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Households' WTP for the Reliability of Gas Supply

Wan-Jung Chou[1], Andrea Bigano[2], Alistair Hunt[3],

Stephane La Branche[4], Anil Markandya[5], Roberta Pierfederici[6]

The security of natural gas supply is an important issue for all EU countries due to the region's heavy dependence on imported supply sources and in light of energy demand for gas that is continuously increasing. Discussions have emphasised strategies for securing the supply at the macro level, e.g. diversification in supply sources, increase in storage capacity, etc. By contrast, consumers' demand for the reliability of gas supply is rarely investigated. Hence this study was conducted to examine the economic implications associated with the security of gas supply directly to domestic consumers. Based on the choice experiment approach, household surveys were conducted in France, Italy and the UK. The results confirmed that the degree of the economic impact of a disruption of gas supply to domestic consumers was a function of the duration of a supply disruption and the season in which a supply cut would take place, as well as other preferences of consumers. The willingness to pay to secure per unit of gas consumption, or alternatively the costs of gas unsupplied, was estimated at between €2.65/cubic metre and €41.48/cubic metre across three different European countries.

Keywords: Energy security; gas supply; households; willingness to pay; choice experiment; EU

JEL Classification: C35, C83, C93, D12, Q41

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[1] APEC Research Centre for Typhoon and Society, Taiwan. Corresponding author.

[2] Fondazione Eni Enrico Mattei, Italy.

[3] University of Bath, UK.

[4] Institute of political studies, Grenoble, France.

[5] Basque Centre for Climate Change (BC3). Bilbao, Spain; and University of Bath, UK.

[6] Fondazione Eni Enrico Mattei, Italy.

1. INTRODUCTION

The importance of security of natural gas supply has been widely noted by stakeholders of various backgrounds, including policy makers, energy companies, academic experts, etc. As Stern (2002) has put forward, the risks of having a gas supply disruptions in the future can be attributable to the following factors: the *sources* of gas supplies, the *transit* of gas supplies and the *facilities* through which gas is delivered. The risk with facilities lies in the situation that a network does not offer sufficient redundancy of capacity to allow for the redirection of flows in the event of the failure of a major component. This is thought to be the case for the current European pipeline networks, as well as for many national networks, e.g. in the UK. Whilst the EU's energy policy is largely established on the prerequisite towards liberalised markets, keeping redundant capacity has become costly for energy suppliers and this is inevitably putting the supply of natural gas in greater risks. In comparison, risks associated with source and transit dependence are largely political in nature (Luciani, 2004). Luciani (2004) has also suggested that the only event that may precipitate a critical situation for the security of European gas supplies is the total interruption of supplies from Russia which is the largest supplier of gas to the EU. Besides, regional instability can have a significant impact on the sustainability of an established cross-national pipeline transit route.

Actions that can reduce the threats associated with these risk factors will need to be taken in order to: 1) address, in the long term, the issues of supply adequacy, infrastructure required to deliver the supply to the market, and catastrophic failure of major supply sources and facilities, and 2) ensure, in the short run, supply availability and operational security of gas markets, e.g. daily and seasonal stress and strains of extreme weather (Stern, 2002). Potential solutions are available and many of them are gradually being put in place: for example, developing LNG (Liquefied Natural Gas) technology has the advantage of diversifying supply sources and transit routes; storage obligation and emergency supply rights are considered in order to overcome short-term stress in the market (Cayrade, 2004). Yet the costs of implementing any of these measures will eventually be passed on to final consumers, and at the same time, energy markets in the EU countries are moving towards a deregulated framework in which energy companies require an adequate incentive structure to maintain high service reliability. From this viewpoint, the extent to which consumers demand the reliability of natural gas supply, expressed in monetary terms, provides essential and valuable inferences regarding the plausibility of undertaking any of these investment measures. In addition, it is also important for policy makers to be informed of consumers' valuation on the reliability of gas supply in the future, so that an acceptable mix of regulatory and economic tools can be applied to maintain adequate security of supply that are socially optimal and economically efficient.

Studies that have investigated the economic impacts of a gas supply disruption are very rare. In the report prepared for the Department of Trade and Industry in the UK in 2007 (Oxera, 2007), the costs of a gas outages were measured as the gross value added (GVA) lost due to an interruption on industry users only. The average cost due to an outage was estimated at £5/therm[7] or €17/cubic metre[8] and for large interruptions, the marginal cost may be above £30/therm (€102/cubic metre). The other illustration of measuring the value of a secure gas supply at the national level can be seen in Damigos, Tourkolias and

[7] This figure was obtained across a range of outages from 10mcm/day to 90mcm/day. 1 therm = 0.36 cubic metre natural gas.
[8] 1€ = 0.796£ (2008£).

Diakoulaki (2009). This study measured households' willingness to pay to have reliable natural gas supply in electricity generation, rather than the natural gas supply directly to domestic consumers. The findings showed that Greek households were willing to pay €4.1- €11.8 on top of their bi-monthly electricity bills. Considering these estimates together with the total number of households in Greece and the country's total annual electricity production from natural gas, the results indicated that households were willing to pay a premium between €4.5 and €12.7 per MWh, approximately equivalent to €0.05-0.14 / cubic metre[9].

