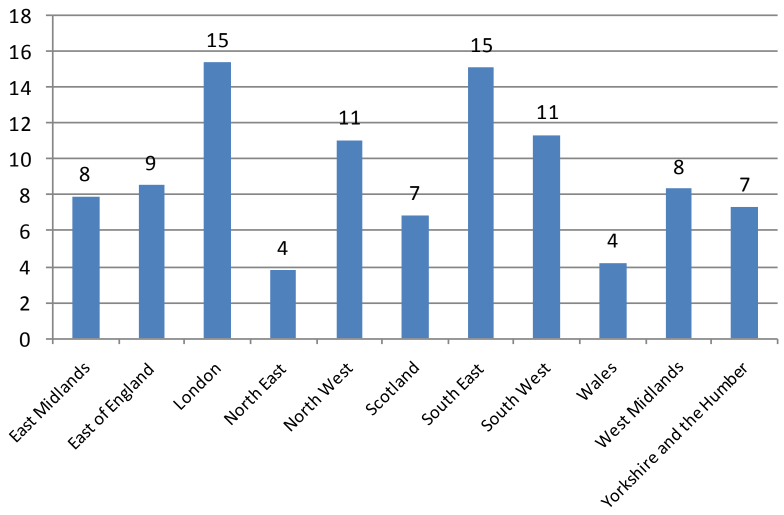
Source : On-line and face-to-face domestic survey.

Table 45: Labour force status of survey respondent and socio-economic characteristics of households – on-line survey only

Labour force status as % of total		Socio-economic characteristics as % of total	
Working full-time (30 hours a week or more)	46	AB	25
Working part-time (8-29 hours a week)	14	C1	33
Working part-time (fewer than 8 hours a week)	2	C2	18
Unemployed and looking for work	3	DE	24
Retired	21	Total	100
Looking after family or home	5		
Full time student / in school	4		
Other	5		
Total	100		

Source : On-line and face-to-face domestic survey.

Figure 47: Regional distribution of households having participated in the on-line survey (% of total)



Source : On-line and face-to-face domestic survey.

Table 46: Distribution (in %) of households by number of household members– on-line survey only

Number of household members	Children under 4	Children aged 4 to 15	Adults 16 to 64	Adults aged 65 and older
0	88.8	78.8	15.8	77.7
1	9.3	12.2	19.6	10.2
2	1.8	7.3	41.9	12.1
3	0.2	1.3	11.4	
4		0.1	7.4	
5		0.4	2.5	
6			1.0	
7			0.4	
8			0.2	
Total	100	100	100	100

Source : On-line and face-to-face domestic survey

Annex 3 Representativeness of SME sample

This annex provides a table comparing GB SME population characteristics with sample characteristics for the SME sample. The annex also provide more detailed sample characteristics based on the survey responses.

The sample matches population characteristics perfectly when it comes to the regional split. However, we note that there are some differences between the sample and the SME population with respect to the size and sector characteristics.

Table 47: Comparing population and sample characteristics for the SME sample

	SME population	Survey
Region		
England	86%	86%
Scotland	9%	9%
Wales	5%	5%
Size (number of employees)		
0-9	83%	72%
10-49	14%	19%
50-99	2%	6%
100-249	1%	3%
Sector		
Primary	1%	1%
Production	9%	10%
Construction	10%	6%
Services	80%	83%

Source: OMB Research

The differences between the sample and the SME population are most likely due to the differences between the total SME population and the SME population of gas users. The aim of the sampling process was to achieve a representative sample of SME gas users in GB. However, population characteristics for the population of SME gas users in GB are not available. However, following analysis of the sample characteristics after 306 completed interviews, London Economics and OMB Research in consultation with Ofgem decided to relax the quotas set to make the sample match the total population characteristics for GB SMEs. The analysis showed that small SMEs with fewer than 10 employees were less likely to be gas users (Table 48) and there were also concerns that businesses in the construction sector were less likely to be gas users because they often work on construction sites rather than out of a fixed location.

Table 48: Estimate of SME gas user population characteristics based on call outcomes for the first 306 completed interviews

Number of employees	Estimate of % using gas
0-9	39%
10-49	49%
50-99	68%
100-249	70%

Note: Call outcomes those that were known/believed use gas (i.e. completed interviews, appointments, refusals) and those that did not use gas (because they screened out for this reason) were identified.

Source: OMB Research

A3.1 More detailed sample characteristics

The tables below provide more detailed information on the economic characteristics of the sample of SME having participated in the survey.

Table 49: Industrial sector of the SMEs having particicpated in the survey

Sector	Percentage of total sample
Agriculture, Hunting & Forestry	1.2
Manufacturing	10.4
Construction	5.6
Wholesale & Retail Trade	15
Hotels & Restaurants	16
Transport, Storage & Communication	3.4
Financial Intermediation	1
Real Estate, Renting & Business Act	12.6
Public Administration & Defence	1
Education	7.2
Health & Social Work	9.4
Other Community, Social & Personal	16
Private Households With Employed Pe	1
Extra-territorial Organisations & B	0.2
Total	100

Source: SME survey

Table 50: Regional distribution of the SMEs having particicpated in the survey

Region	Percentage of total sample
East Midlands	3.8
Greater London	8.2
North	9
North West	4.8
Scotland	11.6
South East	9.2
South West	19.4
Wales	11.2
West Midlands	5.2
East Midlands	9.4
Yorkshire and the Humber	8.2
Total	100.0

Source: SME survey

Annex 4 Linear models for WTP and WTA for SME and domestic gas users

The annex provides alternative estimation results for a linear model specification. The WTP and WTA estimates provided in this section are for outages lasting one day and, due to the linear structure, they can be directly scaled to outages lasting one week and one month by multiplying by 7 and 30 respectively. Note also that all WTP and WTA estimates provided here should be multiplied by -1.

It should be noted that discounted estimates are presented in this section and the estimates from the linear model are quite different from the estimates obtained from the non-linear model. This suggests that the linear models force an inappropriate model structure on the data.

Figure 48:Linear estimation results WTA for domestic consumers (on-line sample)

	Coef.	**Std. Err.**	**z**	**P>|z|**	**Lower**	**Upper**
Duration	-0.10104	0.004358	-23.19	0.0000	-0.10958	-0.0925
Duration * Summer	0.046135	0.003033	15.21	0.0000	0.04019	0.05208
Duration * 1 in 20	0.038817	0.003603	10.77	0.0000	0.031756	0.045879
Duration * 1 in 50	0.041336	0.003603	11.47	0.0000	0.034276	0.048397
Price	-0.0197	0.000725	-27.17	0.0000	-0.02112	-0.01828
DK option	-3.56509	0.081605	-43.69	0.0000	-3.72503	-3.40514
WTA per day outages calcualted in STATA via 'nlcom' command						
	Coef.	**Std. Err.**	**z**	**P>|z|**	**Lower**	**Upper**
Winter, 1 in 5	-5.13	0.227739	-22.52	0.0000	-5.57509	-4.68236
Winter, 1 in 20	-3.16	0.190637	-16.57	0.0000	-3.53207	-2.78479
Winter, 1 in 50	-3.03	0.166171	-18.24	0.0000	-3.35626	-2.70488
Summer, 1 in 5	-2.79	0.160723	-17.34	0.0000	-3.10203	-2.472
Summer, 1 in 20	-0.82	0.145066	-5.63	0.0000	-1.10104	-0.53239
Summer, 1 in 50	-0.69	0.134824	-5.11	0.0000	-0.95311	-0.42461

Note: Standard errors and confidence intervals for WTA estimates are calculated using the delta method.
Source: London Economics

Figure 49:Linear estimation results WTP for domestic consumers (on-line sample)

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.0136	0.0026	-5.2500	0.0000	-0.0186	-0.0085
Duration * Winter	-0.0461	0.0030	-15.2100	0.0000	-0.0521	-0.0402
Duration * 1 in 20	-0.0025	0.0033	-0.7700	0.4420	-0.0089	0.0039
Duration * 1 in 5	-0.0413	0.0036	-11.4700	0.0000	-0.0484	-0.0343
Price	-0.0197	0.0007	-27.1700	0.0000	-0.0211	-0.0183
DK option	-3.5651	0.0816	-43.6900	0.0000	-3.7250	-3.4051

