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Abstract: We use survey data for 139,517 individuals in 26 European Countries, 2002-2011, to estimate the relationship between subjective well-being (SWB) and production shares of various types of electricity generation. The estimated relationships are taken to represent preference relationships over attributes of electricity supply systems (costs, safety, environmental friendliness etc.). Controlling for a variety of individual and macro-level factors, we find that individuals' SWB varies systematically and significantly with differences in the electricity mix across countries and across time. Among other results, we find that a greater share of solar and wind power relative to nuclear power is associated with greater SWB and that the implied preference for solar and wind power over nuclear power has risen drastically after the Fukushima nuclear accident. In general, our results suggest that environmental and safety concerns are of major importance in European citizens' preference function over electricity supply structures.

Keywords: energy mix; preference; subjective well-being; energy transition; Fukushima

JEL classification: Q42; Q48; I31

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1. Introduction

Several European countries are currently undertaking fundamental revisions of their energy policy, in particular with regard to the structure of electricity supply. Germany, for instance, has proclaimed the *Energiewende* (energy transition), which entails an accelerated phase-out of nuclear power and an ambitious goal for phasing-in renewable energies. Contrary to this, France has announced to extend the lifetime of its nuclear power stations and the United Kingdom is planning to build new ones.

Different sources of electricity supply all have their specific advantages and drawbacks. Electricity from fossil fuels (in particular coal) is relatively inexpensive but problematic with respect to greenhouse gas emissions and air pollution, whereas electricity from some renewable sources (in particular wind and solar power) is more environmentally benign but less reliable and more expensive. Hydro power is inexpensive, but its expansion may be difficult and conflict-prone. Nuclear power is considered to be inexpensive but has unresolved problems of nuclear waste disposal and nuclear safety; the latter concern has recently gained increased attention in the aftermath of the Fukushima nuclear accident.

Against this background, this paper provides an assessment of the structure of electricity supply in terms of citizens' experienced utility, operationalized as subjective well-being (SWB). Specifically, we use SWB regressions to infer European citizens' preferences for alternative configurations of the electricity supply system. The identified relationship between the electricity mix and SWB implicitly captures the above concerns – costs and security of supply, safety of electricity facilities, and environmental impacts – as perceived by representative individuals, and weighs these concerns according to their significance for SWB.

To perform our analysis, we combine survey data on SWB for 139,517 persons in 26 European countries, 2002-2011, with data on the electricity mix in the respective countries and years. By employing the calendar dates at which surveys were conducted, we are able to investigate whether the Fukushima accident of March 11, 2011, may have affected the relationship between the electricity mix and SWB in Europe.

Our approach of using SWB regressions for an assessment of the electricity supply system follows a recent trend in economics of using subjective data for evaluating policies, institutions, and non-market goods. The SWB approach has previously been applied to environmental issues (e.g. Welsch 2002, 2006; Rehdanz and Madison 2005; van Praag and Barsma 2005; Luechinger 2009; Ferreira and Moro 2010; Levinson 2012) and to various societal phenomena, including inflation and unemployment (Di Tella et al. 2001), crime (Powdthavee 2005), civil conflict (Welsch 2008a), corruption (Welsch 2008b) and terrorism (Frey et al. 2009). Since SWB regressions typically include people's income, calculating the utility-constant trade-off between income and the non-market good in question provides a tool for non-market valuation (see Welsch and Kühling 2009 for a review and discussion). Though applying the SWB approach to energy issues nicely fits into this line of research, we are unaware of any study in which this has been done as of yet.

Our method of preference elicitation by means of SWB data does *not* rely on people's stated assessments of different forms of electricity supply. Instead, by measuring the purely statistical relationship between indicators of the electricity mix and a proxy for experienced utility we derive what may be referred to as experienced preference. In contrast to stated preference methods, the experienced preference approach is not subject to biases stemming from strategic response or the warm-glow effect.[1] Even though survey data on SWB may be an imperfect approximation of experienced utility, there is no reason to expect that imperfections in the

[1] For instance, Menges et al. (2005) found in a case study that the ex-ante stated willingness to pay for wind energy was twice as high as the amount revealed in a field experiment, presumably because people wanted to signal environmental awareness by stating a high willingness to pay.

measurement of utility vary systematically with the structure of the electricity system, thus biasing the results.[2]

In addition to not relying on statements of preference, our approach does *not* rely on people precisely knowing the supply structures prevailing in their countries. Rather, the approach relies on people's observations or perceptions of reliability, costs, safety and pollution. Given these attributes' statistical association with the electricity mix, we are able to identify relationships between people's SWB and the electricity mix even if the latter is not well known to those people. The measured relationships between SWB and the electricity supply structures are not meant to represent preferences over those structures *per se*, but preferences over those structures' observed or perceived attributes.

A main finding from our empirical analysis is that, controlling for individual and macro-level factors, the SWB of citizens of European countries, 2002-2011, varies systematically and significantly with differences in the electricity mix across countries and across time. At the level of aggregate supply structures, we find that a greater share of (i) fossil-based relative to nuclear electricity, and (ii) fossil-based relative to renewable electricity are significantly correlated with greater SWB, whereas (iii) a greater share of renewable relative to nuclear power (or vice versa) is not significantly correlated with greater SWB. This suggests that, overall, fossil-based electricity is the most preferred type of electricity in terms of SWB, whereas there is no clear preference relationship between renewable and nuclear electricity.

By differentiating our analysis with respect to more detailed supply technologies, we find that the classification into nuclear, fossil, and renewable electricity masks considerable heterogeneity of the latter two categories. At a disaggregate level, we find that solar and wind power and electricity from gas – but not from coal or oil – are preferred over nuclear power. In addition, the

[2] For a discussion of the use of SWB data in economics and pertinent methodological issues, see Frey and Stutzer (2002), Di Tella and MacCulloch (2006), and Kahneman and Krueger (2006).

preference for solar and wind power over nuclear power has risen drastically after the Fukushima nuclear accident.

Our results suggest that environmental and safety concerns are of major importance in European citizens' preference function over electricity supply structures. The implied utility-constant trade-off between supply shares and income suggests a considerable implicit willingness to pay for a safe and environmental friendly electricity supply.

