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Using Subjective Well-Being Data for Energy Policy Analysis

Energy for Well-Being

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Abstract

Several European countries are currently undertaking fundamental revisions of their energy policies. Many of these activities are motivated by concerns about *environmental sustainability* (in particular with respect to climate change), *energy security* (in particular in relation to import dependence), *energy costs* (in particular the costs and prices of electricity), and *nuclear safety* (in particular after the nuclear disaster at Fukushima, Japan).

The project entitled “Using Subjective Well-Being Data for Energy Policy Analysis – Energy for Well-Being” aims at an assessment of such concerns in terms of citizens’ individual welfare or utility. The specific approach pursued in this project is to operationalize utility as subjective well-being (SWB) or ‘happiness’. The encompassing question is what utility people derive from energy. More specific research questions include the following: How do the costs of energy consumption affect SWB? What are citizens’ preferences for alternative configurations of the energy supply system in terms of SWB? What are the consequences for SWB of living close to energy facilities? Are there effects of the Fukushima accident on European/Swiss citizens’ SWB? The project has addressed such questions by means of SWB regressions with energy costs and parameters of the energy system as independent variables. It has used Geographic Information Systems (GIS) to combine regionally disaggregated micro data from five rounds of the European Social Survey (ESS) and the Swiss Statistics on Income and Living Conditions (SILC) with data on energy prices, the energy mix, and the location of energy facilities from the International Energy Agency (IEA) and the International Atomic Energy Agency (IAEA). It was found that citizens’ SWB is systematically and significantly related that energy prices, the energy mix, the proximity to energy facilities and that the relationship between SWB and the electricity mix changed at the time of the Fukushima nuclear accident.

Abstract

Eine Reihe europäischer Länder unternehmen gegenwärtig eine grundlegende Revision ihrer Energiepolitik. Diese Maßnahmen sind durch ein Zielsystem begründet, welches die Dimensionen der *ökologischen Nachhaltigkeit* (insbesondere in Bezug auf den Klimawandel), der *Versorgungssicherheit* (insbesondere in Bezug auf Importabhängigkeit), der *Energiekosten* (insbesondere die Kosten der Elektrizitätsversorgung), und der *nuklearen Sicherheit* (insbesondere nach dem Atomunfall im japanischen Fukushima) umfasst. Das Projekt mit dem Titel “Using Subjective Well-Being Data for Energy Policy Analysis – Energy for Well-Being” zielt auf eine Beurteilung dieser energiepolitischen Dimensionen anhand ihrer Relevanz für die individuelle Wohlfahrt der Bürger ab. Der spezifische Ansatz des Projektes besteht darin, Wohlfahrt (oder Nutzen) durch „subjektives Wohlergehen“ (SWE) oder „Glück“ zu operationalisieren. Die übergeordnete Fragestellung des Projektes lautet, welchen Nutzen die Bürger in Europa und der Schweiz den verschiedenen Dimensionen der Energieversorgung beimessen. Zu den Forschungsfragen im Einzelnen gehören die folgenden: Welche Auswirkungen haben Energiekosten auf das SWE? Welche Präferenzen, gemessen am SWE, haben die Bürger für unterschiedliche Strukturen des Energieversorgungssystems? Welche Auswirkungen auf das SWE hat die Nähe zu Energieversorgungsanlagen? Hatte der Atomunfall in Fukushima Auswirkungen auf das SWE in Europa und der Schweiz? Zur Beantwortung solcher Fragen wurden in dem Projekt ökonometrische Regressionsanalysen eingesetzt, bei denen SWE-Daten die abhängige Variable darstellen und Energiekosten sowie verschiedene Parameter des Energiesystems die unabhängigen Variablen. Dabei wurden Geografische Informationssysteme (GIS) eingesetzt, um räumlich identifizierte Personendaten aus fünf Runden des European Social Survey (ESS) und der Schweizer Statistik über Einkommen und Lebensbedingungen (SILC) mit Daten über Energiepreise, den Energiemix sowie die Standorte von Energieanlagen der Internationalen Energieagentur (IEA) und Internationalen Atomenergieagentur zu verknüpfen. Zu den wesentlichen Ergebnissen gehört, dass das SWE der Bürger systematisch und signifikant mit den Energiepreisen, dem Energiemix und der Nähe zu Energieanlagen im Zusammenhang steht und dass sich der Zusammenhang zwischen dem SWE und dem Elektrizitätsmix nach dem Atomunfall in Fukushima geändert hat.

Executive summary

Several European countries are currently undertaking fundamental revisions of their energy policies. Switzerland is working on a new *Energiestrategie 2050*. Similarly, Germany has proclaimed the *Energiewende*, 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.
These and other activities in the field of energy policy are mainly motivated by concerns about *environmental sustainability* (in particular with respect to climate change), *energy security* (in particular in relation to import dependence), *energy costs* (in particular the costs and prices of electricity), and *nuclear safety* (in particular after the nuclear disaster at Fukushima, Japan).
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- How do the costs of energy consumption affect SWB?
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The project has addressed such questions by means of SWB regressions with energy costs and parameters of the energy system as independent variables. It has used Geographic Information Systems (GIS) to combine regionally disaggregated micro data from five rounds of the European Social Survey (ESS) and the Swiss Statistics on Income and Living Conditions (SILC) with data on energy prices, the energy mix, and the location of energy facilities from the International Energy Agency (IEA) and the International Atomic Energy Agency (IAEA).

Using subjective well-being data for energy policy analysis

Initially being a tool of psychological research, data on SWB are increasingly used in economic analysis to study the welfare significance of social and economic factors. In these studies, SWB is taken to be a proxy of 'experienced utility' or individual welfare.
SWB data are typically elicited from self-reports. Practically all large-scale social surveys include questions on SWB questions, usually specified as 'happiness' or 'life satisfaction'. A typical life satisfaction question is: "All things considered, how satisfied are you with your life as a whole nowadays?" with response options on a scale from 0 = extremely dissatisfied to 10 = extremely satisfied.
The properties of SWB data have been studied in a large validation literature. The overall conclusion from these studies is that SWB data are valid, reliable, and comparable and meet the standards required for use in social and economic research.
The production of energy is expected to affect individual welfare, operationalized as SWB, through the dimensions of costs, security, safety and pollution. Using regression analysis, this project identifies the relationship between SWB and those dimensions of the energy system. Being based on experienced utility, the identified relationships are taken to indicate 'experienced preferences'. In contrast to stated preference methods of preference elicitation, this approach does not rely on potentially biased statements concerning the issues under study, but on statistical associations between SWB and those issues.

SWB and the costs of energy consumption

The research question addressed in this analysis is: What is the impact of residential prices of electricity, oil, and gas on consumer welfare, proxied by SWB? The residential consumption of fuel and power is often considered a basic need whose satisfaction is necessary for an acceptable quality of life. This character of energy consumption as a basic need has spurred an interest in studying so-called energy poverty or, likewise, fuel poverty, and the issue has recently gained increasing attention in the context of rising residential energy prices.

The empirical analysis is framed within a demand theoretic framework which features a minimum (required) level of energy consumption. The framework implies the prediction that the marginal disutility of energy prices is greater at higher levels of energy poverty, i.e., when the cost share of required energy consumption in income is higher.
The empirical analysis studies the relationship between SWB and household energy prices using survey data from the ESS for more than 100,000 individuals in 21 European countries, 2002-2011. It is found that the prices of electricity, heating oil, and gas have statistically and economically significant negative effects on SWB. Effects above average are found in individuals from the lowest income quartile. Effects are strongest at those times of the year when required energy costs can be expected to be highest. These results are consistent with the hypothesized relationship between energy poverty and the welfare effects of energy prices.

SWB and the structure of energy supply

This analysis studies the relationship between SWB and the electricity mix in a multi-country setting. It is based on the assumption that people have preferences over attributes of the electricity supply system (security and cost of supply, safety of electricity facilities, environmental impacts) and that those attributes correlate with different configurations of the system, that is, the electricity mix. The relationship between SWB and the electricity mix is taken to represent preferences over the welfare-relevant attributes of the electricity supply system.
The analysis uses survey data from ESS for 139,517 individuals in 25 European countries, 2002-2011, combined with the supply shares of electricity from coal, oil, gas, nuclear power, hydro power, solar & wind power, and biofuels. It is found that SWB varies systematically and significantly with differences in the electricity mix across countries and across time. It is found that neither electricity from fossil fuels (coal, oil, gas) nor from renewable sources (hydro power, solar & wind power, biofuels) are homogeneous from an SWB perspective. While electricity from biofuels is less preferred than any other supply technology, electricity from gas as well as solar & wind power are preferred over nuclear power. The latter applies at all levels of income, but the intensity of that preference is less when the level of electricity prices is higher. The preference for solar & wind power over nuclear power has risen drastically after the Fukushima nuclear accident. Overall, the results obtained indicate a preference of European citizens for a safe and environmentally benign electricity supply.

SWB and proximity to energy facilities

This analysis studies the relationship between SWB and proximity to nuclear power plants (NPP). This relationship is assumed to involve a trade-off between economic factors related to the proximity to NPPs (e.g. employment opportunities) and concerns about nuclear safety.
The relationship between SWB and NPPs was considered both from a European wide perspective, and with respect to Switzerland as a case study. In the analysis for Switzerland we used data from the Swiss "Statistics on Income and Living Conditions" (SILC) 2009-2011, where survey respondents are characterized by their distance to the nearest NPP in steps of 5 km.
Preliminary analysis showed that 3 sets of 5-km-distance rings differ significantly from each other while not presenting significant within-differences: <40 km, 40-85 km and >85 km. We based the subsequent analysis on these categories, referring to them as Ring 1, Ring 2 and Ring 3. In a first specification of regressions, SWB in Ring 3 areas was found to be significantly lower than in Ring 1 and Ring 2, while there was no significant difference between the latter two. By including, in a second specification, distance-specific unemployment rates and indicators of the language region in which persons live, SWB in Ring 2 was found to be significantly greater than in Ring 1 and Ring 3, while no significant difference was found between the latter two.

SWB and the Fukushima nuclear accident

This analysis is concerned with the question of whether there was a change in the relationship between SWB and nuclear power after the nuclear accident in Fukushima in March 2011. This general question was addressed in a European wide perspective and with respect to Switzerland as a case study.