WTP per year for a 1 day outage calcualted in STATA via 'nlcom' command

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Summer - 1 in 50	-0.68886	0.134824	-5.11	0.000	-0.95311	-0.42461
Summer - 1 in 20	-0.81672	0.145066	-5.63	0.000	-1.10104	-0.53239
Summer - 1 in 5	-2.78702	0.160723	-17.34	0.000	-3.10203	-2.472
Winter - 1 in 50	-3.03057	0.166171	-18.24	0.000	-3.35626	-2.70488
Winter - 1 in 20	-3.15843	0.190637	-16.57	0.000	-3.53207	-2.78479
Winter - 1 in 5	-5.12873	0.227739	-22.52	0.000	-5.57509	-4.68236

Note: Standard errors and confidence intervals for WTP estimates are calculated using the delta method.
Source: London Economics

Figure 50:Linear estimation results WTA for SME consumers

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.04644	0.003984	-11.66	0.000	-0.05425	-0.03863
Duration * Summer	0.030366	0.003208	9.47	0.000	0.02408	0.036653
Duration * 1 in 20	0.004224	0.003311	1.28	0.202	-0.00226	0.010713
Duration * 1 in 50	0.007917	0.003686	2.15	0.032	0.000694	0.015141
Compensation	0.003348	0.001109	3.02	0.003	0.001174	0.005521
DK option	-3.97238	0.190059	-20.9	0.000	-4.34488	-3.59987

WTA per day calcualted in STATA via 'nlcom' command

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Winter, 1 in 5	13.87	4.180995	3.32	0.001	5.677384	22.06658
Winter, 1 in 20	12.61	3.8775	3.25	0.001	5.010422	20.20994
Winter, 1 in 50	11.51	3.970004	2.9	0.004	3.72586	19.28799
Summer, 1 in 5	4.80	1.604083	2.99	0.003	1.656924	7.944813
Summer, 1 in 20	3.54	1.397003	2.53	0.011	0.800992	6.277142
Summer, 1 in 50	2.44	1.452803	1.68	0.094	-0.41163	5.283251

Note: Standard errors and confidence intervals for WTA estimates are calculated using the delta method.
Source: London Economics

Figure 51:Linear estimation results WTP for SME consumers

	Coef.	Std. Err.	z	P>|z|	Lower	Upper
Duration	-0.06048	0.003657	-16.54	0.000	-0.06765	-0.05331
Duration * Summer	0.039862	0.003281	12.15	0.000	0.033431	0.046292
Duration * 1 in 20	-0.00383	0.00371	-1.03	0.302	-0.0111	0.003442
Duration * 1 in 50	0.008589	0.003846	2.23	0.026	0.001051	0.016127
Price	-11.0981	0.763693	-14.53	0.000	-12.5949	-9.60128
DK option	-4.33547	0.147909	-29.31	0.000	-4.62536	-4.04557
WTP per year for a 1 day outage calcualted in STATA via 'nlcom' command						
	Coef.	**Std. Err.**	**z**	**P>|z|**	**Lower**	**Upper**
Winter, 1 in 5	-0.0054	0.000443	-12.31	0.000	-0.00632	-0.00458
Winter, 1 in 20	-0.0058	0.000546	-10.61	0.000	-0.00687	-0.00472
Winter, 1 in 50	-0.0047	0.000401	-11.67	0.000	-0.00546	-0.00389
Summer, 1 in 5	-0.0019	0.000318	-5.84	0.000	-0.00248	-0.00123
Summer, 1 in 20	-0.0022	0.000355	-6.21	0.000	-0.0029	-0.00151
Summer, 1 in 50	-0.0011	0.000308	-3.52	0.000	-0.00169	-0.00048

Note: Standard errors and confidence intervals for WTP estimates are calculated using the delta method.

Source: London Economics

Annex 5 Validity and quality of responses to choice experiments

This annex provides statistics on responses to the choice experiment which can be used to assess the validity and quality of the responses. In particular, we analyse:

- What percentage of respondents responds 'don't know' to all 10 choices?
- What percentage of respondents responds 'alternative 1' to all 10 choices?
- What percentage of respondents responds 'alternative 2' to all 10 choices?
- What percentage of choices involves a choice of the dominated alternative?

If respondents are engaging with the experiment and understand the basic concept of the experiment, we would expect these percentages to be small and we find that to be the case.

Table 51: Choice experiment answering patterns (% of total)

Sample	Always chose 'don't know'[1]	Always chose Option 1[1]	Always chose Option 2[1]	Chose dominated alternatives[2]
Household on-line	1.6%	0.2%	0.0%	0.6%
Household face-to-face	3.0%	2.0%	0.0%	1.3%
SME	0.6%	0.4%	0.4%	0.9%

Note: 1. Percentage of total respondents. The total number of respondents varies according to the sample: on-line = 1,021; face-to-face = 100; SME = 500. 2. Percentage of total options chosen. The total number of options chosen varies according to the sample: on-line = 10,210; face-to-face = 1,000; SME = 5,000.

Source: London Economics analysis.

Table 52: Choice experiment answering patterns by WTA and WTP (% of total)

Sample	Always chose 'don't know'[1]	Always chose Option 1[1]	Always chose Option 2[1]	Chose dominated alternatives[2]
On-line WTA	1.0%	0.2%	0.0%	0.7%
On-line WTP	2.1%	0.2%	0.0%	0.4%
Face-to-face WTA	6.0%	0.0%	0.0%	1.2%
Face-to-face WTP	0.0%	4.0%	0.0%	1.4%
SME WTA	0.0%	0.0%	0.4%	1.4%
SME WTP	1.2%	0.8%	0.4%	0.3%

Note: 1. Percentage of total respondents. The total number of respondents varies according to the sample: on-line WTA = 493; on-line WTP = 528; face-to-face WTA = 50; face-to-face WTP = 50; SME WTA = 251; SME WTP = 249. 2. Percentage of total options chosen. The total number of options chosen varies according to the sample: on-line WTA = 4,930; on-line WTP = 5,280; face-to-face WTA = 500; face-to-face WTP = 500; SME WTA = 2,510; SME WTP = 2,490.

Source: London Economics analysis.

Annex 6 Observations and confidence interval for VoLL estimates by domestic consumers' characteristics

This annex presents further details of the WTP and WTA analysis for domestic consumers. The details presented in this annex are for outages once in 20 years, lasting one month and occurring in the winter. Other estimates are provided in Annex A which is a standalone annex.

A6.1 Number of observations in sub-analyses

Table 53 and Table 54 give an overview of the number of respondents and observations used in each of the WTA and WTP sub-analyses.

We note that each respondent was presented with 10 choice cards implying that, in the baseline, a total of 4,930 choices were made (10 X 493) and each choice consisted of 3 alternatives for the total number of observations 14,790 (3 X 4,930).

We also note that the baseline is based on the GB representative sample which only includes observations from the on-line survey.[47] The face-to-face estimates are based on the data from the face-to-face interviews only, and all other estimates are based on sub-sets of the combined on-line and face-to-face sample, i.e., the estimates for vulnerable consumers include observations for vulnerable consumer in the on-line sample *and* in the face-to-face sample.

---

[47] This is to ensure that vulnerable groups are not overrepresented.

Table 53: Number of respondents in WTA sub-analyses

	Observations	Respondents
Baseline	14,790	493
Face-to-face	1,500	50
Vulnerable	8,220	274
High impact	13,140	438
Low impact	2,850	95
Low Bill	8,580	286
High Bill	5,790	193
Can keep home heated to comfortable level	13,650	455
Cannot keep heated to comfortable level	2,370	79
Low Income	7,260	242
High Income	5,730	191
Stays at home	4,320	144
Urban	11,610	387
Rural	2,220	74
Have children	4,110	137
Male	7,950	265
Female	8,340	278
Home owner	10,290	343
Tenant	4,410	147

Source: London Economics

Table 54: Number of respondents in WTP sub-analyses

	Observations	Respondents
Baseline	15,840	528
Face-to-face	1,500	50
Vulnerable	8,490	283
High impact	12,480	416
Low impact	4,260	142
Low Bill	9,990	333
High Bill	5,730	191
Can keep heated	14,460	482
Cannot keep heated	2,610	87
Low Income	8,490	283
High Income	5,970	199
Stays at home	4,590	153
Urban	12,630	421
Rural	2,040	68
Have children	4,470	149
Male	8,850	295
Female	8,460	282
Home owner	11,520	384
Tenant	4,170	139

Source: London Economics

A6.2 Confidence intervals for results

This section provides two tables with confidence intervals for the WTA and WTP estimates for the different subsamples.