Our well-being regressions include country and year dummies and control for national per capita income and other macroeconomic indicators. The preference for solar and wind power is thus not confounded by higher presence of these technologies in richer countries with good economic performance. In addition, the rise in experienced preference for solar and wind power over nuclear power after the Fukushima accident provides us with some confidence that the identified relationships are meaningful, rather than being mere statistical artifacts. This confidence is further enhanced by a drop in experienced preference for oil-based electricity at the time of the "Arab Spring", as this drop can be rationalized by increased concern over supply security from North Africa.

The paper is organized as follows. In section 2 we lay out our conceptual and methodological framework. Section 3 describes our data. Section 4 presents the empirical approach and section 5 the results. Section 6 concludes.

2. Conceptual and Methodological Framework

In order to explain our method of preference elicitation by means of SWB data, this section lays out the underlying conceptual and methodological framework.

Our basic assumption is that people have preferences over attributes A of the electricity supply system, such as security and cost of supply, safety of electricity facilities, and environmental impacts. Capturing these preferences by a utility function, we have

$$U = f(A). \tag{1}$$

The attributes are assumed to depend on the structure S of electricity supply, that is, they are different for the various supply sources:

$$A = g(S). \tag{2}$$

Empirically, the supply structure can be represented by the shares of the various fuels or technologies in overall supply.

Combining (1) and (2) yields the reduced-form preference function

$$U = f(g(S)) =: h(S). \tag{3}$$

The aim of our analysis is to measure the reduced-form preference function.

This derivation highlights the fact that people are not assumed to have preferences over the supply structure *per se*, but over its attributes. Electricity supply preferences, as captured by $h(S)$, are thus of an indirect nature; they incorporate both the relationship between the supply structure and its attributes, and people's valuation of those attributes.

With respect to the relationship between supply structure and attributes, it can be hypothesized that concern over the safety of electricity facilities relates mainly to nuclear power generation and waste disposal, whereas the issue of the security (reliability) and cost of supply may be dominant with respect to renewable energy. Environmental concern, in particular with regard to air pollution, is likely to be most prominent in the case of fossil-based electricity.[3]

[3] In addition to the "classical" air pollutants (particulate matter, carbon monoxide, sulfur dioxide, nitrogen oxide), electricity generation is a major source of greenhouse gases. In contrast to the former, greenhouse gases do not affect people directly (e.g. via their health impacts).

In spite of these broad patterns, differences may exist with respect to different types of both fossil and renewable electricity. Regarding fossil-based electricity, air pollution may be less of a problem with natural gas than with coal and oil. In addition, to the extent that oil is imported from abroad, the security of oil supply (physical and with respect to cost) may be an issue of concern. Regarding renewable energy, concern over the reliability and cost of supply may apply less to hydro power or bio fuels than to solar and wind power. On the other hand, hydro power may have environmental problems in terms of land use conflicts, and power generation from bio fuels may lead to nuisance from bad smell.[4] An empirical illustration of the relationships between types of electricity generation and some of their preference-relevant attributes can be found in the next section.

Our approach to measuring the relationship $U = h(S)$ involves approximating utility U by data on subjective well-being. Similar as has been done with other societal factors of subjective well-being (ranging from macroeconomic conditions to institutional or environmental quality), we study the statistical relationship between well-being and the electricity supply structure, taking the latter as being associated with varying levels of costs, pollution etc. If we find such empirical linkages between U and S, we take them to be meaningful (non-spurious) if they can be rationalized in terms of (i) plausible relationships between U (well-being) and A (costs, pollution etc.) and (ii) existing or perceived relationships between A and S, as outlined above.

Importantly, this approach does *not* presume that people have a precise knowledge of the electricity supply structures prevailing in their countries. Rather, what people observe or experience are the attributes (costs, pollution etc.), and it is those attributes' well-being effect that manifests in the estimated relationship between well-being and supply structure.[5]

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[4] Electricity generation from bio fuels uses bio gas which is produced by the fermentation of organic wastes such as manure, sewage sludge, green waste and plant material.

[5] In contrast to costs and pollution, the attribute "safety of electricity facilities" is of a subjective nature, that is, it will neither be observed nor experienced directly. However, concern about

To further enhance the credibility of our approach, we will consider a set of exogenous events, the Fukushima nuclear accident and the “Arab Spring”, to study whether the preference relationships we find change in a plausible fashion at the time of those events. While the Fukushima accident may have increased concerns about nuclear safety in European countries, the political unrest and armed conflict in countries of North Africa may have spurred worries about the security (or cost) of oil supply from those countries.

3. Data and Empirical Background

We use survey data from the first five waves of the European Social Survey (ESS); see www.europeansocialsurvey.org. The ESS is a repeated cross-sectional, multi-country survey covering over 30 nations. Its first wave was fielded in 2002/2003, the fifth in 2010/2011. ESS data are obtained using random (probability) samples, where the sampling strategies are designed to ensure representativeness and comparability across European countries. The five-wave cumulative dataset used in this paper includes about 240.000 observations from the following countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the UK. Due to missing observations in some of the variables the final sample for econometric analysis includes 139.517 data points.

The variable used to capture subjective well-being (SWB) is life satisfaction. It is based on the answers to the following question: "All things considered, how satisfied are you with your life as a whole nowadays?" Respondents were shown a card, where 0 means extremely

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safety arguably refers mainly to nuclear power, and the importance of nuclear power in a country’s electricity system is relatively well known to the citizens, not least because the presence and density of nuclear facilities are rather salient.

dissatisfied and 10 means extremely satisfied, and we use the answers on the 11-point scale as our dependent variable.

The explanatory variables at the individual level include socio-demographic and socio-economic factors that have been found to have an impact on SWB (sex, age, marital status, household size, employment status and household income), see, e.g., Dolan et al. (2008). In addition, our regressions include macroeconomic control variables (GDP per capita, inflation rate, unemployment rate), taken from the OECD online data base (www.oecd.org).

Our variables of interest are the shares of different electricity generation technologies in overall electricity supply. The respective data are available for the categories nuclear; coal and peat; oil; gas; hydro power; geothermal, solar and wind; and bio fuels and waste. For simplicity, we will refer to these categories as nuclear, coal, oil, gas, hydro, solar & wind, and bio fuels. Data have been taken from the International Energy Agency, see www.iea.org.