The European wide analysis used survey data for over 100,000 individuals in 23 European countries to study the relationship between SWB and (i) the supply share of nuclear power in those countries, and (ii) the proximity to NPPs. It was found that European citizens' SWB was statistically unrelated to the share of nuclear power before the Fukushima nuclear disaster, but negatively related to the nuclear share after the disaster. Similarly, preliminary results suggest that proximity to NPPs had a negative impact on SWB only after the Fukushima accident. This suggests the existence of an induced change in experienced preference concerning nuclear power.
The analysis for Switzerland builds upon the research on the relationship between SWB and the proximity to NPPs. Consistent with the European wide analysis, preliminary results suggest that the relationship between SWB and proximity to NPPs changed after Fukushima. In particular, after the accident SWB of citizens living more remote from NPPs increased relative to that of people living closer to NPPs. This change was more marked in German speaking regions than in Switzerland overall. The latter may reflect geographic aspects of perceived nuclear safety, such as those related to topography (the Alps) and the prevailing wind direction (westerly wind). These factors may imply a higher level of perceived safety in the southern and the western parts of the country.

Zusammenfassung

Eine Reihe europäischer Länder unternehmen gegenwärtig eine grundlegende Revision ihrer Energiepolitik. In der Schweiz wird an der *Energiestrategie 2050* gearbeitet. In Deutschland wurde die sogenannte *Energiewende* eingeleitet, die einen beschleunigten Ausstieg aus der Kernenergie und ein ehrgeiziges Ziel für den Ausbau erneuerbarer Energien vorsieht. Im Gegensatz dazu hat Frankreich angekündigt, die Laufzeit seiner Kernkraftwerke zu verlängern, und Großbritannien plant den Ausbau der Kernenergie. Diese und weitere Maßnahmen der Energiepolitik sind durch ein Zielsystem begründet, welches die Dimensionen der *ökologischen Nachhaltigkeit* (insbesondere in Bezug auf den Klimawandel), der *Versorgungssicherheit* (insbesondere in Bezug auf Importabhängigkeit), der *Energiekosten* (insbesondere die Kosten der Elektrizitätsversorgung), und der *nuklearen Sicherheit* (insbesondere nach dem Atomunfall im japanischen Fukushima) umfasst.

Das Projekt mit dem Titel "Using Subjective Well-Being Data for Energy Policy Analysis – Energy for Well-Being" zielt auf eine Beurteilung dieser energiepolitischen Dimensionen anhand ihrer Relevanz für die individuelle Wohlfahrt der Bürger ab. Der spezifische Ansatz des Projektes besteht darin, Wohlfahrt (oder Nutzen) durch „subjektives Wohlergehen" (SWE) oder „Glück" zu operationalisieren. Die übergeordnete Fragestellung des Projektes lautet, welchen Nutzen die Bürger in Europa und der Schweiz den verschiedenen Dimensionen der Energieversorgung beimessen. Zu den Forschungsfragen im Einzelnen gehören die folgenden:

- Welche Auswirkungen haben Energiekosten auf das SWE?
- Welche Präferenzen, gemessen am SWE, haben die Bürger für unterschiedliche Strukturen des Energieversorgungssystems?
- Welche Auswirkungen auf das SWE hat die Nähe zu Energieversorgungsanlagen?
- Hatte der Atomunfall in Fukushima Auswirkungen auf das SWE in Europa und der Schweiz?

Zur Beantwortung solcher Fragen wurden in dem Projekt ökonometrische Regressionsanalysen eingesetzt, bei denen SWE-Daten die abhängige Variable darstellen und Energiekosten sowie verschiedene Parameter des Energiesystems die unabhängigen Variablen. Dabei wurden Geografische Informationssysteme (GIS) eingesetzt, um räumlich identifizierte Personendaten aus fünf Runden des European Social Survey (ESS) und der Schweizer Statistik über Einkommen und Lebensbedingungen (SILC) mit Daten über Energiepreise, den Energiemix sowie die Standorte von Energieanlagen der Internationalen Energieagentur (IEA) und Internationalen Atomenergieagentur zu verknüpfen.

Daten zum subjektiven Wohlergehen und energiepolitische Analyse

Daten zum SWE wurden ursprünglich in der psychologischen Forschung eingesetzt und werden seit einiger Zeit in der Wirtschaftswissenschaft genutzt, um die Wohlfahrtswirkungen sozialer und ökonomischer Faktoren zu untersuchen. In diesen Studien wird SWE als empirisches Maß für „Erfahrungsnutzen" (manifestierten Nutzen) oder individuelle Wohlfahrt verwendet.

SWE-Daten werden typischerweise durch Personenbefragungen gewonnen. Praktisch alle großen Sozialbefragungen auf nationaler und internationaler Ebene enthalten Fragen zum SWE, welches üblicherweise als „Glück" oder als „Lebenszufriedenheit" spezifiziert wird. Eine Lebenszufriedenheitsfrage lautet typischerweise wie folgt: „Alles in allem, wie zufrieden sind Sie gegenwärtig mit Ihrem Leben?", wobei Antwortmöglichkeiten auf einer Skala von 0 = „äußerst unzufrieden" bis 10 = „äußerst zufrieden" angeboten werden.

Die Eigenschaften von SWE-Daten wurden in einer umfangreichen Validierungsliteratur geprüft. Diese kann dahingehend zusammengefasst werden, dass SWE-Daten valide, verlässlich und vergleichbar sind und die qualitativen Voraussetzungen für einen Einsatz in der sozial- und wirtschaftswissenschaftlichen Forschung erfüllen.

Die Erzeugung und Bereitstellung von Energie wirkt auf die individuelle Wohlfahrt, operationalisiert als SWE, über die Dimensionen durch die Dimensionen Energiekosten, Versorgungssicherheit, technische Sicherheit und Umweltbelastung. Mit Hilfe von Regressionsanalysen hat dieses Projekt Zusammenhänge zwischen dem SWE und diesen Dimensionen der Energieversorgung identifiziert. Da die Untersuchung sich auf ein Maß für manifestierten Nutzen stützt, werden die gefundenen Zusammenhänge als Ausdruck von manifestierten Präferenzen aufgefasst. Im Gegensatz zu geäußerten Präferenzen, basiert dieser

Ansatz nicht auf Äußerungen zum Gegenstand der Untersuchung, welche verzerrt sein können, sondern auf statistischen Zusammenhängen zwischen dem SWE und dem jeweiligen Untersuchungsgegenstand.

SWE und die Kosten des Energiekonsums

Der private Konsum von Brennstoffen und Elektrizität wird vielfach als Grundbedürfnis aufgefasst, dessen Erfüllung notwendig für eine angemessene Lebensqualität ist. Diese Eigenschaft von Energiekonsum als Grundbedürfnis hat in der Vergangenheit zu einem Interesse an der Frage der sogenannten Energiearmut geführt, welches in letzter Zeit im Zusammenhang mit steigenden Energiepreisen zugenommen hat.
In der vorliegenden Untersuchung wurde der Frage nachgegangen: Welche Auswirkungen haben die Preise von Strom, Heizöl und Gas auf die Konsumentenwohlfahrt, gemessen durch das SWE?
Die empirische Untersuchung erfolgte in einem nachfragetheoretischen Rahmen, der ein unverzichtbares Mindestniveau an Energiekonsum beinhaltet. Dieses Modell impliziert die Aussage, dass der marginale Nutzenverlust durch höhere Energiepreise bei höherer Energiearmutsquote größer ist, d. h. wenn der Ausgabenanteil des Mindestenergiekonsums am Einkommen höher ist.
Die empirische Analyse hat den Zusammenhang zwischen dem SWE und den Haushaltsenergiepreisen anhand von Daten der ESS für mehr als 100.000 Personen in 21 europäischen Ländern im Zeitraum 2002-2011 untersucht. Es ergab sich, dass die Preise von Strom, Heizöl und Gas statistisch und ökonomisch signifikante negative Auswirkungen auf das SWE haben. Überdurchschnittlich starke Effekte betreffen Personen aus dem untersten Einkommensviertel. Ferner sind die Effekte in jenen Jahreszeiten am stärkten, in denen die erforderlichen Mindestausgaben für Energie mutmaßlich am höchsten sind. Diese empirischen Ergebnisse entsprechen dem theoretisch erwarteten Zusammenhang zwischen der Energiearmutsquote und den Nutzeneffekten höherer Energiepreise.

SWE und Energieversorgungsstruktur

Diese Untersuchung analysierte den Zusammenhang zwischen dem SWE und dem Elektrizitätsmix in einem Mehr-Länder-Rahmen. Die empirische Untersuchung basiert auf der Annahme, dass Individuen Präferenzen für bestimmte Attribute des Stromversorgungssystems haben (Versorgungssicherheit und Versorgungskosten, Sicherheit der Stromversorgungsanlagen, Umweltauswirkungen) und dass diese Attribute mit der Struktur des Stromversorgungssystems variieren, d.h. mit dem Elektrizitätsmix. Der Zusammenhang zwischen dem SWE und dem Elektrizitätsmix wird somit als Ausdruck von Präferenzen bezüglich der relevanten Attribute des Stromversorgungssystems interpretiert.
In der Untersuchung wurden Daten für 139.517 Personen in 25 europäischen Ländern für den Zeitraum 2002-2011 verwendet und mit den Erzeugungsanteilen von Strom aus Kohle, Öl, Gas, Kernenergie, Wasserkraft, Solar & Windenergie und Biomasse kombiniert. Es wurde festgestellt, dass das SWE systematisch und signifikant mit Unterschieden im Strommix zwischen den Ländern und über die Zeit variiert. Es zeigte sich, dass in Hinblick auf das SWE weder Strom aus fossilen Energieträgern (Kohle, Öl, Gas) noch aus regenerativen Quellen (Wasserkraft, Solar & Windenergie, Biomasse)als homogen anzusehen sind. Vielmehr zeigte sich, dass Strom aus Biomasse weniger geschätzt wird als Strom aus jeder anderen Erzeugungsform. Ferner erwiesen sich die Stromerzeugung aus Gas sowie Solar & Windenergie als bevorzugt gegenüber der Kernenergie. Letzteres gilt für Personen aller Einkommensstufen; allerdings nimmt die Intensität dieser Präferenz mit höheren Strompreisen ab. Des Weiteren stieg die Präferenz für Solar & Windenergie nach dem Atomunfall in Fukushima deutlich an. Insgesamt weisen die empirischen Ergebnisse auf eine hohe Wertschätzung der Bürger für eine sichere und saubere Stromversorgung hin.