Table 55: WTA a one month outage once in 20 years in the winter – domestic consumers

	WTA in £	WTA as % of income	Confidence interval	
			LB	UB
Baseline	**448**	1.25%	257.25	638.92
Face-to-face	**199**	1.69%	66.04	331.88
Vulnerable	**297**	1.26%	170.62	423.68
Low impact	**167**	0.49%	64.12	270.50
High impact	**521**	1.57%	266.82	775.49
Low bill	**326**	1.10%	183.44	469.55
High bill	**509**	1.30%	147.20	871.33
Can keep home heated to comfortable level	**505**	1.44%	260.80	749.31
Cannot keep home heated to comfortable level	**157**	0.62%	68.18	244.90
Low income	**251**	1.55%	151.54	350.50
High income	969	1.75%	-384.86	2323.15
Stays at home	**229**	0.89%	131.15	326.66
Urban	**461**	1.28%	233.24	689.52
Rural	487	1.34%	-34.52	1009.18
Have children	1428	3.71%	-2279.69	5135.40
Men	**381**	1.03%	170.25	591.03
Women	**422**	1.40%	217.49	625.62
Home owner	**511**	1.28%	221.07	801.90
Tenant	**343**	1.30%	124.14	562.62

Note: Numbers in bold are statistically significantly different from zero. Confidence intervals are calculated based on the Delta method. WTA as a percentage of income is calculated as WTA in pounds divided by the average income for consumers in each subgroup where the income is calculated based on the midpoint of the ranges with the exception of the top and bottom range for which the lower bound and the upper bound of the range are used respectively. Detailed estimation results are provided in Annex B.

Source: London Economics

Table 56: WTP to avoid a one month outage once in 20 years in the winter – domestic consumers

	WTP in £	WTP as % of income	Confidence interval	
			LB	UB
Baseline	**89**	0.27%	79.32	99.51
Face-to-face	**52**	0.47%	15.18	89.28
Vulnerable	**83**	0.44%	69.01	96.78
Can keep heated	**90**	0.27%	79.12	100.73
Cannot keep heated	**67**	0.32%	45.33	88.45
Low income	**85**	0.54%	70.81	98.45
High income	**104**	0.19%	87.94	120.20
Low impact	**63**	0.23%	46.73	79.29
High impact	**97**	0.29%	84.92	108.35
Low bill	**86**	0.29%	73.96	97.42
High bill	**86**	0.25%	67.44	104.37
Stays at home	**99**	0.45%	79.60	119.17
Have children	**85**	0.21%	68.34	100.76
Men	**84**	0.25%	70.19	98.06
Women	**91**	0.31%	77.73	104.73
Urban	**84**	0.25%	72.92	94.36
Rural	**121**	0.35%	84.33	157.48
Home owner	**88**	0.24%	75.36	100.15
Tenant	**96**	0.40%	79.06	113.91

Note: Numbers in bold are statistically significantly different from zero. Confidence intervals are calculated based on the Delta method. WTP as a percentage of income is calculated as WTP in pounds divided by the average income for consumers in each subgroup where the income is calculated based on the midpoint of the ranges with the exception of the top and bottom range for which the lower bound and the upper bound of the range are used respectively. Detailed estimation results are provided in Annex A.

Source: London Economics

Annex 7 Observations and confidence interval for VoLL estimates by SME and interview characteristics

This annex presents further details of the WTP and WTA analysis for SMEs. The details presented in this annex are for outages once in 20 years, lasting one month and occurring in the winter. Other estimates are provided in Annex B which is a standalone annex.

A7.1 Number of observations in sub-analyses

Table 54 and Table 58 give an overview of the number of respondents and observations used in each of the WTA and WTP sub-analyses presented in this annex.

We note that each respondent was presented with 10 choice cards implying that in the baseline a total of 2,510 choices were made (10 X 251) and each choice consisted of 3 alternatives making the total number of observations 7,530 (3 X 2,510).

Table 57: Number of respondents in WTA sub-analyses

	Observations	Respondents
Baseline	7,530	251
Low Impact	2,310	77
High Impact	5,190	173
Services	6,120	204
Non Services	1,410	47
Small	5,610	187
Medium	1,920	64
Urban	6,300	210
Rural	1,230	41
Copy of choice cards available	5,760	192
Phone only	1,770	59

Source: London Economics

Table 58: Number of respondents in WTP sub-analyses

	Observations	Respondents
Baseline	7,470	249
Low Impact	2,400	80
High Impact	5,070	169
Services	6,300	210
Non Services	1,170	39
Small	5,220	174
Medium	2,250	75
Urban	6,000	200
Rural	1,470	49
Copy of choice cards available	5,940	198
Phone only	1,530	51

Source: London Economics

A7.2 Confidence intervals for results

This section provides two tables with confidence intervals for the WTA and WTP estimates for the different subsamples.

Table 59: WTA for a one-month outage once in 20 years in the winter - SMEs

	WTA in £	WTA as % of bill	Confidence interval	
			LB	UB
Baseline	**236**	3.24%	140.43	331.92
Low impact	**206**	8.74%	46.84	365.04
High impact	**255**	2.75%	132.72	376.40
Services	**210**	3.36%	119.80	300.05
Non services	353	3.35%	-53.70	758.85
Small	**195**	4.92%	116.16	274.38
Medium	514	3.12%	-334.36	1363.16
Urban	**200**	2.57%	124.04	276.24
Rural	**1,808**	23.24%	-12,733	16,348
Choice cards available	**254**	3.88%	131.49	375.65
Phone only	**194**	2.11%	45.11	343.29

Note: Numbers in bold are statistically significantly different from zero. Confidence intervals are calculated based on the Delta method. WTA as a percentage of the average bill is calculated as WTA in pounds divided by the average bill for SMEs in each subgroup (except for the baseline where an estimate of the average bill based on the full sample is used). If the size of the bill is provided in a range the size of the bill is calculated based on the midpoint of the ranges with the exception of the top and bottom range for which the lower bound and the upper bound of the range are used respectively . Detailed estimation results are provided in Annex B.

Source: London Economics

Table 60: WTP for a one-month outage once in 20 years in the winter – SMEs

	WTP in £	WTP as % of income	Confidence interval	
			LB	UB
Baseline	**1,140**	15.65%	914	1,366
Low impact	**130**	7.91%	81	179
High impact	**2,389**	22.98%	1,769	3,008
Services	**1,395**	17.44%	1,087	1,703
Non services	**456**	10.26%	254	659
Small	**347**	11.44%	347	558
Medium	**3,222**	17.88%	1,994	4,451
Urban	**1,199**	15.73%	934	1,464
Rural	**995**	15.14%	547	1,443
Choice cards available	**1,208**	14.89%	952	1,465
Phone only	**1,366**	27.85%	602	2,129

Note: Numbers in bold are statistically significantly different from zero. Confidence intervals are calculated based on the Delta method. WTP as a percentage of the average bill is calculated as WTP in pounds divided by the average gas bill for SMEs in each subgroup (except for the baseline where an estimate of the average bill based on the full sample is used). If the size of the bill is provided in a range the size of the bill is calculated based on the midpoint of the ranges with the exception of the top and bottom range for which the lower bound and the upper bound of the range are used respectively . Detailed estimation results are provided in Annex B.

Source: London Economics

Annex 8 Discussion of gas critical production by industry

Gas-critical Industry

We believe that the important issue is not only the extent that each industry sector is “gas intensive” but more the extent to which the sector is “gas-critical” in the sense that loss of gas supply will disrupt output. For example gas use at Petroleum Refineries represents only about 0.4% of energy inputs which are dominated by crude oil. However, our analysis in the next subsection shows that gas supply is critical to meeting quality standards of the petroleum products.

The percentage of GVA that would be lost in the event of a gas disruption is impossible to determine within the scope of this kind of study. The following is a highly subjective and speculative assessment to grade the various sectors in terms of high, medium and low levels of gas-criticality.

Iron and Steel

Gas use appears to be critical to most segments of the iron and steel industry as it is used in basic steel making and also further downstream for heating metal for producing intermediate and final products as described in Section 3. Basic steel making represents about 16% of the GVA in the Iron and Steel sector.