Tables A1 and A2 in the Appendix contain the variable descriptions and the descriptive statistics, respectively.

In order to illustrate the relationships between types of electricity generation and some of their preference-relevant attributes, Table 1 reports correlations between the shares of those types of electricity and emissions of sulfur dioxide (SO_2) per capita as well as correlations between the supply shares and electricity end use prices for households.[6] As expected, air pollution is positively and significantly correlated with the share of coal and the share of oil. Household electricity prices are positively and significantly correlated with the share of solar and wind power, while being negatively and significantly correlated with the share of hydro power.

Assuming that people dislike air pollution (correlated with coal and oil) and high electricity prices (correlated with solar and wind power), we expect the trade-off people make between pollution and prices to translate into preferences regarding the underlying electricity supply

[6] We consider air pollution and costs for illustrative purposes.

structures. Similar considerations are expected to apply to supply security and the safety of electricity facilities.

4. Empirical Approach

We estimate a micro-econometric SWB function in which the self-reported life satisfaction (*LS*) of individual *i*, in country *c* and year *t* depends on a set of individual socio-demographic and socio-economic indicators ($\boldsymbol{micro}_{ict}$), macroeconomic indicators ($\boldsymbol{macro}_{ct}$), the shares of different types of electricity supply by country and year ($\boldsymbol{share}_{ct}$), and country and year dummies ($country_c$, $year_t$, respectively).

We will start our empirical analysis by considering the aggregate supply structure; later we take a more disaggregate view. The types of electricity generation at the aggregate level are nuclear (*n*), fossil (*f*) and renewable (*r*), hence $\boldsymbol{share}_{ct}$ = ($share_{n,ct}$, $share_{f,ct}$, $share_{r,ct}$). Due to adding-up, we cannot include all three shares simultaneously in one regression. Therefore, we include the three possible pairs of shares in three separate regressions. The general form of the estimating equations thus reads as follows:

$$LS_{ict} = \boldsymbol{\alpha}'\boldsymbol{micro}_{ict} + \boldsymbol{\beta}'\boldsymbol{macro}_{ct} + \sum_k \gamma_k share_{k,ct} + country_c + year_t + \varepsilon_{ict} \,. \qquad (4)$$

where, alternatively, $k \in \{f, r\}$, $k \in \{n, r\}$, and $k \in \{n, f\}$; ε_{ict} denotes the error term. The *micro* indicators are sex, age, marital status, household size, employment status, and household income. The *macro* indicators are GDP per capita, the inflation rate, and the unemployment rate. The *country* dummies account for unobserved time-invariant country characteristics that affect well-being whereas the *year* dummies account for unobserved time-specific well-being factors that are common to all countries.

The coefficients of interest in this specification are the γ_k's. Because of adding-up of the share variables, a positive relationship between SWB and one of the included share variables (positive coefficient) implicitly indicates a negative relationship between SWB and the respective omitted share variable. Likewise, a negative relationship between SWB and one of the included share variables (negative coefficient) indicates a positive relationship between SWB and the omitted share variable. Thus, the signs of the γ_k's allow us to infer a preference relationship between an included type of electricity and the respective omitted one: A positive and significant coefficient is taken to mean that the corresponding type is preferred to the omitted one, whereas a significant negative coefficient indicates the converse. The size of the coefficients indicates the effect of a 1-percentage point increase in the share of an included type that offsets a 1-percentage point decrease in the respective omitted type.

In a second step, we will disaggregate fossil-based electricity into electricity generated from coal, oil, and gas. Likewise, we disaggregate electricity from renewable sources into solar & wind power, hydro power, and power from bio fuels. Again, we will omit one of the technologies at a time; the interpretation of the coefficients is as discussed above.

Finally, we will study whether a set of events in 2011 (the Fukushima nuclear accident and the political unrest in North Africa) may have altered the relationship between SWB and the electricity mix. To that purpose, we augment the estimating equation (4) to include interactions of the share variables with a dummy variable (*post*) that takes the value 1 if an observation was generated after the event and 0 otherwise:

$$LS_{ict} = \boldsymbol{\alpha' micro}_{ict} + \boldsymbol{\beta' macro}_{ct} + \sum_k \gamma_k share_{k,ct} + \sum_k \delta_k \ post_{ict} \cdot share_{k,ct} + \lambda \cdot post_{ict} + country_c + year_t + \varepsilon_{ict} \,. \quad (5)$$

The main coefficients of interest in this specification are the δ_k's. If significant, they tell us whether and how the preference for a particular technology has changed after the event.

The dependent variable in our estimating equations, life satisfaction, is an ordinal variable on an 11-point scale, which suggests using an estimator for ordered data. We therefore estimate equations (4) and (5) using an ordered probit model. We checked that the qualitative findings reported below (signs and significance of coefficients) are robust to using an alternative estimation method and an alternative dependent variable (see subsection 5.3). We report robust standard errors adjusted for clustering at the county-year level.

5. Results

We first present our estimation results for the aggregate supply structure (nuclear, fossil, renewable) before disaggregating fossil-based electricity and renewable power into more detailed categories. While starting with qualitative results (sign and statistical significance of coefficients), their economic significance (effect sizes) will be discussed in a separate subsection towards the end of this section.

5.1 Aggregate Supply Structure

Table 2 presents the main estimation results for equation (4).[7] Specification A includes the shares of fossil-based and renewable electricity and omits the share of nuclear power. The share of fossil-based electricity enters positively and significantly, whereas the share of renewable electricity enters positively but insignificantly. Switching from nuclear power to fossil-based

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[7] More detailed results concerning the micro and macro controls are presented in Table A3 in the Appendix. These results do not qualitatively differ with respect to the way the electricity mix is included. As is common in data sets for developed countries (see Dolan et al. 2008), life satisfaction is higher for females than for males, u-shaped in age, highest for married and lowest for separated persons, lowest if being unemployed than in any other employment status, and increasing in health and in household income. At the macro level, life satisfaction is negatively related to the inflation and the unemployment rate and insignificantly related to GDP per capita, the latter being in line with the so-called happiness-income paradox (Easterlin et al. 2010).

electricity is thus associated with significantly greater life satisfaction whereas switching to renewable power has no such effect.[8]

Specification B includes the shares of nuclear and renewable electricity while omitting the share of fossil-based electricity. The share of nuclear power enters the regression negatively and significantly, as does the share of renewable power. The former result mirrors, of course the result from specification A concerning the nuclear-fossil comparison. Thus, switching from fossil-based electricity to nuclear power or to renewable electricity is associated with less life satisfaction.