SWE und die Nähe zu Energieversorgungsanlagen

In dieser Untersuchung wurde der Zusammenhang zwischen dem SWE und der Nähe zu Kernkraftwerken (KKW) untersucht. Es wurde dabei davon ausgegangen, dass dieser Zusammenhang einen Trade-off zwischen wirtschaftlichen Faktoren (bspw. Beschäftigungsmöglichkeiten im Umfeld von KKW) und Erwägungen zur nuklearen Sicherheit beinhaltet.
Der Zusammenhang zwischen dem SWE und KKWs wurde sowohl in einem gesamteuropäischen Rahmen als auch speziell mit Bezug auf die Schweiz untersucht. In der gesamteuropäischen Betrachtung wurden mit Hilfe Geografischer Informationssysteme (GIS) Befragungsdaten zum SWE aus den Euro-

pean Social Surveys mit Daten zu KKW-Standorten verknüpft, um Informationen über die Entfernung der Befragten zum nächsten KKW zu generieren. Es ergab sich, dass Personen in größerer Nähe zu KKW ein höheres SWE aufweisen. Eine Analyse der dahinter stehenden Faktoren steht noch aus.
In der Untersuchung für die Schweiz wurden Daten der "Statistik über Einkommen und Lebensbedingungen" (SILC) für die Jahre 2009-2011 verwendet, wobei die Befragten durch ihre Nähe zum jeweils nächsten KKW in Schritten von 5 km charakterisiert waren. Eine erste Analyse ergab, dass 3 Gruppen von 5-km-Ringen sich significant voneinander unterscheiden, während es innerhalb dieser Gruppen keine signifikanten Unterschiede gibt: <40 km, 40-85 km und >85 km. Die folgenden Untersuchungen basieren auf diesen Kategorien, die als Ring 1, Ring 2 und Ring 3 bezeichnet werden. Anhand einer ersten Spezifikation der Regressionsgleichung ergab sich, dass das SWE in Ring 3 signifikant niedriger war als in Ring 1 und Ring 2, wohingegen sich die letzteren nicht signifikant unterscheiden. In einer zweiten Spezifikation wurden Arbeitslosenraten, differenziert nach der Entfernung zum nächsten KKW, sowie die Sprachregion berücksichtigt. Dabei ergab sich dass das SWE in Ring 2 signifikant höher als in Ring 1 und Ring 3 ist, wohingegen sich die letzteren nicht signifikant unterscheiden.
Diese Ergebnisse legen die Vermutung nahe, dass das niedrige SWE-Niveau in Ring 3 im Vergleich zu Ring 1 laut erster Spezifikation auf ungünstigeren wirtschaftlichen Bedingungen beruht, da die Arbeitslosenraten in Ring 3 erheblich höher sind. Filtert man diesen Faktor heraus, ist das SWE in der äußersten Entfernungskategorie (Ring 3) so hoch wie in der innersten Kategorie (Ring 1). Dieses Ergebnis stützt die Idee eines Trade-off zwischen wirtschaftlichen Faktoren und wahrgenommener nuklearer Sicherheit und unterstreicht darüber hinaus die Bedeutung der Berücksichtigung potentieller dritter Faktoren bei der Regressionsanalyse.

SWE und der Atomunfall in Fukushima

Diese Untersuchung beschäftigt sich mit der Frage, ob es nach dem Atomunfall in Fukushima zu einer Änderung im Zusammenhang zwischen dem SWE und der Nutzung der Kernenergie kam. Diese Frage wurde sowohl auf gesamteuropäischer Ebene als auch speziell für die Schweiz untersucht
Bei der gesamteuropäischen Analyse wurden Umfragedaten für mehr als 100,000 Personen in 23 europäischen Ländern verwendet, um den Zusammenhang zwischen dem SWE und (i) dem Erzeugungsanteil der Kernenergie in diesen Ländern sowie (ii) der Nähe zu KKWs zu untersuchen. Es ergab sich, dass auf europäischer Ebene das SWE vor dem Atomunfall keinen statistisch signifikanten Zusammenhang mit dem Kernenergieanteil aufwies, nach dem Unfall hingegen einen signifikant negativen Zusammenhang. Ferner zeigen erste Ergebnisse, dass die Nähe zu KKWs nur nach dem Unfall in Fukushima einen negative Effekt auf das SWE hatte. Dies deutet auf eine induzierte Änderung der manifestierten Präferenz für Kernenergie hin.
Die diesbezügliche Untersuchung für die Schweiz baut auf der Analyse des Zusammenhangs zwischen dem SWE und der Nähe zu KKW auf. Ähnlich wie die europaweite Untersuchung zeigen vorläufige Ergebnisse eine Änderung im Zusammenhang zwischen dem SWE und der Nähe zu KKW nach Fukushima. Insbesondere stieg das relative SWE von Personen in größerer Entfernung zu KKW im Vergleich mit Personen, die näher an KKW leben. Diese Änderung war stärker im deutschsprachigen Teil der Schweiz als in der Schweiz insgesamt. Letzteres könnte mit geografischen Gesichtspunkten bei der subjektiven Wahrnehmung nuklearer Sicherheit im Zusammenhang stehen. Insbesondere könnten topographischen Gegebenheiten (die Alpen) und die vorherrschende Windrichtung (Westwind) zu einem höheren Sicherheitsgefühl im Tessin bzw. der Westschweiz führen.

1 Introduction

Several European countries are currently undertaking fundamental revisions of their energy policies. Switzerland is working on a new *Energiestrategie 2050*. Similarly, Germany has proclaimed the *Energiewende*, 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.
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- Are there effects of the Fukushima accident on European/Swiss citizens' SWB?

The project has addressed such questions by means of SWB regressions with energy costs and parameters of the energy system as independent variables. It has used Geographic Information Systems (GIS) to combine regionally disaggregated micro data from five rounds of the European Social Survey (ESS) and the Swiss Statistics on Income and Living Conditions (SILC) with data on energy prices, the energy mix, and the location of energy facilities from the International Energy Agency (IEA) and the International Atomic Energy Agency (IAEA).

This report

Section 2 presents an introduction of the use of SWB for energy policy analysis. The rest of the report is structured around the specific research questions. Section 3 (work package 2): SWB and the cost of energy consumption. Section 4 (work package 3): SWB and the structure of energy supply. Section 5 (work package 1): Measurement of proximity to energy facilities: the case of nuclear power plants. Section 6 (work package 4): SWB and the location of energy facilities: the case of nuclear power plants. Section 7 (work package 5): SWB and the Fukushima accident. Section 8 (work package 6): Dissemination.

2 Using subjective well-being data for energy policy analysis*

Initially being a tool of psychological research, data on SWB are increasingly used in economic analysis to study the welfare significance of economic factors such as income, employment status, economic growth, the rates of unemployment and inflation etc. In these studies, SWB is taken to be a proxy of 'experienced utility' or individual welfare.

SWB data have been used, in particular, in environmental and resource economics, where the number of pertinent articles indexed in EconLit quintupled from 2002-2005 to 2010-2013. The focus of these studies is the contribution of environmental amenities to SWB. By yielding estimates of the marginal rate of substitution of income for amenities, SWB regressions have been used as a novel tool for non-market valuation.

SWB data are typically elicited from self-reports. Practically all large-scale social surveys (such as the World Values Survey, the Eurobarometer, the European Social Survey, the German Socio-Economic Panel, the Swiss Statistics on Income and Living Conditions and the British Household Panel Study) include SWB questions. SWB is usually specified as 'happiness' or 'life satisfaction', where the former refers to the affective and the latter to the cognitive and evaluative aspect of SWB. A typical life satisfaction question, asked in the ESS, is: "All things considered, how satisfied are you with your life as a whole nowadays?" (with response options on an 11-point scale where 0 = extremely dissatisfied and 10 = extremely satisfied).

Assessment of SWB data

A large validation literature has studied the properties of SWB data (see Diener et al. 1999, Frey and Stutzer 2002 for reviews). In these studies the following has been found:

- Self-reported SWB is associated with health status (e.g. hypertension) and objective circumstances and events.
- Self-reported SWB is correlated with physiological responses and electrical readings in the brain.
- SWB scores are correlated with rates of suicide.
- Different measures of self-reported well-being exhibit high correlations with one another.
- Self-reported SWB is correlated with assessments of persons' SWB by friends, family, and spouse.

From this validation research it is concluded that SWB data are valid, reliable and (at least ordinally) comparable.

Use of SWB in this project

The production of energy has impacts on individual welfare beyond the satisfaction of demands for heating, cooling, cooking and the operation of appliances. Additional welfare-relevant dimensions of energy supply are costs, security, safety and pollution. Using regression analysis, this project identifies the relationship between SWB and those dimensions of the energy system. Taking those relationships as indicators of preferences, SWB regressions serve as a tool for preference elicitation which can inform policy-making. By not relying on statements of preference but on statistical analysis of how energy impacts on individual welfare, the SWB approach represents an alternative source of information, in addition to more traditional approaches based on attitudes and opinions.

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* The discussion in this section is partially based on the working paper "Environment, Well-Being, and Experienced Preference" (Heinz Welsch & Susana Ferreira 2014) produced as a deliverable for this project. This paper has been accepted for publication in the International Review of Environmental and Resource Economics. See appendix to this report.