An exception is basic steel making in Electric Arc Furnaces in which an electric current is used to generate an arc which melts the metal. Some 21% of bulk steel is made by the EAF method in UK. It follows that a complete loss of gas supply would not necessarily result in a complete loss of GVA in this sector as EAF could presumably continue in business. On the other hand, we note that BOS furnaces are typically run continuously for many years and shut down could cause considerable costs in terms of damage to equipment.

Assuming a high level of gas dependency for BOS (90%), zero for EAF and somewhat lower dependency for downstream processes leads to an overall assessment of 65 to 85% gas-critical production for this sector.

Non-Ferrous Metals

Some thirty or so non-ferrous metals are in commercial use in the UK and aluminium, copper, nickel, lead and zinc are the most important. The industry is heterogeneous including 300 companies active in the top five metals alone. Some large multi-nationals companies are present but the majority of companies are small or very small.

The industry spans a range of processes from primary production to imported ores and semi-manufacturing of products such as sheet, strip, wire, extrusions, tubes, forgings and castings. The finishing of such products by processes such as anodising and coating and metal recycling are also carried out.

Our judgmental estimates give us a range of 60-80% gas-critical production for this sector.

Chemicals

Gas is used as a feedstock in the petrochemicals sector as well as for process heat. The Chemical sector is described in some detail in the next sub-section.

The manufacture of bulk chemicals makes up 27.5% of the GVA of the chemicals sector and the remainder of GVA is associated with manufacture of consumer chemicals and speciality chemicals. The manufacture of fertilisers and nitrogen compounds (ammonia and methanol) is considered separately as gas is used as feedstock in these processes. Such feedstock is identified in DUKES as non-energy use and this use is 100% gas-critical.

Not all bulk chemical processes are dependent on gas and we would estimate that perhaps 60 to 75% of GVA in the bulk chemical sector would be lost in a gas disruption. Consumer chemicals are considered to be less gas dependent so that overall some 45 to 65% of total chemical GVA is considered as gas-critical.

Petroleum Refineries

This sector is the most homogeneous of the sectors considered comprising 8 major refineries and 3 smaller ones as described in detail in the next sub-section. Whilst gas use is tiny compared to crude oil feedstock and petroleum products use in furnaces, gas is process critical because it is used to make hydrogen which is required for desulphurisation of fuels.

We assume that between 80 and 100% of GVA for this sector would be lost in the event of a gas disruption.

Agriculture

The agriculture sector includes growing of crops and animals on farms but excludes industrial food processing activities which are included under Food and Beverages. Gas use in the sector is relatively small and includes heating of farm buildings. Average consumption is about twice the average level for residential gas. We would anticipate that a gas disruption would have little impact on production in this sector, as the growing of crops and animals would be expected to continue regardless of gas supply. We note that for a relatively small portion of the sector, there could be the possibility of production lost if say, incubating chicks or something were to be impacted by heating loss in winter (0% gas-critical production).

Mineral Products

The mineral products sector comprises both quarrying of raw minerals and manufacture of mineral products including glass, ceramics and building materials.

Whilst the manufacturing side is a major user of gas and production would be severely affected by a gas disruption, the same is unlikely to be the case for quarrying. For this reason we would assess this sector as medium gas-criticality, and we give it a range estimate of 40-60% gas-critical.

Textiles, Leather etc.

This sector covers a range of activities from spinning and weaving to manufacturing of finished garments, and household fabrics and from tanning to manufacturing of leather goods.

Gas may be used intensively in some parts of the industry such as for heating and drying in tanning but is most likely used for space heating in many segments of the industry such as manufacture of completed garments—30-50% gas-critical production is our best estimate.

Other Industries

Other industries include mining of metal ores, manufacture of various products not included elsewhere (wood products, furniture, plastic products etc), metal recycling and the water industry.

These sectors do not generally rely heavily on gas process applications and we have assessed this on the basis that 0 to 40% of GVA would be lost in the event of a gas disruption.

Food Beverages etc.

This sector is one of the largest users of gas and for heating and drying and we would assess the gas-criticality as fairly high at 40 to 60%.

Paper, printing etc.

This sector includes the manufacture of paper and paper products, printing of books and newspapers, production of recording media, and publishing. Whilst the manufacturing side relies on gas and on electricity generated from CHP, publishing activities are less gas intensive. Overall we estimate that 40 to 60% of GVA would be lost in the event of a gas disruption.

Vehicles

This sector includes manufacturing of all kinds of vehicles and transport equipment including ships, boats and aircraft as well motor vehicles. Much of the UK vehicles industry – almost 80% of GVA, is derived from assembly motor vehicles and aircraft from component parts and such activities are highly dependent on gas. We therefore estimate that 30 to 40% of GVA would be lost in the event of a gas disruption.

Electrical Equipment (SIC 30 to 33)

This sector manufactures office equipment and computers, electrical distribution equipment, batteries, radio and television equipment and precision optical equipment. Gas used directly for process purposes is relatively low although the industry does have significant reliance on gas for autogeneration of electricity and heat. We therefore estimate that 30 to 40% of GVA would be lost in the event of a gas disruption.

Metals and Mechanical Equipment (DJ and DK or SIC 27-29)

This sector includes fabrication of metal products and machinery. We therefore estimate that 30 to 40% of GVA would be lost in the event of a gas disruption.

Construction

This section includes construction and civil engineering projects, fitting out and completion of buildings and renting of construction and demolition equipment. Very little natural gas is used on construction sites – most of which are not connected to the mains gas supply until the project is complete. We believe that most of the gas usage allocated to this sector relates to space heating and other use at office buildings and a disruption of gas supply would have little impact on output.

Gas-critical Load

The VAR calculation rests on the important assumption that without a firm gas supply, all production stops and no output is produced.

This assumption is critical and needs to be investigated in detail before the results of the VoLL analysis can be applied with any confidence to establishing the price that users would be willing to pay to secure a gas supply. Initial analysis of the VoLL data across all sectors indicates that the least gas-intensive users appear to have the highest VoLLs. This seems to indicate a problem with the methodology, as it would at first instance seem counter-intuitive that low gas-intensity users would have the highest VoLLs.

One way to treat the problem would be to re-calculate the VoLL using intensive gas users only. However, even with this refinement, which uses the ratio of gas cost to GVA for each sector, there are still some counter-intuitive results. For example on this measure Petroleum refineries and agriculture are both defined as equally “gas intensive”, whereas in reality, a gas interruption is more likely to result in a cessation of operations at an oil refinery that it is likely to stop crops and animals from growing on a farm. Ideally the methodology should be refined to reflect the true impact of gas curtailment on each industry segment as best possible.

Annex 9 Iron and Steel detailed analysis

A9.1 Coverage

The Digest of Energy Statistics includes end-use energy for Iron Steel using SIC code 27, Manufacture of basic Metals and Fabricated Metal Products but excluding subcategories 27.4 (Manufacture of basic precious and other non-ferrous metals), 27.53 and 27.54.

A9.2 UK steel industry

The UK steel industry produced 9.7 million tonnes of steel in 2010 which was 1.8% down on the already low level of 2009 and a third below the recent peak of 14.4 million tonnes achieved in 2007. Within the 2010 total, 7.3 million tonnes was produced using basic oxygen (BOS) and 2.4 million tonnes was produced in electric arc furnaces (EAF). BOS production fell by 6% in 2010 whilst EAF production increased by 15%. Production was affected by the mothballing of Tata Steel's Teesside facility in February 2010.

A9.3 Steel making processes

There are two process routes for making steel in the UK today: through an Electric Arc Furnace and through the Basic Oxygen Steelmaking (BOS) process. Apart from special quality steels (such as stainless steel), all flat products in the UK, and long products over a certain size, are rolled from steel made by the BOS process.

The key component in the BOS process is the Basic Oxygen Converter, however before this process can begin a blast furnace is required to create a charge of molten iron.

The raw materials for producing molten iron are iron ore, coking coal and fluxes (materials that help the chemical process) - mainly limestone. The iron ore and coal used in the UK is imported by to the four steelworks that use it. These steelworks are at Teesside and Scunthorpe on the North East coast, and Port Talbot in South Wales.