Finally, specification C includes the shares of fossil-based electricity and nuclear power and omits the share of renewable electricity. The results from this specification confirm those from specifications A and B; actually, they are mirror images of what was found above: The share of nuclear power enters the regression insignificantly, whereas the share of fossil-based electricity enters the regression positively and significantly, meaning that a switch from renewable electricity to fossil-based power enhances life satisfaction.

In summary, we obtain the following

Result 1: Other things equal, greater shares of (i) fossil-based relative to nuclear electricity and (ii) fossil-based relative to renewable electricity are correlated with greater SWB (life satisfaction), whereas a greater share of renewable relative to nuclear electricity (or vice versa) is not significantly correlated with SWB.

If, as discussed in section 4, we take the correlation with SWB as an indicator of preference, we get the following

[8] The size of the effects will be discussed below (see subsection 5.5).

Result 2: In the set of countries under study, 2002-2011, fossil-based electricity is the most preferred type of electricity in terms of SWB, whereas there is no clear preference between renewable and nuclear electricity.

5.2 Detailed Supply Structure

Table 3 presents results for fossil-based electricity disaggregated into coal, oil, and gas, and renewable electricity disaggregated into solar & wind power, hydro power, and power from bio fuels. Results for the controls are again omitted from the presentation. They do not differ appreciably from those in Table A3.

We continue to take a significantly positive (negative) coefficient to indicate that the corresponding technology is preferred to (less preferred than) the respective omitted technology, whereas insignificant coefficients indicate a lack of preference.

Specification A omits nuclear power. Results indicate that electricity from bio fuels is less preferred than nuclear power, whereas electricity from gas and solar & wind power are preferred to nuclear power. No statistically significant preference can be established between nuclear power and electricity from oil, coal and hydro power.

Specification B omits coal-based electricity and suggests that electricity from bio fuels is less preferred than electricity from coal, whereas no significant preference between electricity from coal and the other types of power is obtained.

When omitting the share of oil (specification C), we find that electricity from bio fuels is less preferred than oil-based electricity, whereas no significant preference exists between oil-based electricity and the other types of power.

Specification D omits electricity from gas. The results tell us that nuclear power and electricity from bio fuels are less preferred than electricity from gas, whereas no significant preference exists between electricity from gas and the other types of power.

When omitting solar & wind power (specification E), it is seen that nuclear power and electricity from bio fuels are less preferred, whereas no significant preference can be found between solar & wind power and the other types of electricity.

Considering hydro power as the omitted category (specification F) we find electricity from bio fuels to be less preferred, whereas no significant preference is found between hydro power and the other types of electricity.

Omitting electricity from bio fuels (specification G) indicates that all other generation technologies are preferred to this one.

Similar as in the case of the aggregate supply structure, the specifications A – G yield mutually consistent results, that is, the preference relationships identified are independent of which category is omitted. This is true not only qualitatively (signs and significance of coefficients) but also with respect to the size of coefficients. In spite of being consistent, however, the preference ordering identified is only a partial one, that is, we cannot establish a preference between several pairs of technologies.

The overall qualitative findings can be summarized as follows:

Result 3: In the set of countries under study, 2002-2011, electricity from gas as well as solar & wind power are preferred over nuclear power Electricity from bio fuels is less preferred than all other types of electricity.

Result 3 suggests that people’s preferences concerning electricity supply structures are more complex than is reflected in the broad categories nuclear, fossil and renewable. People do not perceive the categories of fossil-based and of renewable electricity as homogeneous. Rather, they differentiate between gas on the one hand and oil and coal on the other, presumably because gas is less polluting than are coal and oil. They also differentiate between solar & wind power and electricity from bio fuels. The most disliked type of electricity generation is from bio fuels, presumably because of the nuisance from bad smell that is associated with power generation from organic waste.

The overall impression from these results is that environmental and safety aspects play an important role in the relationship between well-being and the structure of electricity supply. In particular, well-being is positively related to a substitution of solar & wind power for nuclear electricity in spite of the higher cost of the former.

5.3 Robustness Checks

We conducted robustness checks concerning the estimation method and the dependent variable (results not shown).

The first robustness check concerns the estimation method. Even though life satisfaction is an ordinal variable, results by Ferrer-i-Carbonnel and Frijters (2004) suggest that least squares yield similar qualitative results as an ordered probit. With respect to the aggregate supply structure, this is in fact the case in our data: using least squares, fossil electricity is significantly preferred over both nuclear and renewable electricity, whereas there is no clear preference relationship among the latter two. At the disaggregate level, all results are the same as discussed in the preceding subsection except that the preference of solar & wind over nuclear power becomes insignificant.

A second robustness check reverts to the ordered probit but replaces the dependent variable “life satisfaction” with “happiness” (which is available in the ESS and is also measured on an 11-point scale). The results are the same as with life satisfaction in terms of signs and significance. The only exception is that oil is now significantly preferred over nuclear power. Results using happiness as the dependent variable thus indicate that electricity from oil, gas and solar & wind are preferred to nuclear power, which is preferred to electricity from bio fuels, as are all other types of electricity.

5.4 Results for the Post-3/11 Period

To further investigate the plausibility of our results, we checked whether events that may have affected people's electricity supply preferences are associated with corresponding changes in the relationship between well-being and the supply structure. Specifically, we focus on the nuclear accident at Fukushima, Japan, on March 11, 2011, and the political unrest in North Africa ("Arab Spring"). Both events had extensive media coverage worldwide. In addition, the Arab Spring went along with a much recognized rise in the price of oil.[9]

To account for the Fukushima accident, we created a dummy variable *post-3/11* that takes the value 1 if a respondent's life satisfaction was elicited after the accident and 0 otherwise. We included this dummy variable in versions of our life satisfaction regression both as a shift variable and as an interaction with our variables of interest. We note that this variable may capture not only the Fukushima accident but also the Arab Spring. While the former may have affected subjective well-being through increased concern about nuclear safety, the latter may have spurred worries about oil supply from North African countries.