Methodological issues

In economic analysis SWB data are used as a proxy for unobserved utility. Depending on the assumptions on SWB data and their relationship to utility, different econometric methods are appropriate. In addition, issues of endogeneity need to be addressed.
In using SWB data as a proxy for utility, necessary assumptions are (Ferrer-i-Carbonell and Frijters 2004): (a) a positive monotonic relationship between SWB and the underlying true utility U (if $SWB_{it} > SWB_{is}$, then $U_{it} > U_{is}$ for individual i at times t and s), and (b) ordinal interpersonal comparability (if $SWB_{it} > SWB_{jt}$, then $U_{it} > U_{jt}$ for individuals i and j).
Validation research has produced a variety of supporting evidence of those assumptions (see Diener et al. 1999, Frey and Stutzer 2002, Ferrer-i-Carbonell and Frijters 2004). Under ordinal interpersonal comparability SWB can be treated as an ordinal variable, and SWB equations can be estimated using estimators for discrete choice models (ordered logit or probit). These methods augment the structural relationship between unobserved utility (as the latent dependent variable) and its determinants with a measurement equation that specifies the relationship between utility and SWB.
If, more restrictively, cardinal interpersonal comparability is assumed ($SWB_{it} – SWB_{jt}$ is proportional to $U_{it} – U_{jt}$), SWB can be treated as a cardinal variable.[1] In this case, SWB data can be used as the dependent variable, and a least squares estimator is in principle appropriate. Ferrer-i-Carbonell and Frijters (2004) and many others found that assuming the data to be ordinal or cardinal and applying the corresponding estimation methods has little effect on the main results.
Focusing on least squares, the arguably most important and pervasive methodological issue is endogeneity, which can be defined as a correlation between the explanatory variables and the error term in a regression.[2] Since endogeneity leads to biased and inconsistent parameter estimates, recognition of endogeneity issues has increased noticeably over the last decade. In spite of its importance, however, a serious limitation of dealing with endogeneity is that it cannot be tested formally. As Roberts and Whited (2013) state in their recent survey of the subject: “We repeat there is no way to empirically test whether a variable is correlated with the regression error term because the error term is unobservable. Consequently, there is no way to statistically ensure that an endogeneity problem has been solved.” They argue, however: “The first step in addressing endogeneity is identifying the problem. More precisely, researchers must make clear which variable(s) are endogenous and why they are endogenous.”
We follow this advice by briefly discussing the relevance of endogeneity concerns in our analysis, addressing the causes of endogeneity – omitted variables, measurement error, and simultaneity – one by one.
Omitted variables are those variables that should be included among the explanatory variables, but for various reasons are not. The inability to include these determinants means that instead of appearing among the explanatory variables, these omitted variables appear in the error term. If these omitted variables are uncorrelated with the included explanatory variables, then there is no problem for inference; the estimated coefficients are consistent. If the omitted variables are correlated with the included explanatory variables, the estimated coefficients are inconsistent.
In our analysis we minimize the risk of omitted variable bias by controlling for those factors that the literature has found to affect SWB, both at the micro and macro level (see Dolan et al. 2008). In addition, in our European-wide analysis we control for unobserved country-specific time-invariant factors by including country fixed effects and for unobserved time-specific factors that are common to all countries by time fixed effects.
The statistical implications of measurement error in the dependent variable are similar to those of an omitted variable since, similar as the latter, the measurement error appears in the regression error term. If the measurement error is uncorrelated with the explanatory variables, then least squares estimation produces consistent estimates; if correlated, then least squares estimates are inconsistent.
With respect to subjective data as dependent variable, Bertrand and Mullainathan (2001) have expressed concern about measurement error (misreporting) that is correlated with explanatory variables. Though the examples they offer relate to attitudes and opinions, misreporting may exist in the case of SWB too. However, we consider this to be less of a problem in our analysis because there is no reason to expect that

[1] Cardinal interpersonal comparability amounts to assuming that the difference between an SWB score of, say, 8 and 9 is the same as the difference between a 4 and a 5 (Ng 1997).
[2] We closely follow the concise discussion in Roberts and Whited (2013).

misreporting of SWB, if any, is correlated with our variables of interest, electricity supply shares, energy prices and the location of energy facilities.
Finally, simultaneity bias occurs when the dependent variable and one or more of the explanatory variables are determined in equilibrium so that it can plausibly be argued either that the latter cause the former or vice versa.
In our analysis, there is no reason to expect that the dependent variable, individual-level SWB, causes the national electricity supply structure (which is the subject of WP2) or the level of national energy prices (WP3). By contrast, people's location (relative to energy facilities) and their SWB arguably are (co-)determined in equilibrium, as suggested by spatial equilibrium theory. We address this issue in WP4 and WP5 by formulating and testing two alternative models that treat proximity as exogenous and endogenous (due to location choice), respectively.

3 SWB and the costs of energy consumption*

The residential consumption of fuel and power contributes to well-being through heating and cooling, lighting, cooking, and the operation of appliances. Fuel and power consumption are often considered a basic need whose satisfaction is necessary for an acceptable quality of life. This character of energy consumption as a basic need has spurred an interest in studying so-called energy poverty or, likewise, fuel poverty (Boardman 1991). Energy poverty has gained increasing attention in the context of rising residential energy prices (e.g., Hills 2012, Moore 2012, Thomson and Snell 2013).
The research question addressed in this analysis is: What is the impact of residential energy prices on consumer welfare, proxied by SWB?

Conceptual Framework: Energy Poverty, Energy Prices, and Welfare

Measures of energy poverty typically rely on the energy poverty ratio (*EPR*). *EPR* is the ratio between the costs of “required” energy consumption *R* and income *Y*:

$$EPR = \frac{pR}{Y}$$

Definitions of energy poverty usually relate the *EPR* to some threshold level (poverty line).

The welfare significance of energy poverty can be illustrated using a simple framework, in which the individual derives utility from the consumption of energy *E*, non-energy *N* (assumed to be the numeraire), and where a certain minimum (subsistence) level *R* of energy has to be consumed. Denoting by *p* and *Y* the energy price and income, respectively, the individual solves the following optimization problem:

$\text{Max}_{E,N}$ *u = U(E-R,N) s.t. p*E + N = Y*

This implies the indirect utility function *u = V(p,Y,R)*.
With some additional assumptions on the (direct) utility function, the following result can be established:

Proposition: The marginal disutility $(-\partial V / \partial p)$ from a rise in the energy price increases in the *EPR*.

The empirical task in this research is to estimate the marginal disutility of energy prices using SWB as a proxy for utility. Based on the proposition above, the hypothesis is that the SWB effect of energy prices is greater at greater *EPR*, that is, at higher *p* and *R* and at lower *Y*.

Empirical Strategy and Data

We consider the following estimating equation:

$$LS_{ict} = \boldsymbol{\alpha}'\mathbf{micro_{ict}} + \boldsymbol{\beta}'\mathbf{macro_{ct}} + \gamma\ energyprice_{ct} + country_c + time_t + \varepsilon_{ict}.$$

In this formulation, LS_{ict} denotes life satisfaction of individual *i* in country *c* at time *t*, and time *t* refers to the quarters 2002.I to 2011.IV. The vector ***micro*** comprises the usual individual-level correlates of SWB (in particular gender, age, household size and income, marital status and employment status), whereas the vector ***macro*** comprises controls at the country level (in particular per capita income and the rates of unemployment and inflation). The estimating equation controls for unobserved time-invariant country-specific factors through country-fixed effects and for unobserved time-specific factors that are common to

* The discussion in this section is based on H. Welsch, P. Biermann (2014) “Energy Prices, Energy Poverty, and Subjective Well-Being”, working paper produced as a deliverable for this project within work package 2. See appendix to this report.

all countries through time-fixed effects. The main variables of interest are the *energyprices*, that is, prices of electricity, gas and light fuel oil (heating oil) for households by country. Energy prices are available by quarter and are defined as average unit prices, that is, expenditures per unit purchased.
The individual-level data come from rounds 1 - 5 of the European Social Survey (ESS), 2002 - 2011. In particular, *LS* is obtained from the following life satisfaction question: "All things considered, how satisfied are you with your life as a whole nowadays?" 0 = extremely dissatisfied, …, 10 = extremely satisfied.
The data for the macro controls come from the OECD (quarterly GDP per capita, inflation and unemployment). The prices of electricity, gas and light fuel oil are real unit energy prices for households at PPP-corrected USD by country and quarter and come from the IEA.
Matching price data to survey data yields 3 data sets with 100,908 observations (electricity), 117,819 observations (oil), and 101,937 observations (gas) in about 20 European countries. Table 1 reports the summary statistics of the energy price data. The average prices are 0.189 USD/kWh for electricity, 0.856 USD/liter for heating oil and 0.068 USD/kWh for gas. All price data exhibit sufficient variation to allow identification of their SWB effects.

Table 1: Energy Price Data

	Obs.	Unit	Mean	SD	Min	Max
Electricity Price	100,908	USD/kWh	0.189	0.062	0.064	0.342
Oil Price	117,819	USD/liter	0.856	0.394	0.259	2.767
Gas Price	101,937	USD/kWh	0.068	0.025	0.018	0.162

An important feature of the energy price data is that they follow a seasonal pattern over the year, as can be inferred from regressing them on dummies for the 1st to 4th quarter (controlling for country and year fixed effects). In particular, electricity prices are highest in the 1st and 4th quarter, which may reflect new contracts and/or payments of areal, whereas oil and gas prices are highest in the 3rd quarter. This may reflect seasonal price discrimination in the case of oil. Gas prices, which equal (fixed) expenditures per unit purchased, are high when the quantity is small, that is, in summer.

Results

Table 2 reports the estimation results for the impact of energy prices on SWB. It should, first, be noted that the coefficient of determination (R^2) in these regressions (as well as in subsequent ones) has the order of magnitude typically found in SWB regressions: Not more than about 20 percent of the individual-level variation of SWB can be explained by objective circumstances. The coefficients of the energy prices have the expected negative sign for all three types of energy but are significant only for the electricity price (at the 10-percent level) and the gas price (at the 5-percent level).

Table 2: Impacts of Energy Prices on SWB

Prices in PPP Dollars per Unit	Electricity (USD/MWh)	Oil (USD/1000 liter)	Gas (USD/MWh)
Price	-0.00155*	-0.00035	-0.00459**
	(0.00092)	(0.00023)	(0.00196)
R-squared	0.208	0.182	0.190

Notes: Omitted from this table are the micro controls, macro controls, country & quarter FE that were included in the regressions. Methods: least squares. (Estimates from ordered probit were robust). Robust standard errors adjusted for clustering at the country-quarter level. *p<0.1, **p<0.05.

We extended this basic analysis by including interactions of the price variables with income and other factors which, as suggested by our conceptual framework, may affect the relationship between energy prices and well-being. Results are presented in Table 3.

Table 3: Impacts of Energy Prices on SWB - interactions

Panel A: Interactions of price variables with income

	Electricity	Oil	Gas
Price*Income<6k	-0.00232**	-0.000397*	-0.00590***
	(0.000962)	(0.000228)	(0.00198)
Price*Income6k-24k	-0.00122	-0.000299	-0.00397**
	(0.000925)	(0.000234)	(0.00201)
Price*Income24k-60k	-0.00114	-0.000382*	-0.00413**
	(0.000913)	(0.000228)	(0.00206)
Price*Income>60k	-0.00118	-0.00049**	-0.00500**
	(0.000933)	(0.000228)	(0.00211)
R-squared	0.209	0.182	0.191

Panel B: Interactions of price variables with time of the year

	Electricity	Oil	Gas
Price*QI	-0.00207**	-0.000378	-0.00247
	(0.00104)	(0.000272)	(0.00247)
Price*QII	-0.00190	-0.000427	-0.00173
	(0.00176)	(0.000286)	(0.00672)
Price*QIII	-0.00121	-0.000736**	-0.00717***
	(0.00114)	(0.000286)	(0.00317)
Price*QIV	-0.00158*	-0.000288	-0.00324
	(0.000933)	(0.000224)	(0.00213)
R-squared	0.208	0.182	0.190

Notes: Omitted from this table are the micro controls, macro controls, country & quarter FE that were included in the regressions. Methods: least squares (Estimates from ordered probit were robust). Robust standard errors adjusted for clustering at the country-quarter level. *p<0.1, **p<0.05, ***p<0.01..