Blended coal is first heated in coke ovens to produce coke. This process is known as carbonisation. The gas produced during carbonisation is extracted and used for fuel elsewhere in the steelworks. Other by-products (such as tar and benzole) are also extracted for further refining and sale. Once carbonised, the coke is pushed out of the ovens and allowed to cool.

Fine-sized ore is first mixed with coke and fluxes and heated in a sinter plant. This is a continuous moving belt on which the coke is ignited. The high temperatures generated fuse the ore particles and fluxes together to form a porous clinker called sinter. The use of sinter in the blast furnace helps make the iron making process more efficient.

Iron ore lumps and pellets, coke, sinter and possibly extra flux are carried to the top of the blast furnace on a conveyor or in skips and then tipped, or charged, into the furnace. Hot air is blasted into the bottom of the furnace through nozzles called tuyeres. The oxygen in the air combusts with the coke to form carbon monoxide gas, and this generates a great deal of heat. Frequently oil or coal is injected with the air, which enables less (relatively expensive) coke to be used. The carbon monoxide flows up through the blast furnace and removes oxygen from the iron ores on their way down, thereby leaving iron. The heat in the furnace melts the iron, and the resulting liquid iron is tapped at regular intervals by opening a hole in the bottom of the furnace and allowing it to flow out. The fluxes combine with the impurities in the coke and ore to form a molten slag, which floats on the iron and is also removed (tapped) at regular intervals.

The hot metal flows into torpedo ladles. These are specially constructed railway containers which transport iron, still in liquid form, to the steel furnace.

The process described above goes on continuously for ten years or more. (This is known as a campaign.) If the furnace were allowed to cool, damage could be caused to its lining of refractory bricks as a result of their contracting as they cooled.

Eventually the refractory brick linings are worn away, and at that stage the process is stopped and the furnace relined with new bricks, ready to begin its next campaign. The iron produced by the blast furnace has a carbon content of 4 to 4.5% as well as a number of other "impurities". This makes it relatively brittle. Steelmaking refines iron, amongst other things by reducing its carbon content, to make it a stronger and more manipulable product.

A9.3.1 Electric arc furnaces

In the UK, EAFs are used to produce special quality steels which are alloyed with other metals and some ordinary quality steels including the lighter long products such as those used for reinforcing concrete. EAFs making special quality steels are located in Sheffield and Rotherham, while there are EAFs making ordinary quality steels at Sheerness on the Thames estuary in Kent and Cardiff in South Wales.

Unlike the basic oxygen route, the EAF does not use hot metal. It is normally charged with "cold" material including steel scrap and other raw materials. An electric current is passed through electrodes to form an arc creating the heat needed to melt the scrap.

A9.3.2 Secondary steel making

Steels after they have been tapped (poured) from the furnace frequently undergo a secondary steelmaking process before the steel is cast. This applies to both the basic oxygen process route and to the electric arc furnace route. The molten steel is tapped from the furnace into a ladle and a lid is placed over the ladle to conserve heat. A range of different processes is then available, such as stirring with argon, adding alloys, vacuum de-gassing or powder injection. The objective in all cases is to fine tune the chemical composition of the steel and/or to improve homogenisation of temperature (making sure that the steel is the same temperature throughout) and remove impurities. Ladle arc heating is a process used to ensure that the molten steel is at exactly the correct temperature for casting.

A9.3.3 Casting

In the UK, casting largely uses the continuous casting process (concaster), although the ingot route is retained for certain applications where it is the most suitable way of producing the steel required. Molten steel is poured into a reservoir at the top of the continuous casting machine and passes at a controlled rate into a water cooled mould where the outer shell of the steel becomes solidified. The steel is drawn down into a series of rolls and water sprays, which ensure that it is both rolled into shape and fully solidified at the same time. At the end of the machine, it is straightened and cut to the required length. Fully formed slabs, blooms and billets emerge from the end of this continuous process.

The slabs, blooms or billets are then transported to the hot rolling mill for rolling into steel products which can be used by manufacturing industry.

A9.3.4 Hot rolling

Semi-finished products called blooms, billets and slabs are transported from the steelmaking plant to the rolling mills. In many plants steelmaking and rolling are both carried out on the same site. However there are also many stand-alone rolling mills in the UK (some are independently owned while others are part of a larger group but located away from the steelmaking works).

Steel products can be classified into two basic types according to their shape: flat products and long products. Slabs are used to roll flat products, while blooms and billets are mostly used to roll long products. Billets are smaller than blooms, and therefore are used for the smaller type of long product.

Semi-finished products are first heated in a re-heat furnace until they are red hot (around 12000 C). On all types of mill the semi-finished products go first to a roughing stand. A stand is a collection of steel rolls (or drums) on which pressure can be applied to squeeze the hot steel passing through them, and arranged so as to form the steel into the required shape. The roughing stand is the first part of the rolling mill. The large semi-finished product is often passed backwards and forwards through it several times. Each pass gradually changes the shape and dimension of the steel closer to that of the required finished product.

A9.3.5 Plate mills

Slabs are used to make plate. Typically, after leaving the plate mill's roughing stand, they are passed through a finishing stand. This is a reversing mill: like on the roughing stand, the steel is passed backwards and forwards through the mill. It is also turned 90 degrees and rolled sideways at one stage during the process.

Plate is a large, flat piece of steel perhaps 10mm or 20mm thick (although it can be up to 50mm thick) and up to 5 metres wide. It is used for example to make the hulls and decks of ships or to make large tanks and boilers. It can also be rolled up and welded to form a large steel tube, used for oil and gas pipelines.

A9.3.6 Strip mills

Slabs are also used to make steel strip, normally called hot rolled coil. After leaving the roughing stand, the slab passes continuously through a series of finishing stands which progressively squeeze the steel to make it thinner. As the steel becomes thinner, it also of course becomes longer, and starts moving faster. And because the single piece of steel will be a whole range of different thicknesses along its length as each section of it passes through a different stand, different parts of the same piece of steel are travelling at different speeds. This requires very close control of the speeds at which each individual stand rolls; and the entire process is controlled by computer. By the time it reaches the end of the mill, the steel is travelling at about 40 miles per hour. Finally the long strip of steel is coiled and allowed to cool.

Hot rolled strip is a flat product which has been coiled to make storage and handling easier. It is a lot thinner than plate, typically a few millimetres thick, although it can be as thin as 1mm. Its width can vary from 150mm to nearly 2 metres. It frequently goes through further stages of processing such as cold rolling and is also used to make tubes (smaller tubes than those made from plate).

A9.3.7 Long product mills

Blooms and billets are used to make long products. After leaving the roughing stand, the piece of steel passes through a succession of stands which do not just reduce the size of the steel, but also change its shape. In a universal mill, all faces of the piece of steel are rolled at the same time. In other mills, only two sides of the steel are rolled at any one time, the piece of steel being turned over to allow the other two sides to be rolled.

Long products are so called because they come off the mill as long bars of steel. They are however produced in a vast range of different shapes and sizes which are used for construction and engineering purposes. Rod is coiled up after use and is used for drawing into wire or for fabricating into products used to reinforce concrete buildings, as are some types of bar.

A9.3.8 Cooling

In all rolling processes, cooling the steel is a critical factor. The speed at which the rolled product is cooled will affect the mechanical properties of the steel. Cooling speed is controlled normally by spraying water on the steel as it passes through and/or leaves the mill, although occasionally the rolled steel is air-cooled using large fans.

A9.3.9 Further processing

Hot rolled products can undergo many forms of further processing before they are finally used to make an end-product. Such processing includes:

- Cold rolling and drawing
- Fabricating. Steel sections are cut, welded and otherwise prepared to form the steel frame of a building. Rods and bars are similarly cut and shaped to form the steel reinforcement for concrete buildings.
- Coating
- Cutting and slitting - Service centres cut steel into many complex shapes.
- Profiling - Sheet steel may be pressed into the correct shape for crash barriers or the cladding of buildings (known as profiling).

A9.4 Impact of a gas disruption

Gas is critical for the operation of BOS blast furnaces which account for about 75% of steelmaking in the UK. Gas is critical to the Integrated Gas System at BOS plant and loss of gas supply leading to unscheduled shut down could be hazardous and could cause damage to the lining of the blast furnace. Electric Arc Furnaces which account for the remaining 25% of steel production is less gas critical as an electric arc is used to melt the metal. However, where power is generated on site using gas even EAF steel making would be impacted by a gas disruption.