Natural gas is a growingly important source of energy supply to people's houses, in which it is mainly used for room heating, water heating and/or cooking. The share of gas energy consumption of households of the total gas energy consumption has been rising in the last decade. As shown in Figure 1, the figure is over 60% for the UK and over 40% for both France and Italy. Despite showing a high reliance on gas supply, the domestic sector, however, is the most vulnerable group amongst all types of consumers. This is because industry users usually have the capacity of negotiating with energy suppliers a contract in which the reliability of supply, by and large, can be guaranteed at a predefined level and these users, in the same time, have back-up facilities in case of a supply disruption. By contrast, this is rarely the case seen amongst domestic users.

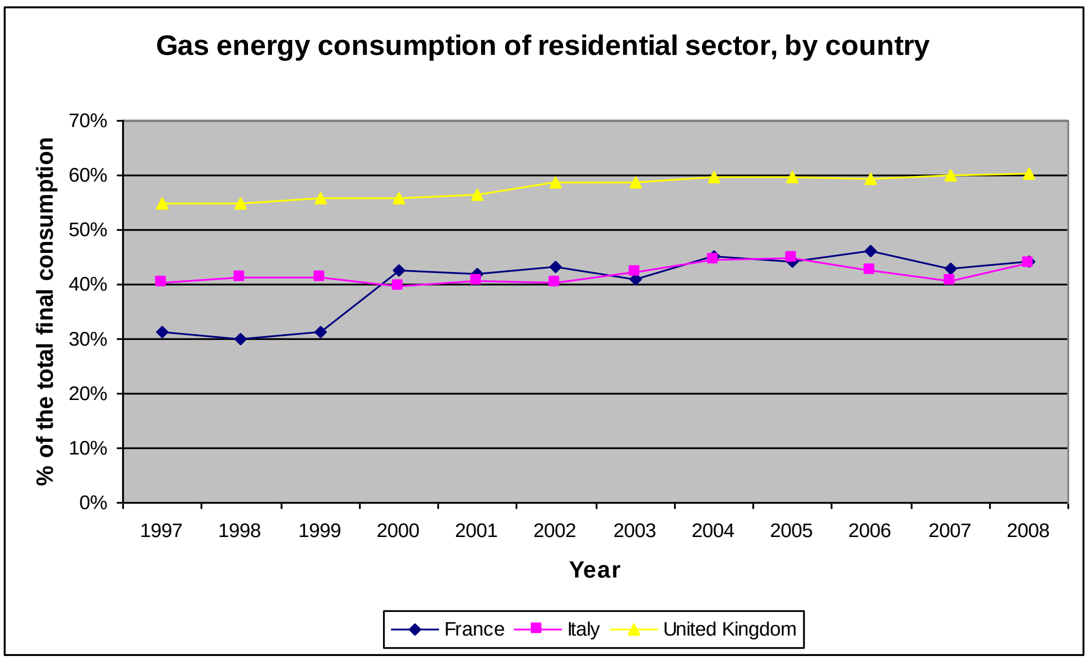

Figure 1: Gas consumption of residential sector, in France , Italy and the United Kingdom (source: EUROSTAT)

This study sets out to investigate domestic consumers' valuation on the security of natural gas supply directly to their dwellings. To our best knowledge, this is the first study to value households' willingness to pay for the reliability of gas supply to their homes at the national level as well as across various EU

[9] 1 cubic metre natural gas= 11.06 kWh.

countries. The choice experiment method is employed and 725 households in total from three different European countries are interviewed. The countries of study include France, Italy and the UK.

The data and the details related to the design of experiment are displayed in section 2. Section 3 presents the econometric model used for estimation. We present and discuss the estimated outcomes in section 4 and section 5 concludes this paper.

2. DATA AND EXPERIMENT DESIGN

Data based on the choice experiment approach was collected via surveys, in which respondents were asked to complete a few pre-designed experiments. Main surveys were carried out in late March and April of the year 2010 in France, Italy and the UK[10], by using computer assistant personal interviewing (CAPI). The raw data included 303 households (heads of household) in the UK, 222 in Italy and 200 in France[11].

The choice instruments were designed as forced choice exercises. In a forced choice exercise, an opt-out option (usually a status quo option) is not available and therefore respondents must choose one out of the available alternatives and every alternative option has a price tag other than zero. This is considered as a suitable approach to apply when the trade-off effects amongst attributes are of higher interest to analysts than the aggregate effects across alternatives. We adopted this design in consideration of the following. First there is no reason to believe that a realistic status quo can be developed, as far as the reliability of gas supply is concerned. The current level of reliability in a country is an outcome of continuous private investments and policy inputs for a certain period of time, and the level will not be sustained in the future if private investment or policy instructions are not in place. Hence it is more appropriate to treat the level of reliability in the future as a random event to be determined by several changeable factors, rather than to assume the current situation will certainly carry on to the time to come. Moreover, the implied property rights are with the network companies, i.e. people have to pay to have the supply of natural gas to their homes, as well as to have more stable supply. Hence an opt-out option is unrealistic. (Hensher, Shore and Train, 2005; Carlsson and Martinsson, 2008).

This study considered the following attributes to define the reliability of gas supply to people's homes: the frequency of disruptions over a period of 5 years, the duration of one disruption and the seasons in which one supply cut takes place. We acknowledge that up to now the occurrence of disruptions of gas supply to people's homes has been rather rare and the nature of a supply cut is distinct itself in that one

[10] Although the selected countries are not representative of the EU as a whole, it is believed that the results can offer useful implications to the policy making process at the EU level, in addition to that at the national level.