Table 4 reports the results for equation (5), the model with interactions between the supply shares and a post-Fukushima dummy. Since standard errors may be biased in an ordered probit with interaction terms (Ai and Norton 2003), we report results from both ordered probit and least squares estimation. Results from the ordered probit suggest a statistically significant increase in the preference over nuclear power for almost all types of electricity in the aftermath of the Fukushima accident. An exception is electricity from oil, for which a statistically significant *decrease* in preference relative to nuclear power is found. The same findings are obtained in the case of least squares except that there is no (significant) increase in the preference of gas over nuclear power.

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[9] The crude oil spot market price went up from US$96 in January 2011 to US$123 in April 2011 (IEA Data Service).

We conjecture that most of the changes in preference after March 11, 2011 may be related to the Fukushima accident, which may have changed the relationship between SWB and the energy mix by altering people's perceptions of damage potentials and damage probabilities associated with alternative electricity generation technologies. In addition, we conjecture that the drop in preference of oil-based electricity over nuclear power may reflect increased worries about oil supply from North African countries, triggered by the Arab Spring.[10]

Though we do not claim that these results prove causal effects, we would stress their plausibility. This plausibility enhances our confidence that the results of our SWB regressions capture people's preferences over attributes of electricity supply systems, rather than being statistical artifacts.

5.5 Valuing Electricity Supply Preferences

As was mentioned in the introduction, well-being regressions provide a tool for calculating the utility-constant monetary value of policies and non-market goods. Technically, this is achieved by dividing the coefficient on the variable of interest by the coefficient on income, thus obtaining the marginal rate of substitution of income for the variable of interest.

Using the coefficient on the gas share from column A in Table 3 (0.00823) along with the coefficient on income (0.06254), we find that a 1-percentage point substitution of gas-based electricity for nuclear power corresponds to moving up 0.13 steps on the 12-point income scale. Observing that one step on the income scale corresponds to 6,000 Euros, this is equivalent to an

[10] The Arab Spring cannot be associated with one particular date. Political unrest started already in January of 2011 and culminated later in that year in the armed conflict in Libya. However, March 11 clearly falls into the relevant period of time.

increase in annual household income by 790 Euros.[11] A 1-percentage point substitution of solar & wind power for nuclear power corresponds to 0.18 steps (0.01121/0.06254) on the income scale, which is equivalent to an increase in annual household income by 1,075 Euros.[12]

Using the estimation results from column A of Table 4 (ordered probit) along with the corresponding income coefficient, we find that in the post-Fukushima period a 1-percentage point substitution of gas for nuclear power corresponds to 0.21 income steps (0.00863+0.00444)/ 0.06225), which is equivalent to 1,260 Euros. A 1-percentage point substitution of solar & wind power for nuclear power corresponds to 0.50 income steps (0.0313)/0.06225), which is equivalent to 3,000 Euros. Using the results from column B of Table 4 (least squares), we get 0.12 income steps (0.0152/0.1317) in the case of gas (equivalent to 697 Euros) and 0.57 income steps (0.0755/0.1317) in the case of solar & wind (equivalent to 3,429 Euros).[13]

These results should be taken as indicative only. In addition, it is unclear to what extent the preference change after the Fukushima accident will persist.[14] Yet these results suggest the existence of considerable monetary equivalents to having a safe and environment-friendly electricity supply.

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[11] This refers to persons with annual household income between 12,000 and 36,000 Euros, who account for about 60 percent of the people in our sample. Table A4 in the Appendix shows how the 12-point income scale matches with income brackets.

[12] When using the estimation results from least squares instead of the ordered probit, the corresponding figures are 0.0143/0.1324 = 0.11 steps for gas and 0.0197/0.1324 = 0.15 steps for solar & wind. This suggests considerable robustness not only of our qualitative but also of our quantitative results.

[13] For these computations, insignificant coefficients were set to zero.

[14] This will be investigated once a new round of the ESS becomes available.

6. Conclusions

This paper has used survey data for 139.517 individuals 26 European Countries, 2002-2011, to estimate the relationship between subjective well-being (SWB) and the shares of several types of electricity generation technology in total electricity supply. Controlling for an array of individual and macro-level factors, we found that SWB varies systematically and significantly with differences in the electricity mix across countries and across time. Among other results, we found that a greater share of solar and wind power relative to nuclear power is associated with greater SWB.

These estimation results can be taken to represent a preference ordering over the technologies considered. We take the results to indicate, in particular, that solar and wind power is preferred over nuclear power. In addition, there exists evidence that the preference for solar and wind power over nuclear power has risen drastically after the Fukushima nuclear accident. In general, our results suggest that environmental and safety concerns are of major importance in European citizens' preference function over electricity supply structures.

The estimated relationships between SWB and the electricity mix capture the preference-relevant features of the various technologies (reliability, costs, safety, environmental impacts), as perceived by the individuals, in an *implicit* fashion. Being of a purely statistical nature, they are not affected by concerns about strategic responses or "cheap talk" that may arise when people are explicitly *asked* about their opinions and preferences. In spite of their statistical nature, however, we maintain that the identified relationships are plausible and meaningful. The rise in preference for solar and wind power over nuclear power after the Fukushima accident supports this idea.

In interpreting our results it should be clear that the preference relationships identified are only of a local nature, that is, they are valid only for configurations of the electricity supply system sufficiently close to the energy mix observed. Nevertheless, our results provide support in terms of SWB for restructuring the supply system towards more renewable electricity. In particular, they suggest well-being benefits from substituting solar and wind power for nuclear power that come down to a considerable monetary equivalent.

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Table 1: Correlation of Electricity Mix with Air Pollution and Electricity Price

	SO2 per capita	Electricity end use price for households
Nuclear share	-0.2819 ***	0.0056 **
Coal share	0.6858 ***	0.2239 ***
Oil share	0.3289 ***	-0.0516 ***
Gas share	-0.1741 ***	0.1061 ***
Hydro share	-0.2894 ***	-0.4095 ***
Solar & wind share	-0.1458 ***	0.4164 ***
Bio fuel share	-0.3493 ***	0.1315 ***

Note: Data for SO_2 emissions and electricity prices are taken from IEA data service (http://data.iea.org/ieastore/statslisting.asp). *** indicates significance on the 1% level and ** indicates significance on the 5% level.