Secondary steel process, casting rolling and milling all require considerable process heat to maintain the temperature of the metal as it being worked so a gas disruption would have impact on lost production throughout the entire sector.

Assuming a high level of gas dependency for BOS (90%), zero for EAF and somewhat lower dependency for downstream processes leads to and overall assessment of 65 to 85% for the proportion of GVA that might be lost due to a gas disruption in this sector.

Annex 10 Chemical detailed analysis

A10.1 Coverage

Natural gas is used in the chemicals industry both as a feedstock for the manufacture of chemicals and as a fuel in chemical plant. Gas as a feedstock is included in DUKES as "non energy use" whereas fuel usage is included as the Chemicals Category of Final Consumption defined by SIC code 24.

A10.2 UK chemicals industry

The UK Chemical industry was originally developed using local resources including salt, coal, limestone, vegetable matter and animal fats. Today it is part of a global industry primarily using natural gas and oil fractions such as naphtha as its dominant raw materials. The industry uses natural gas both as raw materials and for process energy. Turnover exceeds £57bn, and over 180,000 employees work for 3000 organisations. Only 160 companies employ more than 250 people, a fact which demonstrates that not all chemicals activity is large scale.

The UK chemicals industry is active in all three of the principal sectors of the chemical industry – commodity, speciality and consumer chemicals

A10.2.1 Commodity chemicals

Commodity chemicals is the largest sector of the UK chemicals industry in terms of turnover which amounts to an annual total of £18.4 billion. Despite the emergence of new global players in the industrial chemicals arena, the UK remains an important source of industrial gases, inorganics, organics, fertilisers, plastics, synthetic rubber and man-made fibres.

Chemicals produced by the UK's 885 commodity chemicals companies, most of which are based in the northern regions, are used in a range of products such as pulp and paper, batteries, soap and detergents as well as in water and waste-water treatments by industries worldwide. Furthermore, sales of pesticides and other agrochemical products have also grown strongly in recent years.

Leading players in the UK include BP Aromatics and Acetyls which produce bulk chemicals for a wide range of consumer products and plastics. Shell Chemicals has three UK sites manufacturing propylene, higher olefins, plasticiser alcohols, detergent alcohols, ethyl benzene and toluene. Ineos has a number of sites in the UK, including Runcorn, Barry, Northwich, Grangemouth, Helsby, Newton Aycliffe and Teesside.

The chemical industry is located in four main geographical clusters at Grangemouth in Scotland, Teesside, Yorkshire and Humber and the North West. These locations are close to landing points for oil and gas from the North Sea and Morecambe Bay and also the necessary range of utilities, services and engineering support.

A10.2.2 Speciality chemicals

Speciality chemicals includes products with more sophisticated technical input. These products, which have a combined annual turnover of £11.2 billion, include dyestuffs, paints, explosives, adhesives, flavours and fragrances, photographic chemicals, unrecorded media and various industrial specialities. Whilst, by definition, speciality chemicals are produced in relatively small quantities, they represent 28 per cent of EU chemical sales.

The UK has over 1,300 speciality chemical companies widely spread across the country, primarily in Yorkshire, the Midlands, around Nottingham, Loughborough and Birmingham, in the South and South West near Southampton and Bristol, in the North and North West and in South Wales.

A10.2.3 Consumer chemicals

There are over 550 consumer chemicals companies operating across the UK, employing around 34,000 people. The sector generates nearly £6 billion in annual turnover and has an annual GVA of £2 billion. A thriving cluster of some 70 personal care companies is located in Yorkshire and Humber. There are also numerous consumer chemicals companies in the North West such as Unilever, PZ Cussons and McBride.

Consumer Chemical products include soaps, detergents, cosmetics and personal care products. The sector includes some particularly high growth areas such as perfumes, toilet preparations and essential oils and represents approximately 10 per cent of EU chemical sales.

The UK is a major European manufacturing and distribution centre for pharmaceuticals, paints and coatings, detergents and personal care products, as well as specialised products and process enablers for other manufacturing industries such as the automotive and electronics sectors.

A10.3 Impact of a gas disruption

The fertiliser industry uses gas as a feedstock to make ammonia and this element is clearly totally dependent on gas. However it represents only small proportion of total bulk chemicals. The extent to which other bulk chemical processes are dependent on gas will vary from process to process and plant to plant but in general we would judge that bulk chemicals has a fairly high dependence on gas. Speciality chemicals and consumer chemicals sectors are even more diverse with thousands of companies involved in the sector.

The manufacture of bulk chemicals makes up 27.5% of the GVA of the chemicals sector and the remainder of GVA is associated with manufacture of consumer chemicals and speciality chemicals. The manufacture of fertilisers and nitrogen compounds (ammonia and methanol) is considered separately as gas is used as feedstock in these processes. Such feedstock is identified in DUKES as non-energy use and this use is 100% gas-critical.

Not all bulk chemical process are dependent on gas and would estimate that perhaps 60 to 75% of GVA in the bulk chemical sector would be lost in a gas disruption. Consumer chemicals are considered to be less gas dependent so that overall some 45 to 65% of total chemical GVA is considered as gas critical.

Annex 11 Petroleum refining detailed analysis

A11.1 Data coverage

Natural gas use in refineries is classified in Dukes under Energy Industry use.

A11.2 UK petroleum refining

There are eight major refineries now operating in the UK compared with 19 in 1975.The Petroplus refinery in Teesside was shutdown in 2009 and is currently operating as an import terminal.

Refining capacity in the UK is 1.8 million bbls per day, the fourth largest refining capacity in the EU (after Germany, Italy and France). Slightly less than 90% of the UK market for refined products.

Table 61: Refineries in the UK

	Refinery	Owner	Distillation	Reforming	Cracking and Conversion
Major refineries					
1	Stanlow	Shell	11.5	1.5	3.8
2	Fawley	ExxonMobil	16.8	3.0	5.2
3	Coryton	Petroplus	8.8	1.8	3.4
4	Grangemouth	INEOS	9.8	2.0	3.3
5	Lindsey	Total	11.9	1.5	4.1
6	Pembroke	ChevronTexaco	10.1	1.5	6.1
7	Killingholme	ConocoPhillios	11.1	2.1	9.5
8	Milford Haven	Murco	5.3	0.9	2.0
Other refineries					
9	Harwich	Petrochem Carless	0.4		
10	Eastham	Eastham Refinery Ltd	1.1		
11	Dundee (Camperdown)	Nynas UK AB	0.7		
Total all refineries			87.5	14.2	37.4

Source: CECC, Digest of UK Energy Statistics, 2010

A11.2.1 Refining processes

Refinery operations can be broken down into five main processes:

1) Distillation which separates crude oil into different refinery streams
2) Conversion and reforming which improve the quality of these streams and adjusts the yields to meet market demand
3) Desulphurisation which reduces the sulphur in the streams to the required level
4) Blending of the refinery streams to produce the final products meeting current regulations and specifications
5) Desulphurisation and Waste Treatment

A11.2.2 Distillation

The starting point for all refinery operations is the crude distillation unit (CDU). Crude oil is boiled in a fractioning column, which breaks the crude down into more useful components. The crude oil enters the column near the bottom and is heated to around 380°C. The lighter fractions are vaporised and rise up the column. As they rise, they are cooled by a downward flow of liquid and condense at different points. This enables fractions with different boiling points to be drawn off at different levels in the column.

These fractions range from lighter, low boiling point gases such as propane and butane to heavier, higher boiling point diesel and gas oil. They are then sent on to other refinery units for further processing. What is left over at the bottom of the column is a liquid residue, which requires further processing to be turned into more valuable, lighter products or blending components.

This residue is first sent to a second stage of fractional distillation in the vacuum distillation unit (VDU). This unit performs the distillation under reduced pressure which allows the distillation of the crude residue at lower temperatures. Using the same approach as before the VDU separates into different components from gas oil to a heavy liquid residue.

The streams from the CDU and VDU are then processed further by the remaining refinery units to provide final products.

A11.2.3 Conversion and reforming

Distillation does not produce enough of the lighter, more valuable products such as petrol that the market wants. Therefore conversion units (e.g. FCC) are used to treat some of the streams from the vacuum distillation column with the aim of turning the heavy components into lighter transport fuels.