[11] The study looked at, in addition to gas supply, two other types of energy supply, i.e. electricity and transport fuels, on the same sample groups. Each of the whole interviews lasted approximately for 30-40 minutes. Each respondent was asked to complete a questionnaire that contained the following sections. Section A asked one's experience in the reliability of electricity supply in their home, the use of electricity in one's home, one's subjective expectation on the risk of having less reliable supply in the future, etc. In addition, respondents were asked to complete different choice exercises. Section B and C were set out in a similar style with section A but regarding supply of natural gas and transport fuels, respectively.

occurrence usually lasts for some hours or at most days. Although it is not as common to have an unscheduled gas disruption as to have an unplanned power cut, the impacts of a unplanned gas outage can be substantial, particularly when households are increasingly relying on gas in their daily life for the purposes of cooking and/or heating. The details of the attribute levels are illustrated in Table 1. Note that the only differences in the attribute levels across the three countries exist in the attribute of price tag and this closely corresponds to the variations in households' average gas bills across the three nations.

Table 1: Levels of attributes

Attributes	**Levels over a period of 5 years**
April-September	
Number of 1-day disruption without warning	0; 1; 2
Number of 3-day disruption without warning	0; 1; 2
October-March	
Number of 1-day disruption without warning	0; 1; 2
Number of 1-day disruption with warning	0; 1; 2
Number of 3-day disruption without warning	0; 1; 2
Annual back-up equipment connection fee	€17; €34; €51; €68; €85 (France) €24; €48; €72; €96; €120 (Italy) £17; £34; £51; £68; £85 (UK)

One choice card contains two choice situations/options. Drawing upon Louviere et al. (2000), we firstly applied a fractional factorial design to obtain the first choice option in each choice set and then based on Street, Burgess and Louviere (2005), we constructed the corresponding second choice option for each set. Before a respondent carried out the choice experiment, he/she was asked to read carefully a paragraph that addressed the potential risk factors that can reduce the reliability of gas supply in the surveyed country, as well as the solutions to reduce the risk. This paragraph was provided in order to help respondents understand more about the topic of supply security about which, we consider, people in general have limited knowledge. In sequence, choice experiments are then set out with a hypothetical situation as below:

'*Imagine that from now on, there is a possibility of choosing different contracts with your gas supplier and that back-up equipment exists to provide gas to your house in case of a gas supply disruption. The reliability of natural gas supply - number of disruptions in various lengths - which your household will experience can be guaranteed by connecting to this back-up equipment. You have to pay a connection fee on top of your usual gas bills to your gas supplier in order to have this back-up equipment. The annual fee will be payable as a lump sum or on a monthly basis. Note that it is impossible to guarantee no supply interruptions. Please tell us for each of the following cards, which single contract between the two would you prefer?*

A card example used in the UK survey is shown in Figure 2 as an illustration:

	Number of interruptions over a period of 5 years	
Forms of interruptions	**Contract A**	**Contract B**
April –September		
1 day interruption without warning	1	2
3 day interruption without warning	0	1
October-March		
1 day interruption without warning	1	2
1 day interruption with warning	2	0
3 day interruption without warning	0	1
ANNUAL connection fee to the back-up equipment	£85 (£7.08 per month)	£51 (£4.25 per month)

Figure 2: An example of a choice card for the case of gas supply (UK)

Each respondent in the UK was required to complete four different choice exercises, each of which containing two options, and respondents in Italy and France were asked to complete 16 choice exercises[12]. In the questionnaire, we asked respondents about their experience of the use of gas supply in their homes, their expectation on the level of reliability of gas supply in the future, their attitudes towards some contextual statements related to gas supply and their socio-economic backgrounds.

As shown in Table 2, only a very small percentage of our respondents have experienced an unplanned disruption of gas supply in the past 12 months, ranging from 2% in the UK to 7% in Italy. The dependence on gas supply is seen to be higher during October and March than during April and September. Amongst the three countries, France reports the lowest level of dependence during the cold months, whereas Italy and the UK demonstrated significantly high level of dependence. As far as the level of satisfaction with the current reliability of supply is concerned, the average is above 4 for all the three countries, suggesting that respondents in general are satisfied with the current gas supply to their homes. It is generally observed that the percentage of respondents with back-up facilities ranges between 21% in Italy and 40% in France. At last, on average respondents consider it to be unlikely that they will experience more frequent supply disruptions in the near-term and the long-term future, according to the figures ranging between 2.65 and 3.02. This suggests that respondents' expectation on the risk of having a poorer reliability of supply in the future is consistently low across the three countries.

[12] This was a misconduct occurring in the process of data collection. It was reasonable to suspect that having 16 exercises may have caused cognitive stress of respondents and could have reduced the credibility of the data. However, eventually we are not concerned with this issue in that: 1) according to interviewers' report on the level of annoyance of respondents, ranging from '1' not annoyed at all to '5'very annoyed, the average level of annoyance of the sample for both Italy and France was less than 2; 2) each exercise was in a two-option design, which was considered simple to choose from.