Table 2: Estimation Results for Aggregate Supply Structure

	A	B	C
Nuclear share	omitted	**-0.00719**** *(0.00335)*	**-0.00118** *(0.00400)*
Fossil share	**0.00719**** *(0.00335)*	omitted	**0.00601**** *(0.00294)*
Renewable share	**0.00118** *(0.00400)*	**-0.00601**** *(0.00294)*	omitted
Micro controls	Yes	Yes	Yes
Macro controls	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Observations	139517	139517	139517
R2 (pseudo)	0.0488	0.0488	0.0488

Dependent variable: Life satisfaction (0-11). Method: ordered probit. Robust standard errors in parentheses corrected for clustering at the country-year level. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table 3: Estimation Results for Detailed Supply Structure

	A	B	C	D	E	F	G
Variable	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*	**Coeff.** *Std. Error*
Nuclear	*omitted*	**-0.00412**	**-0.00773**	**-0.00823****	**-0.01121***	**-0.00216**	**0.02002****
		(0.00360)	*(0.00578)*	*(0.00352)*	*(0.00672)*	*(0.00437)*	*(0.01019)*
Coal	**0.00412**	*omitted*	**-0.00362**	**-0.00411**	**-0.00709**	**0.00196**	**0.02413****
	(0.00360)		*(0.00631)*	*(0.00328)*	*(0.00668)*	*(0.00440)*	*(0.01003)*
Oil	**0.00773**	**0.00362**	*omitted*	**-0.000494**	**-0.00348**	**0.00558**	**0.02775*****
	(0.00578)	*(0.00631)*		*(0.00498)*	*(0.00714)*	*(0.00545)*	*(0.01065)*
Gas	**0.00823****	**0.00411**	**0.000494**	*omitted*	**-0.00298**	**0.00607**	**0.02824*****
	(0.00352)	*(0.00328)*	*(0.00498)*		*(0.00720)*	*(0.00396)*	*(0.00875)*
Solar&Wind	**0.01121***	**0.00709**	**0.00348**	**0.00298**	*omitted*	**0.00905**	**0.03123****
	(0.00672)	*(0.00668)*	*(0.00714)*	*(0.00720)*		*(0.00702)*	*(0.01425)*
Hydro	**0.00216**	**-0.00196**	**-0.00558**	**-0.00607**	**-0.00905**	*omitted*	**0.02217****
	(0.00437)	*(0.00440)*	*(0.00545)*	*(0.00396)*	*(0.00702)*		*(0.01033)*
Biofuels	**-0.02002****	**-0.02413****	**-0.02775*****	**-0.02824*****	**-0.03123****	**-0.02217****	*omitted*
	(0.01019)	*(0.01003)*	*(0.01065)*	*(0.00875)*	*(0.01425)*	*(0.01033)*	
Micro controls	yes	yes	yes	yes	yes	yes	yes
Macro controls	yes	yes	yes	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes	yes	yes	yes
Country dummies	yes	yes	yes	yes	yes	yes	yes
Observations	139517	139517	139517	139517	13957	13958	13959
R-squared	0.1950	0.1950	0.1950	0.1950	0.1950	0.1950	0.1950

Dependent variable: Life satisfaction (0-11). Method: ordered probit. Robust standard errors in parentheses corrected for clustering at the country-year level. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table 4: Estimation Results with Post-3/11 Interactions

	A (ordered probit)	B (least squares)
Nuclear	omitted	omitted
Nuclear * post-3/11	omitted	omitted
Coal	**0.00670*** *(0.00363)*	**0.0100** *(0.0072)*
Coal * post-3/11	**0.00699**** *(0.00336)*	**0.0209***** *(0.0070)*
Oil	**0.00430** *(0.00528)*	**0.0063** *(0.0107)*
Oil * post-3/11	**-0.0615***** *(0.0107)*	**-0.1771***** *(0.0222)*
Gas	**0.00863***** *(0.00332)*	**0.0152**** *(0.0067)*
Gas * post-3/11	**0.00444**** *(0.00217)*	**0.0033** *(0.0046)*
Solar&Wind	**0.00141** *(0.00608)*	**-0.0018** *(0.0120)*
Solar&Wind * post-3/11	**0.0314***** *(0.00784)*	**0.0755***** *(0.0166)*
Hydro	**0.000272** (0.00403)	**0.0000** (0.0081)
Hydro* post-3/11	**0.00682***** *(0.00188)*	**0.0176***** *(0.0039)*
Bio Fuels	**-0.0127** *(0.0102)*	**-0.0205** *(0.0199)*
Bio Fuels * post-3/11	**-0.0152** *(0.0225)*	**-0.0263** *(0.0475)*
Post-3/11	**-0.190** *(0.152)*	**-0.2642** *(0.3184)*
Micro controls	Yes	Yes
Macro controls	Yes	Yes
Country dummies	Yes	Yes
Year dummies	Yes	Yes
Observations	139517	139517
(pseudo-)/ R2	0.0489	0.1956

Dependent variable: Life satisfaction (0-11). Method: ordered probit/OLS. Post-3/11 is a dummy variable that takes the value 1 if life satisfaction was after March 11, 2011, and 0 otherwise. Robust standard errors in parentheses corrected for clustering at the country-year level. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Appendix

Table A1. List of Variables

VARIABLE	SOURCE	DESCRIPTION
Socio-demographic Indicators	ESS	
Subjective Well-Being ("How satisfied with life as a whole?")		0 (extremely dissatisfied) - 10 (extremely satisfied)
Sex		Dummy: 1= male
Age		Age of respondent in years
Marital Status		4 categories: married or in civil partnership; separated, divorced; widowed; never married nor in civil partnership (reference)
Household Income		Household's total net income (all sources). Discrete: 1 (low income) - 12 (high income)
Employment Status		8 categories: paid work; in education; unemployed and actively looking for job; unemployed and not actively looking for job; permanently sick or disabled; retired; housework; other (reference).
Household size		Number of people living regularly as member of household
Macroeconomic Indicators	OECD (http://www.oecd.org)	
GDP per capita		Measured in 2005 PPP$ per capita
Inflation rate		Measured as the percentage increase of price index compared with the previous year.
Unemployment rate		Measured as the percentage of total civilian labor force
Electricity Supply Indicators	IEA (http://iea.org/)	
Fossil		The share of electricity output generated by electricity plants and CHP-plants using fossil energy input relative to total electricity output (%).
Coal, Oil, Gas		The share of electricity output generated by electricity plants and CHP-plants using oil products, coal and peat, natural gas respectively as energy source relative to total electricity output (%).