Regarding income, we differentiate by four categories which approximately correspond to quartiles. For electricity, the coefficients of the price-income interactions are negative at all income levels, but only significant at the lowest income category. For oil, the coefficients are significant for all but the second category, and for gas they are significant at all income categories. For gas, the effect is strongest at the lowest income category, whereas in the case of oil the SWB-price relationship seems to be u-shaped in income.

Turning to the time of the year, the electricity price effect is significant only in the 1st and 4th quarter, whereas the oil and gas price effects are significant only in the 3rd quarter.

Discussion

Energy prices affect SWB negatively and significantly. Differentiating by income and season leads to results broadly consistent with expectation: Effects are significant and strong at low income and at times when energy requirements and/or bills are high. In particular, the electricity price effect is strong in the 1st and 4th quarter, when bills may be high because of contract changes, payments of areas or (if applicable) heating requirements. The oil price effect is strong before the start of the heating period, when tanks need to be filled and prices are high. The gas price effect is strong when the price (fixed expenditure per unit consumed) is high, that is, in summer. Overall, consistent with our conceptual framework, effects are stronger when the energy poverty ratio $p*R/Y$ may be expected to be higher.

Quantitatively, a 1-standard-deviation change in the electricity price is associated with a change in the 11-point life satisfaction scale by 0.096 for the average person and 0.144 for a person from the lowest income group. For a 1-standard-deviation change in the gas price, the effects are 0.119 (average) and 0.153 (low income). For the oil price the effect is 0.157 at low income and insignificant for the average person. The effects thus correspond to 10-15 percent of one life-satisfaction category.

4 SWB and the structure of energy supply*

This analysis studies the relationship between the electricity mix and subjective well-being in a multi-country setting. It is based on the assumption that people have preferences over attributes of the electricity supply system (security and cost of supply, safety of electricity facilities, environmental impacts) and that those attributes correlate with different configurations of the system, that is, the electricity mix.

Conceptual and Empirical Background

We capture preferences over the attributes *A* by a utility function:

(1) $U = f(A)$.

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

(2) $A = g(S)$,

where *S* = nuclear, coal, oil, gas, solar & wind power, hydro power, biofuels & waste.

Table 4 illustrates the relationship between the supply structure and the associated attributes for the cases of environmental impacts (measured by SO_2 emissions per capita) and costs (measured by residential electricity prices). As expected, air pollution is positively correlated with the supply shares of coal and oil and negatively correlated with nuclear power and power from renewable sources. Electricity prices correlate positively with the shares of solar and wind power and negatively with the share of hydro power.

Table 4: Correlation of Electricity Mix with Air Pollution and Electricity Price

	SO_2 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
Biofuel share	-0.3493	0.1315

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

$U = f(g(S)) =: h(S)$,

which we want to estimate by using SWB as a proxy for *U*.

* The discussion in this section is based on the working paper by H. Welsch and P. Biermann (2014) „Electricity Supply Preferences in Europe: Evidence from Subjective Well-Being Data," produced as a deliverable for this project within work package 3. It has been published in the journal *Resource and Energy Economics* 38 (2014), 38-60. For a working paper version see appendix to this report.

Empirical Strategy and Data

We consider the following estimating equation:

$$LS_{ict} = \boldsymbol{\alpha}' \mathbf{micro_{ict}} + \boldsymbol{\beta}' \mathbf{macro_{ct}} + \sum_k \gamma_k share_{k,ct} + country_c + year_t + \varepsilon_{ict}$$

The structure of this equation is similar to that in section 3, except that we replace the energy prices by the supply shares of the various electricity generation technologies. The prices are not included in the basic specification, because we want to measure the total effect of the supply technologies' attributes, of which the cost (price) is one. Because the (percentage) shares add up to 100, one share has to be omitted from the regression. The coefficients of the included shares indicate the SWB effect of a marginal (i.e. 1-percentage point) replacement of the omitted share with the respective included share.
Empirically, a major difference from the analysis of energy prices (section 3) is that supply shares are available on an annual (not a quarterly) basis only. The temporal unit in this analysis, hence, is a year. Country and year fixed effects control for unobserved country and time heterogeneity.
Individual level data in this analysis again come from rounds 1 – 5 of the European Social Survey (ESS), 2002 – 2011, and refer to 139,517 individuals in 25 countries. The supply shares come from the IEA.

Main Results

Table 5 presents the estimation results, where the various columns systematically omit one of the technologies. *F*-tests confirm that the all columns are mutually consistent with each other. The main results are that a higher share of gas-based electricity and of solar & wind power relative to nuclear power are associated with significantly greater SWB, whereas a greater share of electricity from biofuels relative to nuclear power is associated with significantly lower SWB. In the spirit of the SWB approach to preference elicitation, those significant coefficients indicate a preference for gas-based power and solar & wind power over nuclear power and a preference of nuclear power over electricity from biofuels. In addition, the results indicate that the latter is not only less preferred than nuclear power but less preferred than all electricity supply technologies.

Further Results

In addition to the results in Table 5, additional regression analysis showed that, in spite of higher cost, solar & wind power is preferred over nuclear power not only "on average", but also by people from the lowest income quartile, and that the preference for solar & wind power is decreasing in the electricity price. Over time, the preference for solar & wind power has risen after the Fukushima nuclear accident. Moreover, though SWB was not significantly related to oil-based electricity over the entire period of observation (2001-2011), it was significantly negatively related to oil-based electricity after the political unrest in North Africa.

Table 5: Impacts of the structure of energy supply on SWB - summary table

	Nuclear Omitted	Coal Omitted	Oil Omitted	Gas Omitted	Solar&Wind Omitted	Hydro Omitted	Biofuels Omitted
Nuclear	Omitted	**-0.00412**	**-0.00773**	**-0.0082****	**-0.01121***	**-0.00216**	**0.0200****
		(0.0036)	(0.00578)	(0.00352)	(0.00672)	(0.00437)	(0.01019)
Coal	**0.00412**	Omitted	**-0.00362**	**-0.00411**	**-0.00709**	**0.00196**	**0.0241****
	(0.00360)		(0.00631)	(0.00328)	(0.00668)	(0.00440)	(0.01003)
Oil	**0.00773**	**0.00362**	Omitted	**-0.000494**	**-0.00348**	**0.00558**	**0.0278*****
	(0.00578)	(0.0063)		(0.00498)	(0.00714)	(0.00545)	(0.01065)
Gas	**0.0082****	**0.00411**	**0.000494**	Omitted	**-0.00298**	**0.00607**	**0.0282*****
	(0.00352)	(0.0033)	(0.00498)		(0.00720)	(0.00396)	(0.00875)
Solar&Wind	**0.01121***	**0.00709**	**0.00348**	**0.00298**	Omitted	**0.00905**	**0.0312****
	(0.00672)	(0.0067)	(0.00714)	(0.00720)		(0.00702)	(0.01425)
Hydro	**0.00216**	**-0.00196**	**-0.00558**	**-0.00607**	**-0.00905**	Omitted	**0.0222****
	(0.00437)	(0.0044)	(0.00545)	(0.00396)	(0.00702)		(0.01033)
Biofuels	**-0.0200****	**-0.024****	**-0.0278*****	**-0.0282*****	**-0.0312****	**-0.0222****	Omitted
	(0.01019)	(0.0100)	(0.01065)	(0.00875)	(0.01425)	(0.01033)	
R-squared	0.1950	0.1950	0.1950	0.1950	0.1950	0.1950	0.1950

Notes: Each column corresponds to a different regression. Each regression includes micro controls, macro controls, country & year FE (omitted from the table). Methods: least squares. (Estimates from ordered probit were robust). *p>0.1, **p<0.05, ***p<0.01.

5 Measurement of proximity to energy facilities: the case of nuclear power plants*

The creation of a geo-referenced nuclear power plant (NPP) database for Europe uses two types of information. One is the location of ESS respondents in terms of the NUTS regions where they live. This information is available at different levels of disaggregation (NUTS0, NUTS1, NUTS2, NUTS3), and the available level of disaggregation differs from country to country. The other type of information is the location of NPPs in terms of their geographic coordinates, which required the creation of a GIS NNP database to facilitate geospatial processing and computations. In addition, information is available on the distribution of the population within NUTS regions.

To assess the proximity of population centers to NPPs, a first step involves the spatial assignment of respondents to the center of their NUTS region using GIS analysis. Several definitions of the center are available. The analysis in this project is based on (i) the geographic center (centroid) at the respective level of disaggregation and (ii) the weighted population center. The idea of this work is to represent the distance of the NPP to the 'spatially representative individual', i.e. the individual located at the center. The distance will depend on the chosen definition of the center.

Determining the population centers

The default approach in determining the population center of a NUTS region is the geometric/geographic centre. The geometric center places a point in the geographic centre of the NUTS region implicitly assuming that the population of a NUTS region is equally distributed in that region.

The weighted population center uses the values of an attribute (variable) as weights to determine the most likely population centre. That is, instead of using the geographic locations (x,y coordinates) to determine the mean location of the population in an area, a weight such as the actual population count is used to determine its likely spatial location. We used a raster population dataset to create regular population grid points, each point representing a population value. These grid points are then categorized by NUTS regions to subsequently compute the weighted population centers within the NUTS regions. Figure 1 illustrates both the geometric centre and weighted population centers for Switzerland.

* The discussion in this section is based on the technical report: "GIS Methodology in Determining Population Centers and Distances to Nuclear Power Plants" (Tine Ningal & Finbarr Brereton) produced as a deliverable for this project within work package 1 and publicly available at http://www.uni-oldenburg.de/energy-for-well-being/.