Table 2: Experience of natural gas service and expectation on the reliability in the future

	UK	France	Italy
Experienced disruptions of supply in the past 12 months, without advanced warning (% of the sample)	2	5	7
Average dependence on gas supply ('*1'* very low to '*5'* very high)			
During April and September	3.20	3.21	3.34
During October and the following March	4.49	3.69	4.48
The average level of satisfaction with the reliability of the current gas supply ('*1'* very dissatisfied to '*5'* very satisfied)	4.54	4.10	4.23
Have back-up facilities at home (% of the sample)	35	40	21
Expectation of having more frequent supply disruption than now			
In the short-term ('*1'* very unlikely to '*5'* very likely)	2.65	2.72	2.99
In the long-term ('*1'* very unlikely to '*5'* very likely)	2.94	2.89	3.02

Table 3 illustrates respondents' opinions/attitudes towards some statements related to the issue of gas supply. In general, most of the respondents strongly agreed that it is important to have reliable gas supply, particularly in the UK and Italy. More than half of the respondents in Italy have recently read/heard about the risk of disruption to the natural gas supply in the future, whereas more than 60% of the UK respondents reported the opposite. Although gas disruptions have been rather rare up to now, some respondents expressed that they would like to have more reliable gas supply and this proportion accounted for 70% of the total respondents in Italy, and slightly less than 50% for the UK and France. Finally, there is a high fraction of respondents that would object to paying extra money for an improvement in the reliability of gas supply, ranging from 75% in France to more than 90% in Italy.

Table 4 - Table 6 show the composition of the sample sets in terms of respondents' socio-economic and geographic characteristics, by country. As shown, the sample in each country has an even distribution across different geographical regions, as well as several socio-economic groups of gender, age and educational attainment. The only noticeable differences are that: 1) compared to the British sample or the Italian sample, the French one has a smaller portion of respondents who reported to have the experience of working in the energy-related industry; 2) the share of households with children at home in the British sample outnumbers that in the samples of the other two countries. Note that in the next stage, respondents' demographic backgrounds will enter the choice modelling analysis as control variables.

Table 3: Other contextual information

	France		
	Agree	*Neither agree nor disagree*	*Disagree*
Reliable gas supply is important.	77.8%	16.2%	5.9%
I have recently read/heard about the risk of disruption to the natural gas supply in the future.	33.5%	25.4%	41.1%
I would like to have a more reliable gas supply.	44.3%	43.2%	12.4%
Power companies should pay for improvements in the reliability of natural gas supply without passing this cost to their customers.	84.9%	14.1%	1.1%
I object to paying extra money for an improvement in reliability of natural gas supply.	75.1%	18.4%	6.5%
	Italy		
	Agree	*Neither agree nor disagree*	*Disagree*
Reliable gas supply is important.	93%	7%	0%
I have recently read/heard about the risk of disruption to the natural gas supply in the future.	58.1%	26.1%	15.8%
I would like to have a more reliable gas supply.	69%	23.4%	7.6%
Power companies should pay for improvements in the reliability of natural gas supply without passing this cost to their customers.	85.3%	13%	1.6%
I object to paying extra money for an improvement in reliability of natural gas supply.	90.7%	5.5%	3.8%
	UK		
	Agree	*Neither agree nor disagree*	*Disagree*
Reliable gas supply is important.	99.2%	0.8%	0%
I have recently read/heard about the risk of disruption to the natural gas supply in the future.	30.7%	8.7%	60.6%
I would like to have a more reliable gas supply.	49.8%	34%	16.2%
Power companies should pay for improvements in the reliability of natural gas supply without passing this cost to their customers.	94.6%	3.7%	1.7%
I object to paying extra money for an improvement in reliability of natural gas supply.	89.2%	6.6%	4.1%

Table 4: Demographic breakdown of the sample (France)

Residential area	
North[13]	32.4%
Paris[14]	23.2%
West[15]	11.4%
Southwest[16]	15.7%
Central south[17]	17.3%
Age	
18-24	17.3%
25-34	18.9%
35-44	16.2%
45-54	17.3%
55-64	15.7%
65 and above	14.6%
Gender	
Male	43.8%
Female	56.2%
Education	
With university degree	18.9%
College	18.9%
Normal and technical high school	29.2%
Professional	23.8%
With no qualification	9.2%
With children at home	21.6%
With elderly members at home	15.7%
Experience of working in the energy industry	3.8%

[13] Areas with postcodes starting with 02, 62, 59 and 80 http://upload.wikimedia.org/wikipedia/commons/e/ef/2_digit_postcode_france.png
[14] Areas with postcodes starting with 75, 92 and 94
[15] Areas with postcodes starting with 37
[16] Areas with postcodes starting with 24,33,40 and 64
[17] Areas with postcodes starting with 63 and 69

Table 5: Demographic breakdown of the sample (Italy)

Residential area	
North[18]	39.7%
Central[19]	23.4%
Central south[20]	37.0%
Age	
18-24	10.9%
25-34	19.6%
35-44	20.1%
45-54	21.2%
55-64	16.8%
65 and above	11.4%
Gender	
Male	49.5%
Female	50.5%
Education	
First degree or above	28.8%
A level or equivalents	51.1%
GCSE or equivalents	9.2%
Below GCSE	10.9%
With children at home	32.6%
With elderly members at home	17.4%
Experience of working in the energy industry	9.2%

[18] Regions of Piedmont, Lombardy and Veneto
[19] Regions of Tuscany, Umbria and Latium
[20] Regions of Molise, Campania and Apulia

Table 6: Demographic breakdown of the sample (UK)