Nuclear	The share of electricity output generated by nuclear power plants relative to total electricity output (%).
Renewable	The share of electricity output generated by electricity plants and CHP-plants using renewable energy sources relative to total electricity output (%).
Solar & Wind, Hydro, Biofuels	The share of electricity output generated by electricity plants and CHP-plants using Geoth./Solar/Wind, hydro, Biofuels/ Waste respectively as energy source relative to total electricity output (%).

Table A2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Life Satisfaction	238975	6.763159	2.366564	0	10
Sex					
Male	240145	0.4594682	0.4983555	0	1
Female	240145	0.5405318	0.4983555	0	1
Age	239124	47.37294	18.52812	13	123
Age squared	239124	2587.485	1844.433	169	15129
Household Size	240173	2.800964	1.475175	1	22
Marital Status					
Single	232066	0.281351	0.4496593	0	1
Married	232066	0.5258418	0.4993328	0	1
Divorced	232066	0.077241	0.266974	0	1
Separated	232066	0.0143106	0.1187681	0	1
Widowed	232066	0.1012557	0.3016676	0	1
Employment Status					
Paid Work	238885	0.4849865	0.4997756	0	1
Student	238885	0.0854386	0.2795338	0	1
Unemployed seeking	238885	0.0384871	0.1923695	0	1
Unemployed not seeking	238885	0.0170835	0.129583	0	1
Sick	238885	0.0229734	0.1498189	0	1
Retired	238885	0.2367876	0.4251117	0	1
Social/Military Service	238885	0.0019047	0.0436012	0	1
Housework	238885	0.0997928	0.2997241	0	1
Other	238885	0.0125458	0.1113034	0	1
Income	171818	5.694706	2.738729	1	12
Country Dummies					
Austria	240429	0.0287736	0.1671699	0	1
Belgium	240429	0.0371794	0.1892015	0	1
Czech Republic	240429	0.0365596	0.1876784	0	1
Denmark	240429	0.0319595	0.1758927	0	1
Estonia	240429	0.0289483	0.1676615	0	1
Finland	240429	0.0415549	0.1995701	0	1
France	240429	0.0378324	0.1907911	0	1
Germany	240429	0.0289483	0.1676615	0	1
Greece	240429	0.0405899	0.1973387	0	1
Hungary	240429	0.0130309	0.1134069	0	1
Iceland	240429	0.0024082	0.0490143	0	1
Ireland	240429	0.0435555	0.2041043	0	1
Israel	240429	0.0302917	0.1713891	0	1
Italy	240429	0.0050202	0.0706754	0	1
Luxembourg	240429	0.0132555	0.114367	0	1
Netherlands	240429	0.0405151	0.1971643	0	1
Norway	240429	0.0359482	0.1861615	0	1
Poland	240429	0.0370879	0.1889775	0	1

Portugal	240429	0.0428484	0.2025157	0	1
Slovak Republic	240429	0.0288817	0.1674744	0	1
Slovenia	240429	0.0296387	0.1695888	0	1
Spain	240429	0.0404652	0.197048	0	1
Sweden	240429	0.0382691	0.1918456	0	1
Switzerland	240429	0.0387225	0.1929331	0	1
Turkey	240429	0.0177682	0.1321083	0	1
United Kingdom	240429	0.0462382	0.2100009	0	1
Time Dummies (Year)					
2002	240429	0.1109184	0.3140317	0	1
2003	240429	0.064622	0.2458582	0	1
2004	240429	0.1226183	0.3279993	0	1
2005	240429	0.0679951	0.2517381	0	1
2006	240429	0.1350128	0.341738	0	1
2007	240429	0.0436595	0.2043367	0	1
2008	240429	0.1243694	0.3300031	0	1
2009	240429	0.1099077	0.3127753	0	1
2010	240429	0.0871234	0.2820164	0	1
2011	240429	0.1076077	0.3098849	0	1
GDP per capita	209291	28718.62	9439.162	11394.04	68210.83
Inflation	209291	2.82585	2.253715	-4.479938	14.10775
Unemployment	201477	7.771362	3.740002	2.538279	21.72335
Nuclear Share	203872	0.2127605	0.2256884	0	0.7936616
Renewable Share	203872	0.2234688	0.2386849	0.04386	99.94244
Fossil Share	203872	0.5637707	0.3137406	0.05756	99.95614
Coal Share	203872	0.3184004	0.2538453	0	95.7096
Oil Share	203872	0.0364439	0.0512293	0.02957	26.54308
Gas Share	203872	0.2032514	0.1976337	0	93.90463
Hydro Share	203872	0.1640201	0.2395556	0.02807	99.33354
Solar & Wind Share	203872	0.0310778	0.0474597	0	27.99886
Biofuel Share	203872	0.0340458	0.0336315	0	13.95935