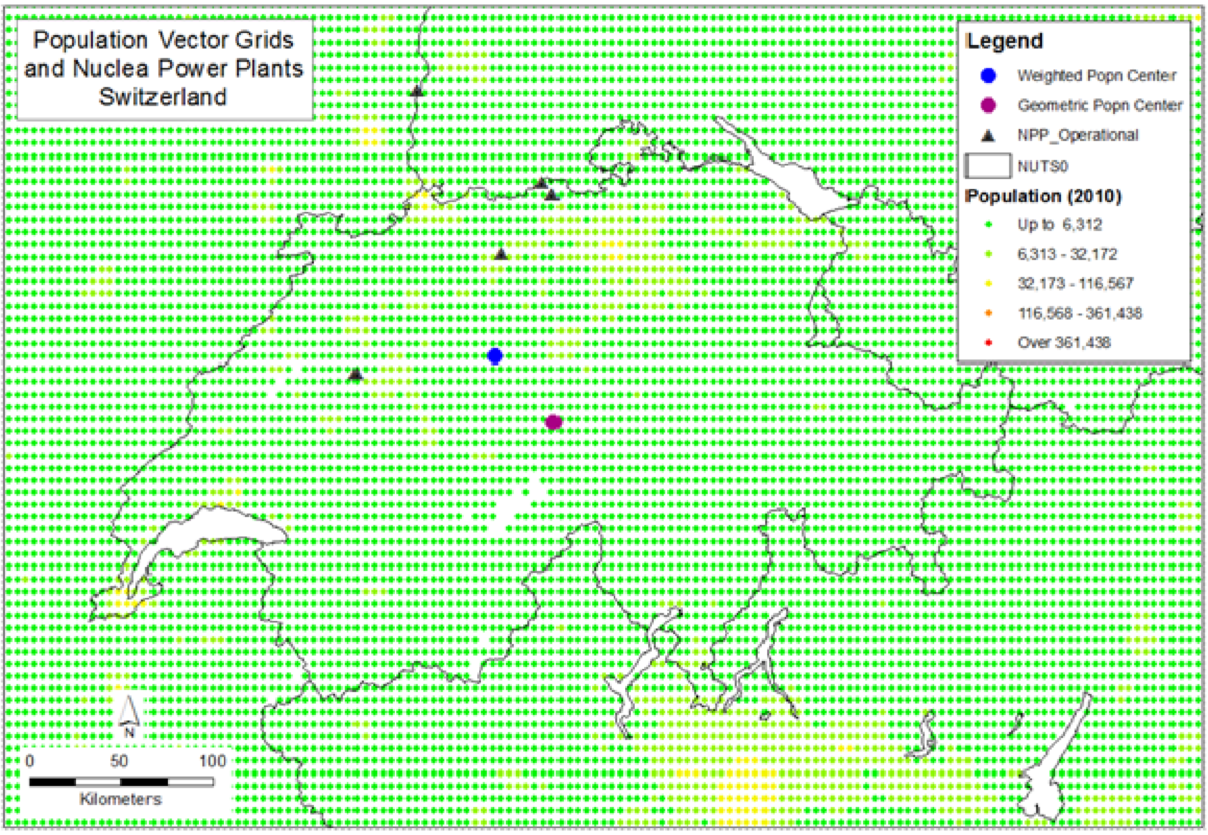

Figure 1: Vector Gridded World Population showing population distribution in Switzerland with geometric and weighted population centers as well as NPPs

The raster to vector grid conversion technique was used to derive the weighted population centers across Europe at different levels of spatial disaggregation (depending on the level at which the individual data are available at the ESS), from NUTS0 (country) to NUTS3 levels. Figure 2 illustrates the difference between the geometric and weighted population centers for the NUTS0 regions, while Table 6 shows the actual distances (in Km) between the two.

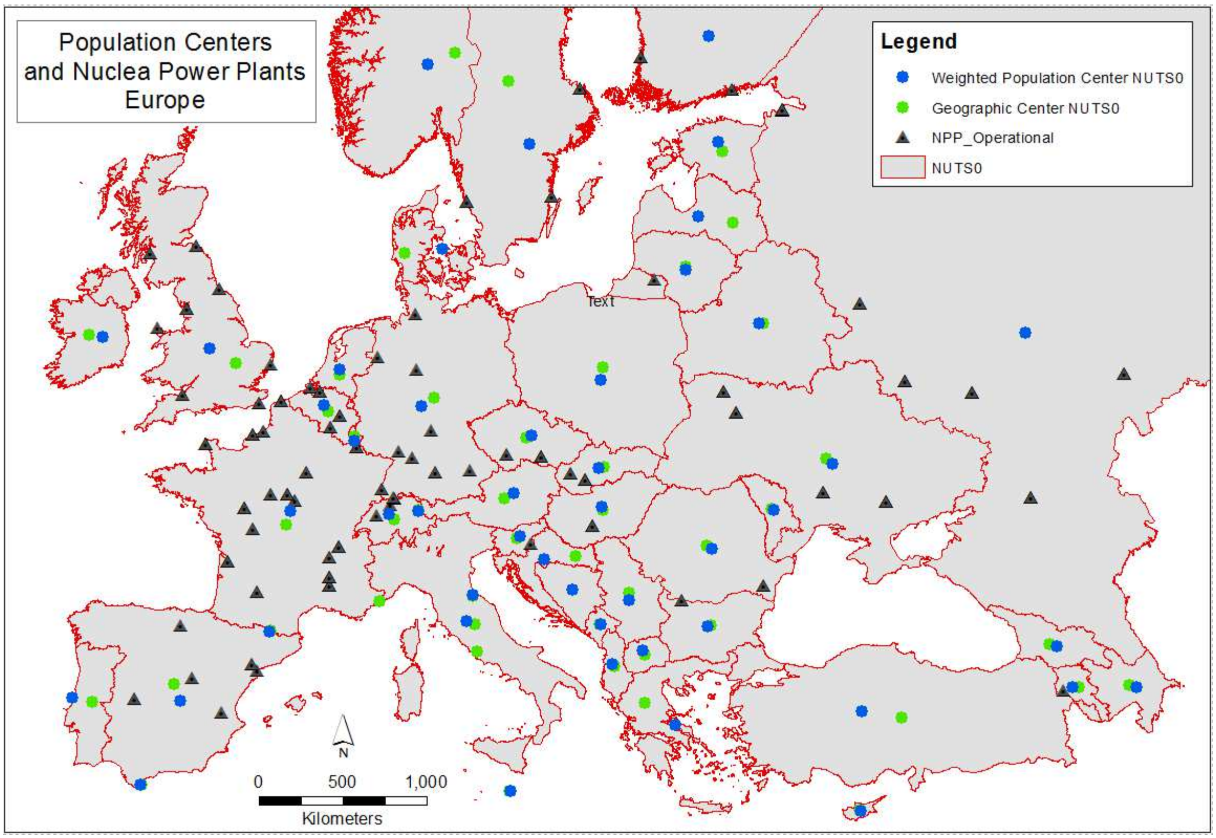

Figure 2: Geographic/geometric centroids (green) and population weighted centers (blue) for NUTS0.

Table 6: Distances between geometric and population weighted centers at NUTS0 (country) level

NUTS Code	NAME	Population in 2010	Distance between Geometric and Weighted Population Centres **(km)**
AL	Albania	3293417	19
AT	Österreich	7990654	62
BE	Belgique-België	10282738	43
BG	Bulgaria	7130081	18
BY	Belarus	9783533	26
CH	Schweiz/Suisse/Svizzera	7012097	48
CY	Kypros / Kibris	760682	10
CZ	Ceska Republika	10157525	34
DE	Deutschland	81138644	90
DK	Danmark	5070912	228
EE	Eesti	1200296	61
ES	España	36519524	103
FI	Suomi / Finland	4998692	693
FR	France	60327620	87
GR	Ellada	9886216	228
HU	Magyarorszag	9495212	20
IE	Ireland	4076898	82
IT	Italia	55184139	56
LT	Lietuva	3592180	22
LU	Luxembourg (Grand-Duché)	489533	22
LV	Latvija	2262272	214
NL	Nederland	16125699	37
NO	Norge	4274026	175
PL	Polska	38118288	76
PT	Portugal	9291428	120
RO	Romania	21690934	38
SE	Sverige	8457175	398
SI	Slovenija	2176370	20
SK	Slovenska Republika	5437742	35
TR	Turkiye	73170303	238
UA	Ukraina	45061659	47
UK	United Kingdom	58175209	182
RU	Russia	98863672	1,066

Notes: Population values for 2010.

Generating buffer distances from population points

After creating both geometric/geographic and weighted population centres, buffers were generated around each. Figures 3 and 4 show, for different buffer distances (25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450 and 500 kilometres), the variation in distances between the geometric and weighted population centers within the same NUTS regions (NUTS0 in this case). The econometric analysis is based on distances from weighted population centers, and use the distances from geometric centers as a robustness check.

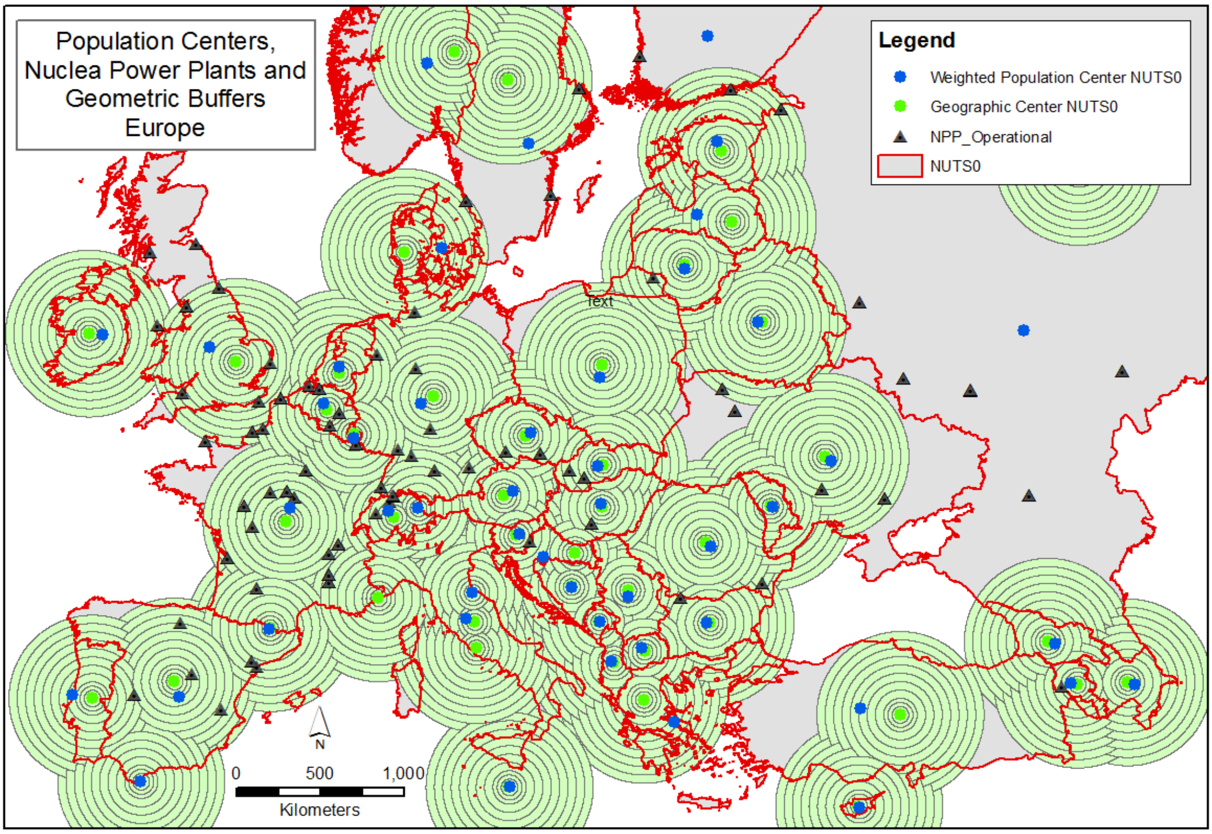

Figure 3. Multiple buffer distances from geometric/geographic population centers for NUTS0