Residential area	
Scotland	32.0%
North Ireland	16.2%
Wales	2.5%
North England	24.9%
Midlands	11.2%
South England	13.3%
Age	
18-24	15.4%
25-34	22.4%
35-44	19.9%
45-54	14.5%
55-64	14.9%
65 and above	12.9%
Gender	
Male	47.3%
Female	52.7%
Education	
First degree or above	25.3%
A level or equivalents	21.2%
GCSE or equivalents	42.7%
No qualification	10.8%
With children at home	43.2%
With elderly members at home	14.1%
Experience of working in the energy industry	9.1%

3. ECONOMETRIC MODEL

We consider a conditional logit model for data analysis. A sampled individual i faces a choice amongst J alternatives, in each of the choice situations (i.e. choice cards, in practice) that are presented to him/her. He/she is assumed to consider the full set of offered alternatives in choice card and to choose the alternative that provides him/her with the highest utility. The utility associated with each alternative j, as evaluated by each individual i in each choice card, is represented in a discrete choice model by a expression of general form shown as follows:

$$U \text{ (choice } j \text{ for individual } i\text{)} = U_{ij} = \beta' x_{ij} + \gamma'_j z_i + \varepsilon_{ij}, \; j = 1,..., J \;. \qquad (1)$$

The utility functions as specified are conditioned on the attributes of the choices, x_{ij}, and observed individuals' choice invariant characteristics, z_i. β, γ are vectors of unknown parameters. Within the logit context, ε_{ij} is assumed to be independently distributed across the utilities (Independence from Irrelevant Alternatives, IIA), each with the same type 1 extreme value distribution, i.e. the error components of different alternatives within a choice card are set to be uncorrelated.

The probability of individual i choosing alternative j in a given choice situation is logit and can be written as the following closed form:

$$\Pr ob(y_i = j) = \frac{\exp(\beta' x_{ij} + \gamma'_j z_i)}{\sum_{q=1}^{J_i} \exp(\beta' x_{iq} + \gamma'_q z_i)}, \qquad (2)$$

where y_i is the index of the choice made.

The estimation is carried out by using the method of maximum likelihood estimation (MLE), and the log likelihood function is described as follows:

$$\ln L = \sum_{i=1}^{n} \sum_{j=1}^{J} d_{ij} \Pr ob(y_i = j), \qquad (3)$$

in which d_{ij} takes on a value of 1 if individual i chooses j, 0 otherwise.

In our unlabelled choice model, the average unobserved effects for all alternatives are constrained to be zero during the estimation process. Also, to estimate the parameters for the socioeconomic and contextual variables that only change across individuals but not within a single choice set requires us to create interaction terms for each of these variables with specific attributes in order for the model to be correctly specified. (Hensher, Rose and Greene, 2005)

With respect to explanatory variables, we consider, in addition to the effects of attributes, respondents' individual characteristics, including their socio-economic backgrounds, residential areas and their reported attitudes towards different contextual information associated with the topic of gas supply. In order to compare the results of the three different countries, we adopt as much similar sets of background variables as possible across the three different countries. They include: 1) whether or not respondents have vulnerable habitants in their households, i.e. children under age 18 and elderly people aged 65 or above; 2) working experience of respondents in energy-related industry; 3) household income level; 4) residential regions; 5) strategic voting behaviour, i.e. objection to pay.

Amongst the variables of use, we incurred a problem of missing observations of household income, consisting of 40% of the UK raw data and 35% for the Italian and French data, respectively. This can be because income level was considered a sensitive piece of information by respondents who therefore were reluctant to reveal it. In response to the issue of large amount of missing data, we applied an ordered probit model to regress households' observed income levels, in an ordered form, on their observable characteristics, including their heads' gender, educational level, age, marital status, whether working or not, the number of adult member in the family, the number of its family members and its residential regions. As a result we obtained a fitted income level observation for each of the households in the sample.

The willingness to pay (WTP) in this study is considered as the annual value of one occurrence of supply disruption avoided over a period of 5 year, and can be calculated as follows:

$$WTP = \frac{\hat{\beta}_{attri}}{\hat{\beta}_{\cos t}}, \quad (4)$$

where $\hat{\beta}_{attri}$ denotes the estimated coefficient of one of the attributes representing the number of supply cuts and $\hat{\beta}_{\cos t}$ is the estimated coefficient of the payment variable.

4. ESTIMATION RESULTS

4.1 France

Table 7 reports the final estimation results for France. It is shown that only the estimated coefficients of the frequency attributes during cold months are significant at the 95% confidence level. Comparing the coefficient of 1-day cuts without warning (-0.096) to that of 1-day cuts with warning (-0.074) revealsthat an advanced warning before a 1-day supply cut occurs would decrease the impacts on households. By contrast, results show that French households are not willing to pay to avoid a 3-day cut during cold months[21]. Whilst this appears rather unreasonable in the first place, one explanation for this can be that interviewees, based on their experience[22], consider the chance of having 3-day cuts in the future to be negligible. Moreover, as shown previously in Table 2, French respondents on average, compared to those in the other two countries, reported a lower level of dependence on gas supply and lower risk expectation of the deterioration in the stability of supply; also, 40% of French respondents have back-up facilities in case of a gas cut, whereas it was only 21% for Italy and 35% for the UK. The estimated positive utility

[21] Note that in a model in which only attributes were considered, the coefficient was insignificant at the 90% confidence level.
[22] It is believed that most of the interviewees have not experienced a 3-day disruption of the gas supply.

associated with a 3-day cut does not at all suggest that households will receive no negative impacts if an event as such takes place; rather, French respondents did not think such events would take place in the future, and hence on average expressed no concern. This is the difference between stakeholders', i.e. domestic consumers' perception of a problem and the reality of its occurrence.