Table A3: Detailed Estimation Results for Aggregate Supply Structure

	(A) LS11	(B) LS11	(C) LS11
Female	0.0697***	0.0697***	0.0697***
	(0.00701)	(0.00701)	(0.00701)
Age	-0.0335***	-0.0335***	-0.0335***
	(0.00193)	(0.00193)	(0.00193)
Age-squared	0.000332***	0.000332***	0.000332***
	(0.0000193)	(0.0000193)	(0.0000193)
Household Size	-0.00147	-0.00147	-0.00147
	(0.00300)	(0.00300)	(0.00300)
Married	0.196***	0.196***	0.196***
	(0.0133)	(0.0133)	(0.0133)
Divorced	-0.0581***	-0.0581***	-0.0581***
	(0.0165)	(0.0165)	(0.0165)
Separated	-0.215***	-0.215***	-0.215***
	(0.0266)	(0.0266)	(0.0266)
Widowed	-0.0630***	-0.0630***	-0.0630***
	(0.0157)	(0.0157)	(0.0157)
In Education	0.104***	0.104***	0.104***
	(0.0177)	(0.0177)	(0.0177)
Voluntary Unempl.	-0.347***	-0.347***	-0.347***
	(0.0350)	(0.0350)	(0.0350)
Sick	-0.504***	-0.504***	-0.504***
	(0.0261)	(0.0261)	(0.0261)
Retired	0.0162	0.0162	0.0162
	(0.0158)	(0.0158)	(0.0158)
Social/Military Serv.	0.101	0.101	0.101
	(0.0978)	(0.0978)	(0.0978)
Housework	-0.00776	-0.00776	-0.00776
	(0.0138)	(0.0138)	(0.0138)
Other Empl.	-0.0763***	-0.0763***	-0.0763***
	(0.0293)	(0.0293)	(0.0293)
Involuntary Unempl.	-0.476***	-0.476***	-0.476***
	(0.0292)	(0.0292)	(0.0292)
Household Income	0.0625***	0.0625***	0.0625***
	(0.00295)	(0.00295)	(0.00295)
Austria	0.911***	0.911***	0.911***
	(0.339)	(0.339)	(0.339)
Belgium	0.884***	0.884***	0.884***
	(0.333)	(0.333)	(0.333)
Switzerland	1.347***	1.347***	1.347***
	(0.413)	(0.413)	(0.413)
Czech_Republic	0.341**	0.341**	0.341**
	(0.162)	(0.162)	(0.162)
Germany	0.507*	0.507*	0.507*
	(0.281)	(0.281)	(0.281)
Denmark	1.226***	1.226***	1.226***

	(0.258)	(0.258)	(0.258)
Spain	0.794***	0.794***	0.794***
	(0.230)	(0.230)	(0.230)
Finland	1.172***	1.172***	1.172***
	(0.292)	(0.292)	(0.292)
France	0.586	0.586	0.586
	(0.376)	(0.376)	(0.376)
United Kingdom	0.483*	0.483*	0.483*
	(0.261)	(0.261)	(0.261)
Greece	-0.00451	-0.00451	-0.00451
	(0.159)	(0.159)	(0.159)
Hungary	0.0343	0.0343	0.0343
	(0.175)	(0.175)	(0.175)
Ireland	0.609*	0.609*	0.609*
	(0.312)	(0.312)	(0.312)
Israel	0.343*	0.343*	0.343*
	(0.178)	(0.178)	(0.178)
Iceland	1.577***	1.577***	1.577***
	(0.424)	(0.424)	(0.424)
Italy	0.364	0.364	0.364
	(0.225)	(0.225)	(0.225)
Luxembourg	0.688	0.688	0.688
	(0.640)	(0.640)	(0.640)
Netherlands	0.564**	0.564**	0.564**
	(0.278)	(0.278)	(0.278)
Norway	1.214**	1.214**	1.214**
	(0.546)	(0.546)	(0.546)
Poland	0.233***	0.233***	0.233***
	(0.0865)	(0.0865)	(0.0865)
Portugal	-0.207	-0.207	-0.207
	(0.137)	(0.137)	(0.137)
Sweden	1.330***	1.330***	1.330***
	(0.372)	(0.372)	(0.372)
Slovenia	0.678***	0.678***	0.678***
	(0.230)	(0.230)	(0.230)
Slovak_Republic	0.514**	0.514**	0.514**
	(0.236)	(0.236)	(0.236)
2003	0.0567	0.0567	0.0567
	(0.0368)	(0.0368)	(0.0368)
2004	0.0403	0.0403	0.0403
	(0.0308)	(0.0308)	(0.0308)
2005	0.0746	0.0746	0.0746
	(0.0456)	(0.0456)	(0.0456)
2006	0.0539	0.0539	0.0539
	(0.0473)	(0.0473)	(0.0473)
2007	0.0677	0.0677	0.0677
	(0.0590)	(0.0590)	(0.0590)
2008	0.123**	0.123**	0.123**
	(0.0603)	(0.0603)	(0.0603)
2009	0.0885	0.0885	0.0885
	(0.0584)	(0.0584)	(0.0584)

2010	0.220***	0.220***	0.220***
	(0.0542)	(0.0542)	(0.0542)
2011	0.164**	0.164**	0.164**
	(0.0655)	(0.0655)	(0.0655)
GDPPC	-0.00302	-0.00302	-0.00302
	(0.0126)	(0.0126)	(0.0126)
Inflation Rate	-0.0106*	-0.0106*	-0.0106*
	(0.00613)	(0.00613)	(0.00613)
Unemployment Rate	-0.0168***	-0.0168***	-0.0168***
	(0.00601)	(0.00601)	(0.00601)
Fossil		0.00719**	0.00601**
		(0.00335)	(0.00294)
Nuclear	-0.00719**		-0.00118
	(0.00335)		(0.00400)
Renewable	-0.00601**	0.00118	
	(0.00294)	(0.00400)	
Observations	139517	139517	139517
Pseudo R-squared	0.0488	0.0489	0.0490

Robust standard errors in parantheses correctet for clustering at the countr-year level; * p<0.1,** p<0.05, *** p<0.01

Table A4: ESS Income Scale

Step	Range	From (€)	Up to (€)
1	1800	0	1800
2	1800	1800	3600
3	2400	3600	6000
4	6000	6000	12000
5	6000	12000	18000
6	6000	18000	24000
7	6000	24000	30000
8	6000	30000	36000
9	24000	36000	60000
10	30000	60000	90000
11	30000	90000	120000
12	>30000	120000	>120000

Source: ESS-Questionnaire Round 3, Showcard 53
http://ess.nsd.uib.no/streamer/?&year=2007&country=&download=%5CFieldwork+documents%5C2007%5C04%23ESS3+-+Showcards%5C.%5CESS3Source_Showcards.pdf

Note: About 60 percent of individuals are in the income categories 4 to 8, for whom moving up one category corresponds to 6,000 €.

Zuletzt erschienen /previous publications:

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