Reforming units are used to upgrade the octane of the petrol components produced from the CDU.

A11.2.4 Desulphurisation

Desulphurisation units are then used to remove sulphur from the products. This enables the products to meet today's tighter fuel specifications and allows the refinery additional flexibility to process higher sulphur 'sourer' crude oils. Reliance on low sulphur crude oils alone limits the flexibility of a refinery.

A11.2.5 Blending

LPG is taken directly from the crude distillation unit and the FCC and used with no further processing.

Petrol streams from the distillation process are cleaned in the unifiner. This unit strips out unwanted sulphur and nitrogen compounds as hydrogen sulphide and ammonia.

The streams are then sent on to the reformer and isomer units for processing to raise the octane number of the petrol by modifying its molecular structure. The reformer produces a large amount of hydrogen as a by-product, and this is recycled for use in desulphurisation (hydrotreater) units.

Finally the petrol streams from the reformer, fluidised catalytic cracking (FCC) unit, the isomerisation unit and the alkylation unit are blended to meet fuel specifications and current regulations.

Jet fuel/kerosene streams from distillation are cleaned in the merox unit. This uses a caustic wash and additives to remove sulphur compounds and to inhibit gum formation.

Diesel/heating oil streams are processed in the hydrotreater, which cleans the streams by removing sulphur and other unwanted compounds using hydrogen and a catalyst. The hydrotreater is supplied with recycled hydrogen from other process units such as the reformer. The diesel/heating oil streams are separately blended to meet fuel specifications and current regulations.

The lighter fuel oil streams from the VDU are processed in the FCC unit whilst the heavier residues from the VDU are processed in the visbreaker.

In the FCC unit, heavy oils are reacted with at high temperature with a catalyst which breaks the heavy fractions into more valuable lighter products. The LPG and petrol components are then cleaned in a merox unit and some of the LPG is converted in an isomerisation or alkylation unit into high octane petrol blending components. The FCC’s products are blended into petrol, LPG, diesel/gas oil and fuel oil product streams.

In the visbreaker, the heavy fractions are held at high temperature until they become less viscous. This stream is then blended into other fuel oil product streams.

The fuel oil components from the different units are then blended to give fuel oil meeting current regulations and specifications.

A11.2.6 Desulphurisation and waste treatment

The sulphur recovery unit takes waste hydrogen sulphide from the units which remove sulphur from product streams. The hydrogen sulphide is then reacted with oxygen to give solid elemental sulphur and water vapour. After treatment, this sulphur is sold to other process industries.

Sulphur removal from transportation fuels has received increasing attention in recent years, mainly for the preparation of clean fuel for the environment and to meet the new stringent specifications for gasoline and diesel fuels. In order to comply with these new regulations, all refineries have installed new fuel desulphurisation processes. Well-known commercially available catalytic hydrotreating processes (hydrodesulphurisation [HDS]) operate at relatively high pressures and use significant amounts of hydrogen and expensive proprietary catalysts.

Some specific processes are required to obtain pure hydrogen and the most usual one is natural gas reforming, where natural gas reacts with superheated steam producing H2, CO, CO2 and H2O.

All other waste streams are treated according to the current regulations.

A11.3 Energy use

According to UKIPA, refineries use the equivalent of between 5 and 6% of oil throughput as fuel for the refinery processes. The average figure for the UK in 2009 was 6.8% (Dukes, 2010).

Most of this fuel is generated on site. Over the last few years the refineries sector has seen a decrease in the use of heavy fuel oil and an increase in the use of refinery gas and natural gas. This may be a reflection of the rise in the market value of heavy fuel oil over this same time period. A refinery selling rather than burning the heavy fuel oil it produces, and substituting this with lower value refinery gas and natural gas, the latter having increased in value less than fuel oil, would likely increase its revenue.

In 2009, Petroleum Products (including refinery gas) accounted for 85% of fuel used in refineries. Natural gas accounted for 6% and the remainder was supplied as heat and power.

A11.4 Impact of gas disruption

A disruption of gas supply would impact refinery output in two ways. First would be the impact on hydrogen production and hence on desulphurisation and secondly gas is used as a substitute for HFO in furnaces.

The requirement to remove sulphur from petroleum products originates from both industrial and environmental factors. Sulphur compounds in petroleum products are converted by combustion to SOx, which poisons catalytic converters, corrodes parts of internal combustion engines and refining equipment and is a major source of acid rain and air pollution. In an emergency, caused by a major disruption to gas supply it is possible that environmental standards could be relaxed. However, the potential physical damage to transport and industrial equipment suggest that SOx standards could not be relaxed without causing significant knock-on costs to the wider economy.

A second issue would be the ability to switch fuels for heating furnaces as different burners are required to burn gas and oil. All of the UK refineries were originally build in the 1970s or earlier and would have been designed initially to burn a combination of fuel oil and refinery gas. Natural Gas burning equipment will have been retrofitted over the years as gas became available from the National Transmission System and it is not clear to what extent oil burners were retained and maintained so that they could be used in an emergency.

These considerations tend to the conclusion that loss of gas supply for any length of time could pose a serious threat to production of petroleum products. However, it is likely that the ability to maintain production and at what level without natural gas would vary from refinery to refinery. Modern refinery operations are complex and each operator would seek to re-optimise processes to maximise production and value within the constraints of their own physical equipment and to the extent that would not cause long term problems.

We estimate that between 80 and 100% of GVA for this sector would be lost in the event of a gas disruption.

Annex 12 Details of the spark spread method

A12.1 Mathematical formulas and details

Adjusted BSM formula for VoLL as spark spread call value

$$V = e^{-rt}\left[P_e^{t,T}N(d_1) - ((P_g^{t,T} + P_c^{t,T})/H)N(d_2)\right]$$

Where:

$$d_1 = \frac{\ln\left[P_e^{t,T}/((P_g^{t,T} + P_c^{t,T})/H)\right] + v^2(T-t)/2}{v\sqrt{T-t}}$$

$$d_2 = d_{1\_}v\sqrt{T-t}$$

$$v^2 = \frac{\int_t^T\left[\sigma_e^2(s) - 2\rho\sigma_e\ (s)\sigma_{gc}(s) + \sigma_{gc}^2(s)\right]ds}{T-t}$$

A12.2 Discussion of the parameters

Risk-free rate and risk neutrality

One of the key assumptions of the BSM formula is that there is a replicating portfolio for an option and the underlying commodity. It can be argued how much such assets might be constructed to create any replicating portfolio, but in the case of electricity commodity prices in the UK, liquidity is already an issue with the underlying commodities, and trading is in some cases illiquid. To argue that a spark spread could be risk-neutralized/hedged could be somewhat tenuous. While there is little doubt that some traders do perform such hedging, the question at hand is whether such an assumption is appropriate for an estimate of VoLL. The risk-free rate, or non-risk free rate used, will impact on the option value based on the discounting. Thus, the value of the option will fall as the value of the discount rate rises. Thus, for estimating the value of the VoLL as a spark spread option further into the future, we might consider discounting by a risk-adjusted cost of capital rather than the risk free rate, or alternatively using an option pricing model specifically designed to incorporate the market price of risk. For our purposes, we will estimate the VoLL based on the year-ahead forward curve, and so discounting will have very little impact on our results. We discuss the rationale for this below.

Time, expiry and discounting

Another issue that needs to be addressed is the timing and time period assumed. We must choose a particular time-period into the future for the option. Financial option contracts typically have a "time of expiry", in other words a fixed time when the option expires.

Because of the risk neutralizing effect of assumed perfect hedging *and* the random walk assumption (which means that the volatility of the price series should increase in proportion to the square root of time), then the value of an option estimated with the BSM formula will increase with time, *ceteris paribus.* It is arguable whether this should be appropriate for using such a formula for an estimate of VoLL.

In general, we cannot make a particular choice about the time period, the time of expiry and the discounting as this needs particular inputs from Ofgem on how they are implementing the VoLL estimates. For example, if Ofgem is considering how much electricity producers might be willing to pay to avoid an outage of one day, continuously over a five year period, then this would imply the time period of the outage and the option value, and the appropriate discount rate and discounting formula would then apply.

Our solution is to choose a "near term period" – call it next year, and this would then avoid the issues created by discounting and by the risk-free assumptions, the lack of a time of expiry, etc.