We examined the effect of heterogeneity in respondents' characteristics on their valuation on the reliability of gas supply. For example, respondents with at least a child[23] at home are more willing to pay to avoid a long cut during cold months, than those without. 3.8% of the sample respondents reported to have the experience of working in the energy-related industry, and this background (considered as a dummy variable) was found to be associated with higher willingness to pay to avoid a 3-day supply cut.

Residential regions are found to have an effect on respondents' choices of reliability of supply and climatic differences are considered one of the explanations for this. When geographic dummies are considered together with the attribute of 3-day cuts during colder months, the estimation results show that respondents in the south west region of France display, compared to those in Paris, the least level of willingness to pay to avoid 3-day cuts. Respondents living in the west or north region of France are, by contrast, more willing to pay to avoid such an event. . The explanation is that it is cold enough in the north in winter time so that heating is necessary, but not in the south.

Previously we have demonstrated the extent to which respondents agreed or disagreed with certain contextual statements. Strategic voting effect is controlled in this model, as demonstrated by the interaction term between cost and whether people are against paying for an improvement in the reliability of gas supply. Results confirmed that respondents who reported an objection avoided paying higher fees, more than their counterparts.

Table 7: Estimation results for France

Conditional logit model	
Explanatory variables	*Coefficients*
During April-September	
1-day cuts, no warning	-0.0003 (0.036)
3-day cuts, no warning	0.043 (0.053)
During October-March	
1-day cuts, no warning	-0.096** (0.038)
1-day cuts, with warning	-0.074**

[23] Aged under 18.

	(0.034)
3-day cuts, no warning	0.439*** (0.131)
Annual cost	-0.03*** (0.003)
Other explanatory variables	
CHILD * 3-day cuts during October-March	-0.327*** (0.105)
Working in energy industry * 3-day cuts during October-March	-0.865*** (0.211)
Geographic dummies * 3-day cuts during October – March (base: PARIS)	
NORTH	-0.677*** (0.127)
WEST	-1.927*** (0.159)
SOUTH WEST	0.366** (0.174)
CENTRAL SOUTH	-0.281* (0.155)
Object to pay extra money for an improvement in reliability of natural gas supply * Cost (base: neither agree or disagree)	
Agree	-0.011*** (0.002)
Disagree	-0.003 (0.004)
Observations	2960
Log likelihood	-1513.894

4.2 Italy

Estimation results are shown in Table 8. A positive willingness to pay to avoid a 1-day cut during the warm months as well as during the cold months may imply high dependence of households on gas supply for cooking and this can, to some extent, explain why gas supply is considered essential during warm month. By contrast, such consistency does not appear between the case of a 3-day cut during warm months and that during cold months. This leads us to consider two possible explanations for people's being not willing to pay to avoid a long cut during warm months. First, respondents may think that having a long cut during low-demand seasons is unlikely. Second, there are other solutions during April and September apart from paying higher bills for securing the reliability, such as going somewhere else for a short holiday.

We further consider the effects of respondents' characteristics on their attitudes towards long cuts during cold months. It is found that respondents with higher household income, with a working experience in energy-related industry or with elderly people at home, are more willing to avoid a long cut, than their counterpart. Respondents' residential regions appear influential on their willingness to pay to avoid a long cut; however, these effects, we consider, do not rise completely as a result of the climate. For example, when compared with those living in the central region of Italy, people living in the colder area, such as the north, are less willing to pay to avoid a long cut during the cold months.

Finally, the effect of strategic voting behaviour is examined together with the attribute 'annual cost'. The results confirmed that those who would object to pay extra money for an improvement in reliability of natural gas supply tend to prefer options with lower prices, and those who would not object to pay are more likely to choose options with higher prices.

Table 8: Estimation results for Italy

Conditional logit model	
Explanatory variables	*Coefficients*
During April-September	
1-day cuts, no warning	-0.070** (0.034)
3-day cuts, no warning	0.035 (0.050)
During October-March	
1-day cuts, no warning	-0.072** (0.035)
1-day cuts, with warning	-0.055* (0.031)
3-day cuts, no warning	-0.528***

	(0.123)
Annual cost	-0.007*** (0.003)
Other explanatory variables	
INCOME * 3-day cuts during October-March	-0.153*** (0.049)
Working in energy industry * 3-day cuts during October-March	-0.857*** (0.130)
ELDERLY * 3-day cuts during October-March	-0.164*** (0.055)
Geographic dummies * 3-day cuts during October – March (base: CENTRAL)	
NORTH	1.158*** (0.118)
CENTRAL SOUTH	0.952*** (0.105)
Object to pay extra money for an improvement in reliability of natural gas supply * Cost (base: neither agree or disagree)	
Agree	-0.011*** (0.002)
Disagree	0.023*** (0.003)
Observations	2944
Log likelihood	-1702.08

4.3 United Kingdom

Table 9 reports the estimation results for the UK. The results indicate that respondents in the UK are only willing to pay to avoid a 3-day during cold months, at the 90% confidence level, but are not willing to pay for other types of cuts specified in this study. These results tell us that if a gas disruption lasts for only a day or if even for three days but in warm months, the negative impact associated with one supply cut, on average, is not significant in the UK.