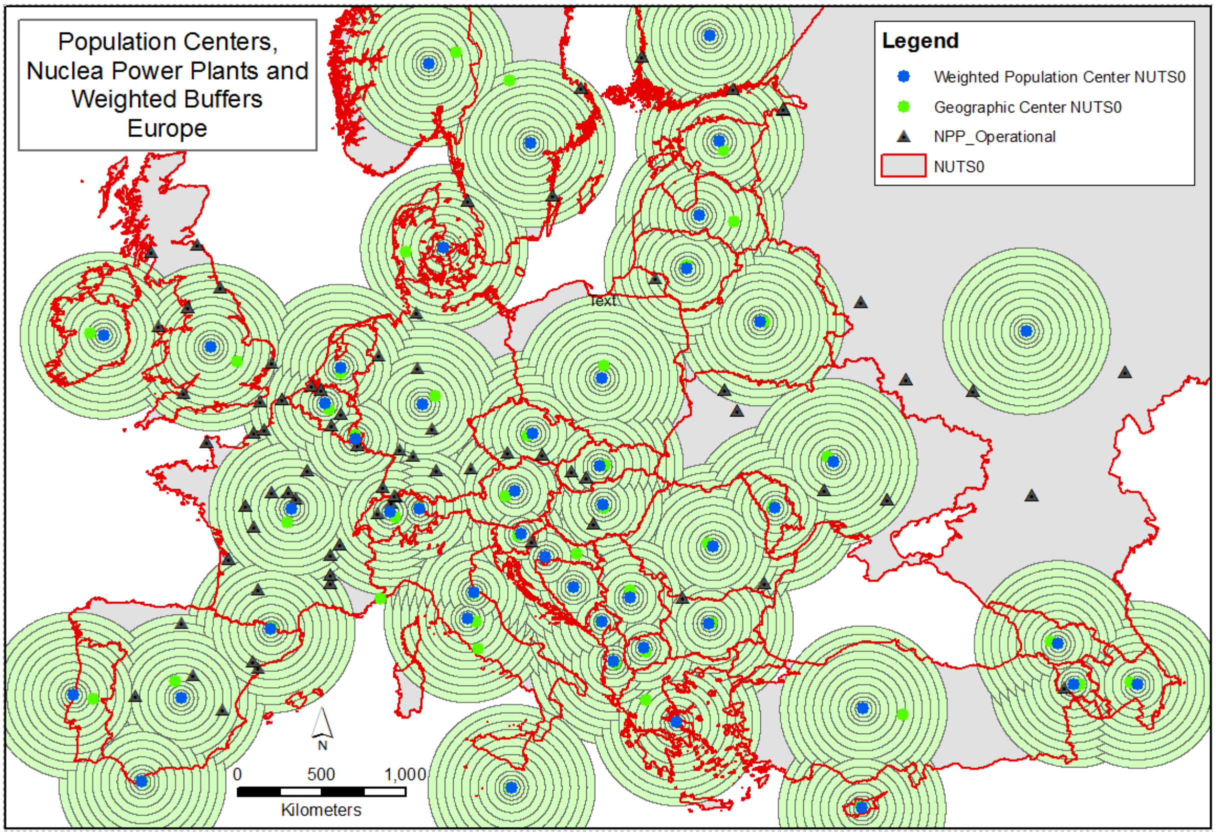

Figure 4: Multiple buffer distances from weighted population centers for NUTS0

Populated centers and distance analysis for Switzerland

In the case of Switzerland, the geometric population center for the country is located generally in the center of the country, 100 kilometres south of Zurich whereas the weighted population center is approximately 56 kilometres east of Bern and 50 kilometres north-north-west of the geometric center (Figures 5-7).

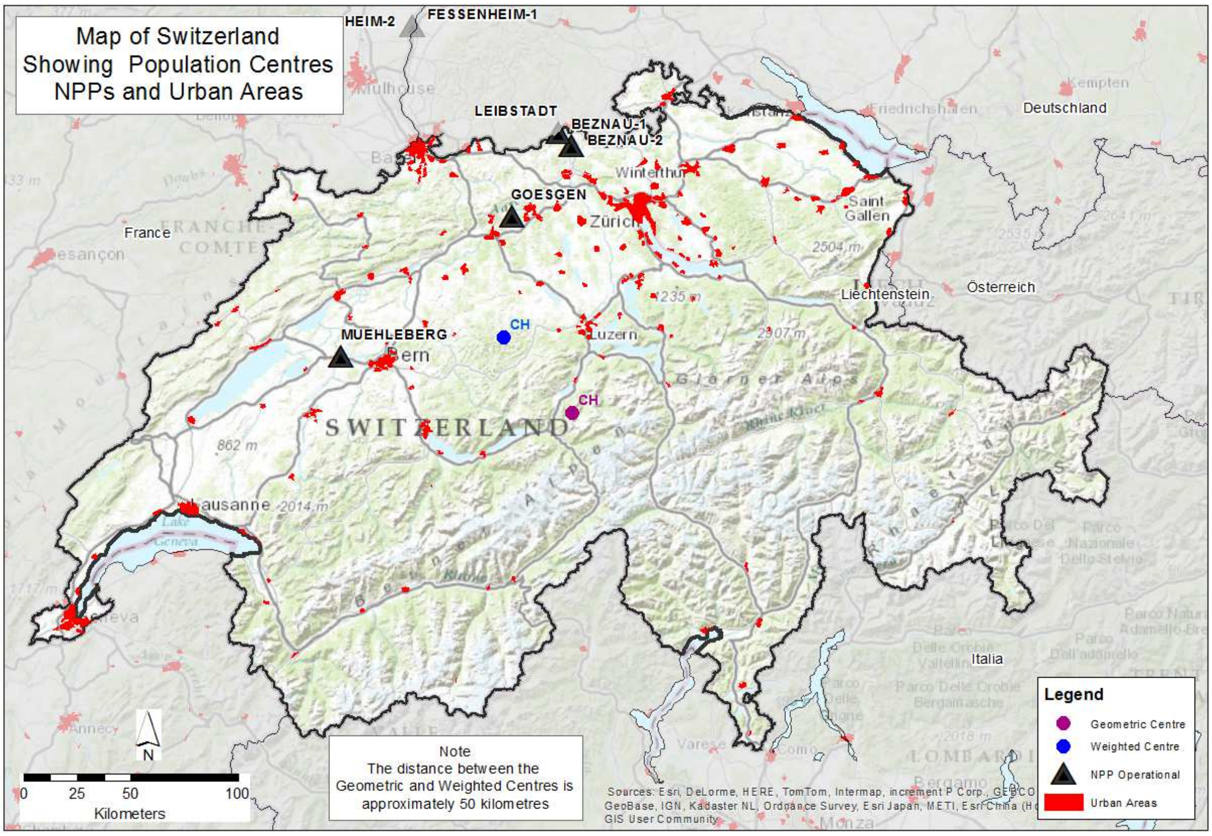

Figure 5: Geometric and weighted population centers with NPPS and urban areas at NUTS0 level for Switzerland.

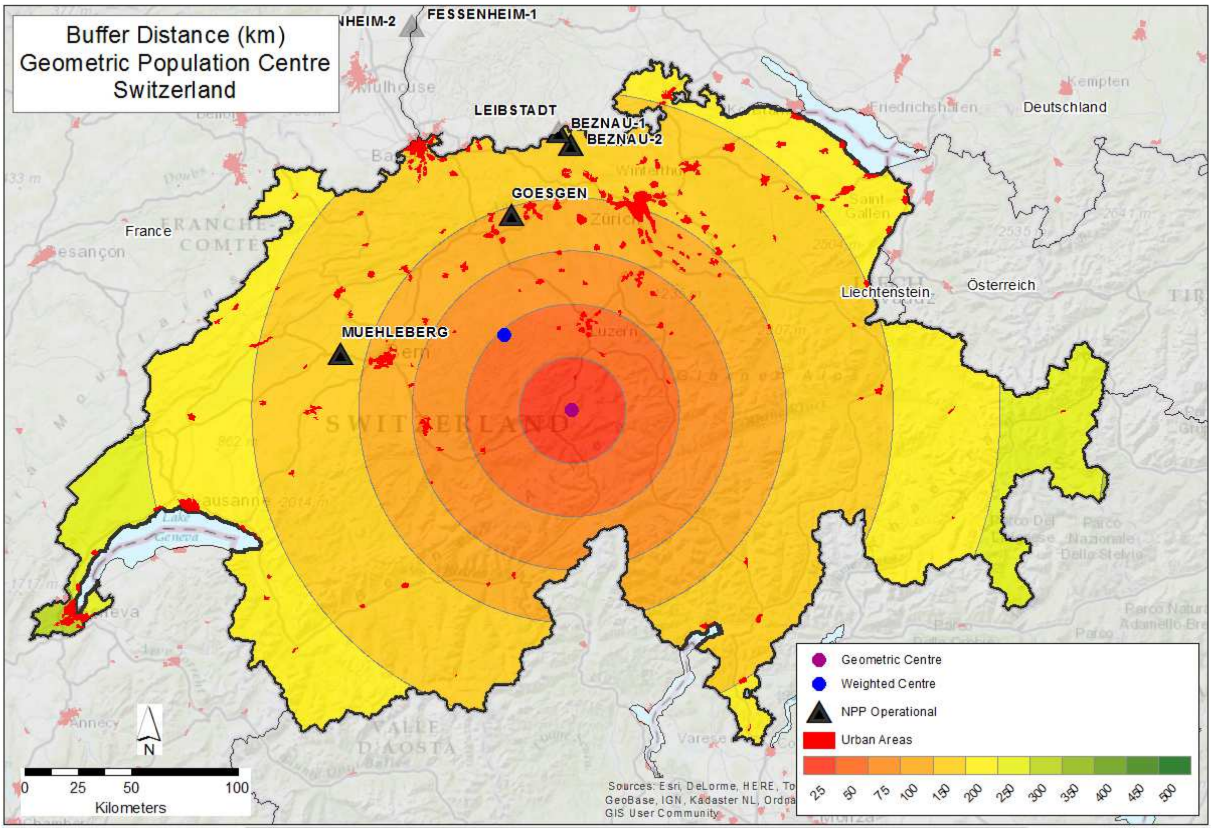

Figure 6: Multiple buffer distances from geometric population center at NUTS0 level for Switzerland.