We also calculated our values on a pure hourly pence-per-therm basis, and then the length of the outage is just proportional to that value. Nonetheless, if we include some additional starting and stopping costs, then the costs of an outage might be sensitive to the length of the outage, as the starting and stopping costs will be fixed for any given outage.

Futures price data

As we discussed previously, there is likely mean reversion in the electricity and gas price series, and thus also the spark spread price series.[48] One way to account for this is to use futures price data in a BSM style pricing formula. To discuss only the intuition, if we use data from the forward curve, then any deviations from the long term equilibrium spread due to transient (non-permanent) recent shocks should effectively be filtered out by traders. In other words, if a short-term supply interruption sends the price of gas or electricity high today, but I as a trader am trading gas and electricity several months, quarters, or even years ahead, then when making these trades they will be based on my expectations of the reversion to the long run mean/equilibrium spread.

Practically, when using futures price data (or any financial data), one must choose some period of observation, as there will be some short term fluctuations. Further, by using the futures price data, we account for the potential mean reversion in the gas and electricity price series (see Deng et al 1999). What we did then was to base our estimates on the average across the forward curve up to one year ahead for each trading day, and then used only the most recent years' data (i.e., from 1/04/2010 to 31/03/2011).

---

[48] In fact, even if the electricity and gas prices followed random walks with drift, their ratio or differences could follow around a stable equilibrium, and so they would be cointegrated.

Volatility estimates

A key input to the spark spread option value estimating formula is the volatility. We estimated the volatility using the most recent years' forward curve price data. This effectively lowers the volatility for the mean reversion property if the longer-dated forward contract prices are less volatile, as they will ignore short-term shocks.

We estimated the volatility for each of the baseload and peakload spark spread data. This was done by taking the standard deviation of the log of the spread. These were then adjusted to 30-day volatility figures, the result was an annualized volatility of 66% for baseload and 87% for peakload.

Risk free rate

We used a risk free rate of 1%. This is based on UK Gilt rates for the BOE and as reported in www.FT.com. The rate is the average (rounded) of the most recent (last three months) short-term (6-month to 1-year) borrowing rates. The official BOE lending rate is at 0.5%, but as inflation in the UK has been above target, the yield curve (the interest rate as bond maturities lengthen) has been fairly steep, with borrowing rates for longer dated bonds near 4%).

A12.2.1 Including start and stopping costs

There are some real starting and stopping costs for gas-fired electricity generation units. Since these can be a real cost of a gas supply interruption, then arguably they should be included in the value of the gas VoLL.

We give details of our methodology for estimating the cost of starting and stopping for a CCGT and OCGT in the annexes. The cost of the outage is primarily the gas cost of heating the unit and ramping it up to full load once it stops (beside the opportunity costs, which we've just estimated).

So for a short outage, the gas cost, C, can be estimated as follows:

$$C = P_g^S \frac{(400)\frac{1}{2}}{0.45}$$

P_g is the gas spot price. The second figure is the capacity of the unit, 400MW. While the unit doesn't produce 400 megawatts while it ramps up, the gas usage will be high/close to capacity, because the additional output of a CCGT comes from using the waste heat from the gas turbine. The ½ figure is the fact that it only takes one half an hour to ramp up, and the gas usage is a MWh or energy figure (converted from therms). The denominator is the thermal efficiency, assumed to be approximately 45%. This is the 50+% efficiency of a standard CCGT with a slight adjustment downward for lower thermal efficiency and the inertia as mentioned.[49]

There is also the possibility of penalties applying in the case of going off-line, but for our estimates here, we assume that these penalties would not apply if the fault is with the gas supply and not with the electricity generation itself.

Applying the formula, and using the last year's average day-ahead spot NBP gas price, 45.11 p/therm, or 27.98£/MWh, and converting to a total £ figure for a 400MW capacity F-class CCGT gives: £12,437.

We note that this is the cost of a 'hot start', i.e., a short outage. For a long outage, the starting costs will be also higher, as there will be a "cold start" cost.

Roughly, the start time will be about 4 times as long as the cold start, so the cost would be about £50,000. However, this would be spread over a longer period.

It should be noticed that the value above is simply in pounds sterling and not £/MWh or p/therm. This is because this is a per start cost. An issue now becomes the 'length' of the outage.

For the purposes of comparison, we should convert the costs to pence per therm and add this to our opportunity cost/option value figures also in pence per therm. To do this, we assume 400MWh of gas is the quantity of gas to spread the cost over. In other words, roughly for one hour's lost production, the gas that would have been used is the cost to spread the fixed start cost over.

400MWh (one hour's production) converts to 13,649 therms, so spreading/dividing £12,437/13,649therm (and multiplying by 100 to get pence from pounds) gives about 91p/therm. Thus the start costs of a one hour outage are higher than the opportunity costs of the labour and capital (the lost production value-added), which were estimated to be about 44p/therm for baseload CCGT plant.

For a 24-hour outage, we take £50,000/(13,649x24), in other words, 13,649therms are 'lost' in each of the 24 hours, and so this is the quantity of lost load that the fixed start cost is spread over. Performing this calculation gives us about 15p/therm.

Of course, for very long outages, the fixed start cost will become negligible, and so the VoLL approaches the pure opportunity cost. Any outage of more than 15 days and the addition to the opportunity cost from the start cost will be less than one p per therm.

We repeat the above process for a peaking generator and assume 15minute hot start, 32% thermal efficiency, and a 20 minute cold start, and a 150MW generator. The notable difference is the quicker cold start time/lower cold start cost. This gives us an estimate of the start/stop costs in p/therm for a one hour outage of 64p/therm, and only 4p/therm for a 24 hour outage. These should be added to the opportunity cost figures.

---

[49] More technically, there will be a heat rate 'curve' and we would want to integrate the heat rate curve and the production over the course of the ramp. The heat rate could be slightly lower from this adjustment, but this is a technical adjustment and would require technical data on the unit's performance that might not be standard.

A12.2.2 Start and stop costs for CCGT

An issue for the estimation of VoLL for the power sector is the starting and stopping cost for the generation unit.

The cost of a trip (something that causes the unit to automatically shut down) is fundamentally the cost of the gas to bring the unit back on line.

Initial Trip – Once there is a loss of gas pressure the unit will trip automatically. It is very rare that a trip caused by lack of gas pressure will damage the machine, so it is unlikely that a gas outage would include any additional cost beyond heat costs. Once the unit is tripped, the gas supply is immediately shut off, the machine then runs down on its own momentum. Hence once gas pressure drops, the unit trips, and no more gas is used (although there is also some heat loss during the stoppage—this can be included in the heating cost when the unit restarts). Typically it takes 20 to 30 minutes for the unit to slow down to turning speed. Turning speed is a few rpm, just enough speed to keep the rotor (shaft) turning so as not to cause the rotor to sag/weep.

Cause of Trip – When a unit trips the operating team will investigate the cause of the trip. Once they are confident what the cause of the trip is and the machine has not been damaged they will bring the unit on-line again (with the permission of the grid). Typically with gas pressure loss it would be immediately apparent that this was the cause and that it is likely no damage would be done. If the unit is damaged, which is very unlikely, replacement of “Hot Gas Parts” may be required. Hot Gas Parts are the parts within the combustion section, i.e., where the combustion takes place and the rotor runs between the stationary parts.

Turning Gear – After 20/30mins the unit is on turning gear, this means the rotor is turned by an electric motor. This is turned using “in-house” electricity, the amount of in-house electricity used is negligible maybe a few hundred kilowatts, and so we will ignore this in the estimation of gas VoLL.

Start Up – An “F” class typical 400MW CCGT can “Hot Start” in fewer than 30 minutes. Hot start is bringing a machine back on-line soon after it has come offline, i.e., the unit is still hot. The cost of this start up is the amount of gas used, which would be less than that used at full load. At full load the gas used can be calculated by estimating about 50% efficiency and producing 400MW for 30 minutes (or one half hour). The unit will ramp up from 0MW to 400MW during this time the gas usage will be proportional to the output but slightly higher than directly proportional efficiency due to the inertia required acceleration of the rotor etc.

If trips occur regularly then the normal inspection interval between outages will decrease based on the high number of stopped starts. This would only be of significance if one started to have 10 plus stop/starts, and so we suggest one can ignore the ‘wear and tear’ elements of stopping and starting for the purposes of gas VoLL estimation.