People having higher household income tend to be more willing to pay to avoid one such cut, compared to their counterparts, as shown by the interaction variable of households' income variable, INCOME, and the attribute of 1-day cut in warm months. However, different from the findings in the other two countries, UK households with at least a child at home are less willing to pay to avoid a 3-day supply disruption in the cold months than those without, according to the results. To search possible explanations for this result, we looked further into other characteristics of these two groups of respondents. We then found that: 1) on average, respondents with children reported lower, although not much, level of reliance on gas supply, both in warm and cold months, than those without; 2) also, respondents with children, on average, use gas supply for fewer types of purposes, such as heating, cooking, etc, than their counterparts.

Respondents' residential regions are found to be related to their willingness to pay to avoid a long cut during cold months, but the results do not suggest a climate-related cause. This is because those living in Scotland, a place considered being colder than south England, demonstrate lower willingness to pay to avoid a 3-day cut, than their southern counterparts. The expectation for the future may be one explanation, as it is found that respondents in Scotland have lower risk expectation of having a less reliable gas supply both in the long term and in the short term, than those in south England, hence lower willingness to pay for a long cut.

Finally, strategic voting effect is observed but not strongly evident, as we find that respondents who would object to pay for an improvement in the reliability of supply appear more likely to choose options with lower prices.

Table 9: Estimation results for the UK

Conditional logit model	
Explanatory variables	*Coefficients*
During April-September	
1-day cuts, no warning	-0.066 (0.088)
3-day cuts, no warning	0.031 (0.094)
During October-March	
1-day cuts, no warning	-0.093 (0.057)
1-day cuts, with warning	-0.054 (0.056)
3-day cuts, no warning	-0.347* (0.200)
Annual cost	-0.018***

	(0.007)
Other explanatory variables	
INCOME * 1-day cuts during April – September	-0.191*** (0.074)
CHILD * 3-day cuts during October – March	0.290** (0.138)
Geographic dummies * 3-day cuts during October - March (base: SOUTH ENGLAND)	
SCOTLAND	0.766*** (0.153)
NORTH IRELAND	-0.157 (0.166)
WALES	-0.594* (0.360)
NORTH ENGLAND	-0.093 (0.141)
MIDLANDS	-0.307* (0.177)
Working in energy industry * 3-day cuts during October-March	-0.456* (0.234)
Object to paying extra money for an improvement in reliability of natural gas supply * Cost (base level: neither agree nor disagree)	
Agree	-0.007* (0.004)
Disagree	0.005 (0.007)
Observations	964
Log likelihood	-578.402

4.4 Willingness to pay to avoid a supply disruption

Table 10 reports the estimated values of willingness to pay to avoid supply disruptions of various characteristics. The value of the willingness to pay to avoid supply cuts during warm months over a period of 5 years is evident amongst Italian households and estimated at €10/household/year. During cold months, respondents in both France and Italy are found willing to pay between €3.20 and €10.29/household/year, respectively, to avoid a 1-day cut without warning. In comparison, the WTP for a 1-day cut with warning is estimated at €2.47 and €7.86, respectively, and these estimates are approximately 77% of the previous WTP estimates associated with cuts without warning. Finally, we obtained various evidences about the magnitude of the willingness to pay to avoid a 3-day cut during cold months across the three countries, ranging from a negative value -€14.63 for France and positive ones for the UK (€24.22) and Italy (€75.43). When comparing UK to Italy, we find that the WTP of Italian respondents are willing to pay three times as much as their counterparts in the UK. The findings overall confirm that a supply cut during cold months would have higher impact than one during warm months. In addition, the scale of such impact would increase non-linearly with the duration of a cut, as suggested by the findings in the UK and Italy. French households' negative WTP to avoid a 3-day supply disruption points out that: 1) if this figure were to be considered as an indicator of the potential welfare benefits of making further investment to reduce the risk of a 3-day supply disruption in France, the magnitude of benefits would be considerably underestimated; 2) if the undervalued WTP is as a result of households perceiving the risk of having a 3-day supply disruption to be trivial, French consumers, as a consequence of being less alert, can be more prone to the impacts of a long supply cut than their counterparts in Italy and the UK.

Table 10: Marginal Willingness to Pay to avoid a supply disruption over a period of 5 years

	Annual WTP (2008 £/€)		
	UK (£/€)	**France (€)**	**Italy (€)**
During April-September			
A 1-day cut, no warning	0	0	10.00
A 3-day cut, no warning	0	0	0
During October-March			
A 1-day cut, no warning	0	3.20	10.29
A 1-day cut, with warning	0	2.47	7.86
A 3-day cut, no warning	19.28/24.22[§]	-14.63[24]	75.43

[*] '0' represents statistically insignificant results at the 10% significance level.

[§] 1€ = 0.796 £

[24] Note that the negative value of WTP corresponds to the positive sign of the estimated coefficient of 0.439 shown in Table 7.

To measure the WTP per unit of gas, we firstly obtained the average annual gas consumption per domestic consumer over the period of 2005-2009 in Great Britain, which was 17433 kWh/per household, higher than this in Scotland and lower in south England. Therefore, the derived daily consumption is approximately 48 kWh/per household. Considering the seasonal demand factors[25], the adjusted daily gas consumption is estimated at 57 kWh/per household during the months from October to March, and at 39 kWh/per household during the rest of the months (from April to September). Therefore a 3-day gas outage to a household during cold months would mean that 171 kWh of natural gas is not delivered. Using the discount rate of 3%, the present value of the aggregate WTP per household to avoid a 3-day cut, over a period of 5 years, is approximately £91 or €114. Hence the WTP to secure a unit of gas consumption is £0.53 or €0.67/kWh, equivalent to £5.86 or €7.41/cubic metre (2008£/€), in the UK. The aggregate WTP of domestic users[26] to avoid a 3-day gas outage during cold months would be £2.05 million or €2.57 billion. Domestic users' total expenditure on gas over 5 years is estimated at £59.01 billion, based on the average gas price of £0.03/kWh[27] and the average annual gas consumption as stated above (2008£). Considering WTP (security premium) as a percentage of the total expenditure, we obtained a figure of 3.48%.

In France, the gas consumption data from the EUROSTAT and from the Eurogas Statistics[28] suggest that the average annual gas consumption is at around 15305 kWh/per household. Considering the proxy seasonal factors[29], the adjusted daily gas consumption is estimated at 48 kWh/per household during the months from October to March, and at 36 kWh/per household during the rest of the months (from April to September). The WTP to secure a unit of gas consumption therefore ranges between €0.24 and €0.31/kWh (€2.65 - €3.43/cubic metre) during October and March, considering only the positive WTP estimates. The potential welfare impacts of a supply outage in winter can be reduced by €0.07/kWh (€0.77/cubic metre) as a result of a warning ahead of the disruption. The aggregate WTP of domestic users to avoid a 1-day gas outage during cold months would be €125.03 – €161.98 million (2008€) over a period of 5 years. This suggests that security premium as a percentage of households' total expenditure on gas is between 0.35% and 0.45% for France.

In Italy, the average annual gas consumption is measured at 10554 kWh/per household, according to the data[30] from the EUROSTAT and the estimated number of households[31]. Similar to the case of France, the adjusted daily gas consumption, considering the proxy seasonal factors, is estimated at 32 kWh/per household during the months from October to March, and at 26 kWh/per household during the rest of the months (from April to September). Accordingly, the WTP to secure a unit of gas consumption is

[25] We used the data of total monthly demand of natural gas between years 1998 and 2009 to obtain the average seasonal variation patterns across different months within a year. http://www.nationalgrid.com/uk/Gas/Data/misc/
[26] The number of the total domestic users was 22,567,500 in year 2009.
http://www.nationalgrid.com/uk/Gas/Data/misc/
[27] Average price of gas for domestic users between year 2005 and 2009, calculated based on data from EUROSTAT.
[28] The number of the total domestic users was approximately 10,731,000 at 1 January 2005 (Eurogas Statistics, 2004). Note that the number of domestic consumers in the most recent year, although not available, should exceed the figure provided above.
[29] The average indexes of monthly relative heating degree days during the period of 1998-2009 are used as the proxy seasonal factors.
[30] Of years 2005-2009
[31] The number of the total domestic users was approximately 18,631,700 in 2009. (ISTAT, 2010)

calculated at €1.81/kWh (€20.02/cubic metre) during April and September and at between €1.16 and €3.75/kWh (€12.83 - €41.48/cubic metre) during October and March. Note that this study also shows that the provision of an early warning before a supply disruption can reduce the impact of a supply outage on Italian households by approximately €0.36/kWh (€3.98/cubic metre). The aggregate WTP of domestic users to avoid a 3-day gas outage during cold months would be €6.63 billion (2008€) over a period of 5 years in Italy, or 15.68% of households' total expenditure on gas, and that to avoid a 1-day gas outage would range between €689.4 and €913 million (2008€), or between 1.63% and 2.14% of households' total gas expenditure.

5. CONCLUSIONS

This study, applying a choice experiment approach, investigated the value of the reliability of gas supply to domestic users' homes. Data was collected from three European countries: France, Italy and the UK, and this allowed us to scrutinise the similar or different preferences for the levels of energy security in national as well as EU contexts.

The results of this study have shown that the degree of the economic impact of a disruption of gas supply to domestic consumers was subject to the duration and the season in which a supply cut would take place, as well as other preferences of consumers. It was also suggested that, by and large, consumers' preferences for the level of supply reliability could vary from one country to another. For example, a disruption in warm months would likely have impact on Italian households, but this may not be the case for British or French households. Besides, British households may show a higher level of tolerance for having a 1-day disruption during cold months over a period of 5 years, than their French or Italian counterparts.

The concept of willingness to pay in this study refers to the value of a supply cut avoided. The results of this study allow us to conclude that the marginal WTP to secure per unit of gas consumption is estimated at between €2.65/cubic metre and €41.48/cubic metre across three different European countries. Accordingly, security premium as a percentage of the gross expenditure on gas ranges between 0.35% and 15.68%. These figures, we propose, have important policy implication in that: 1) they correspond to the potential household welfare impact incurred as a result of gas outages; 2) they also can be considered as an indicator for the value/benefits of an improvement in supply reliability at the demand side, which can be compared against an investment plan which policy makers/energy suppliers may consider in order to secure a certain level of reliability of supply to domestic users.

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