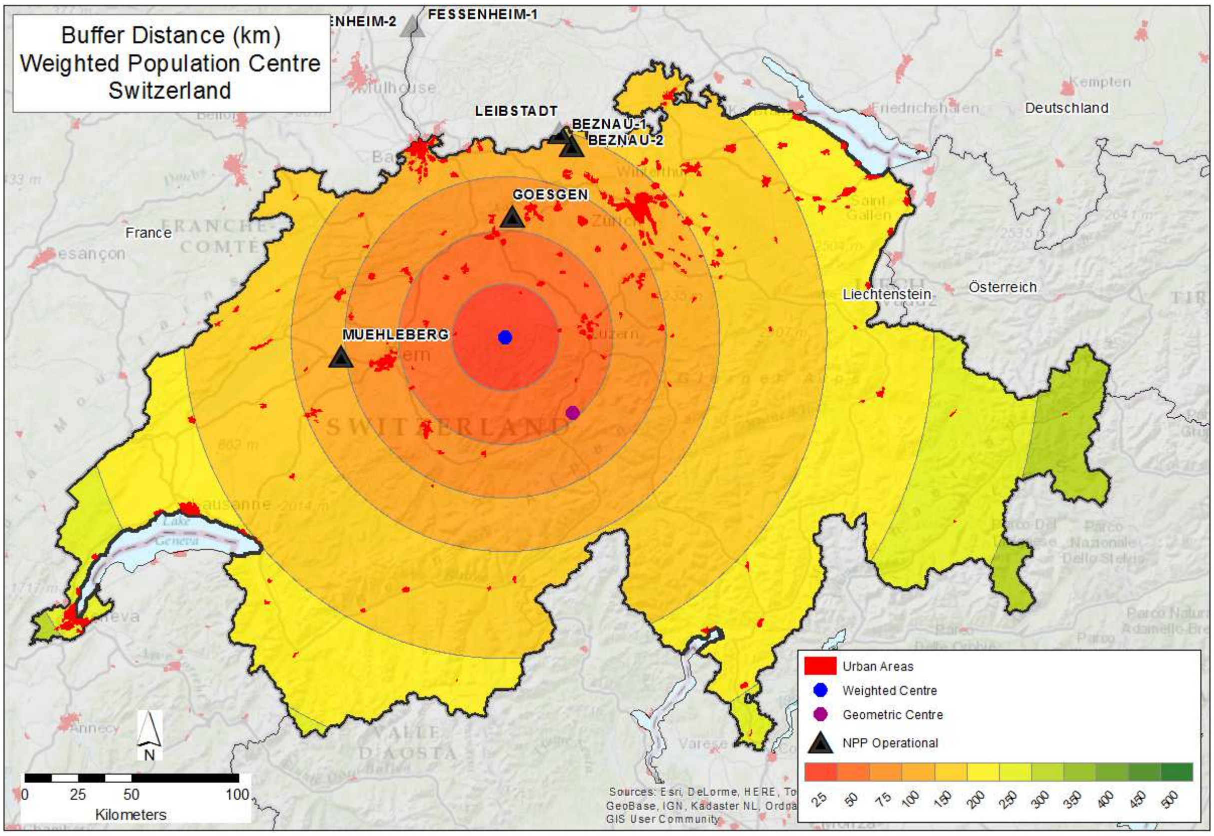

Figure 7: Multiple buffer distances from population weighted center at NUTS0 level for Switzerland

In contrast to the NUTS0 level where a single population center represents the country, at NUTS2 aggregation level, there are seven regions with their own geometric and population weighted centers (Figures 8-10).

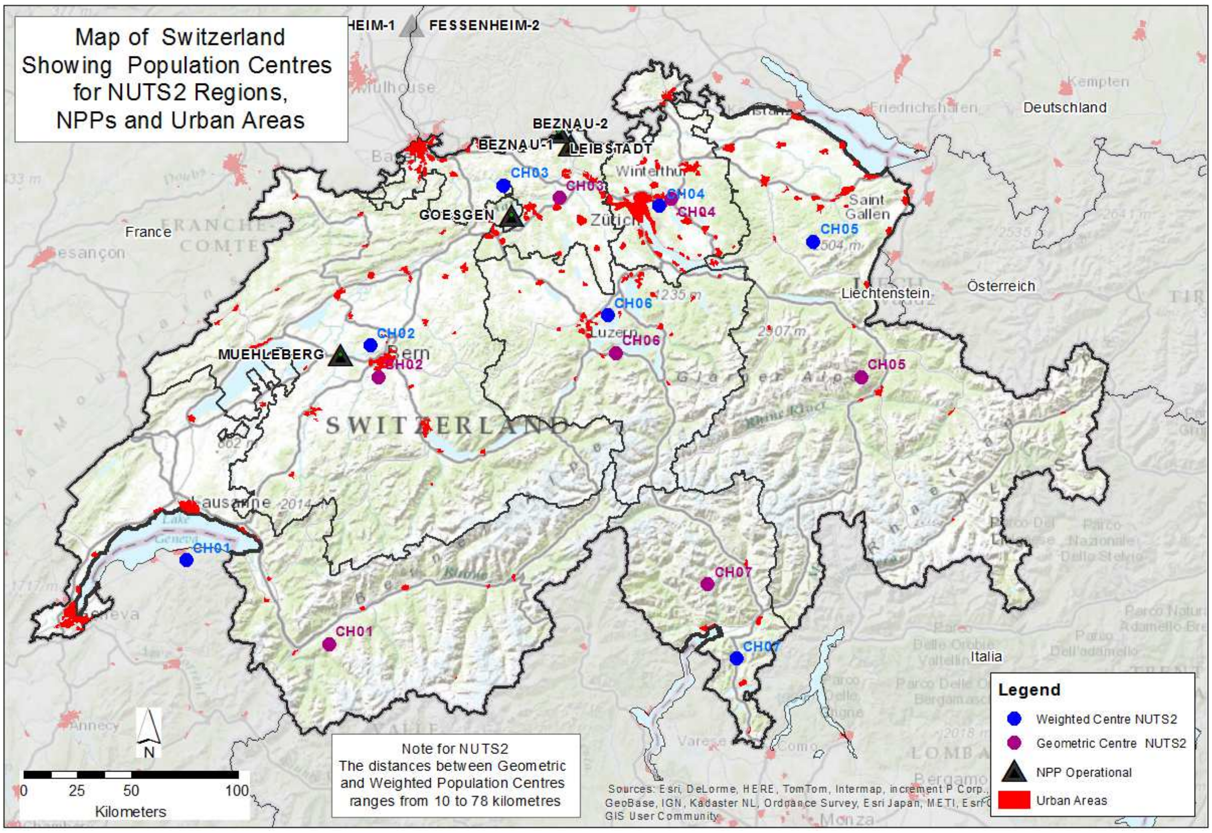

Figure 8: Geometric and weighted population centers with NPPS and urban areas at NUTS2 level for Switzerland.

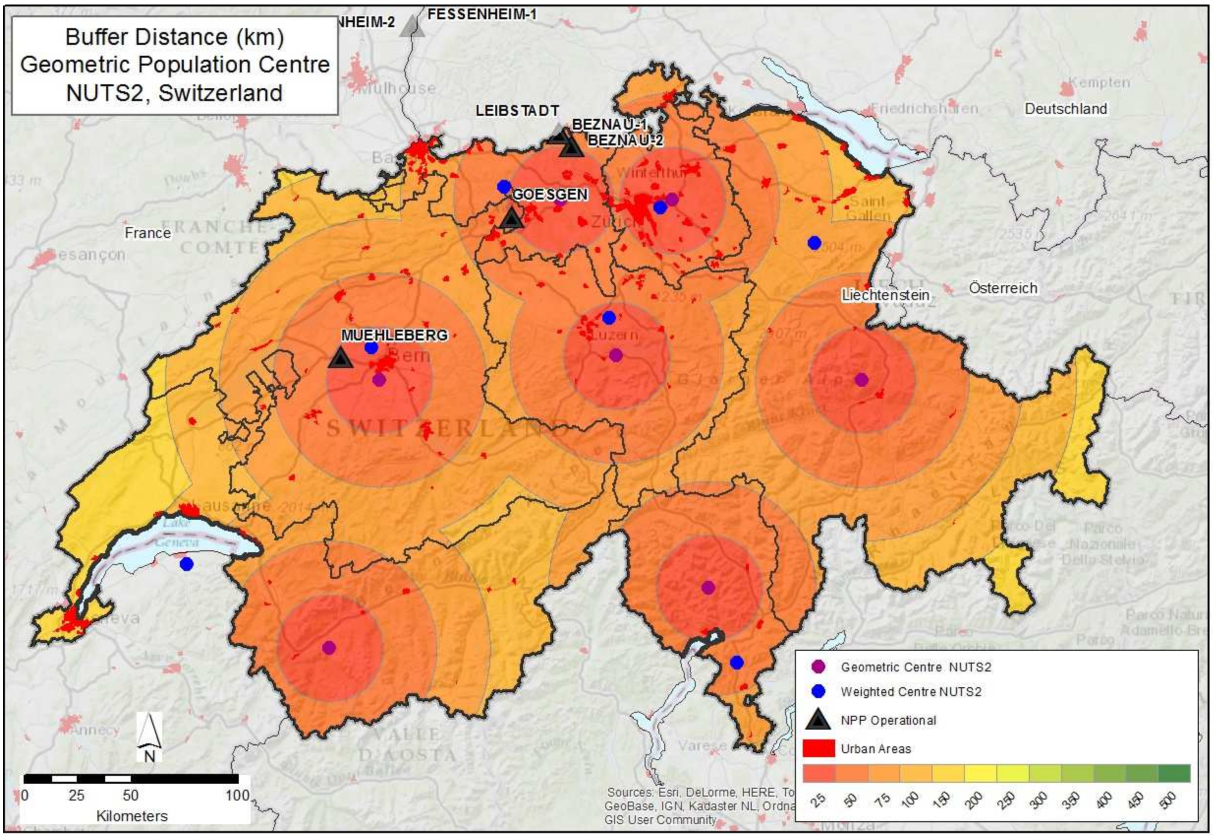

Figure 9: Multiple buffer distances from geometric population centers at NUTS2 level for Switzerland.

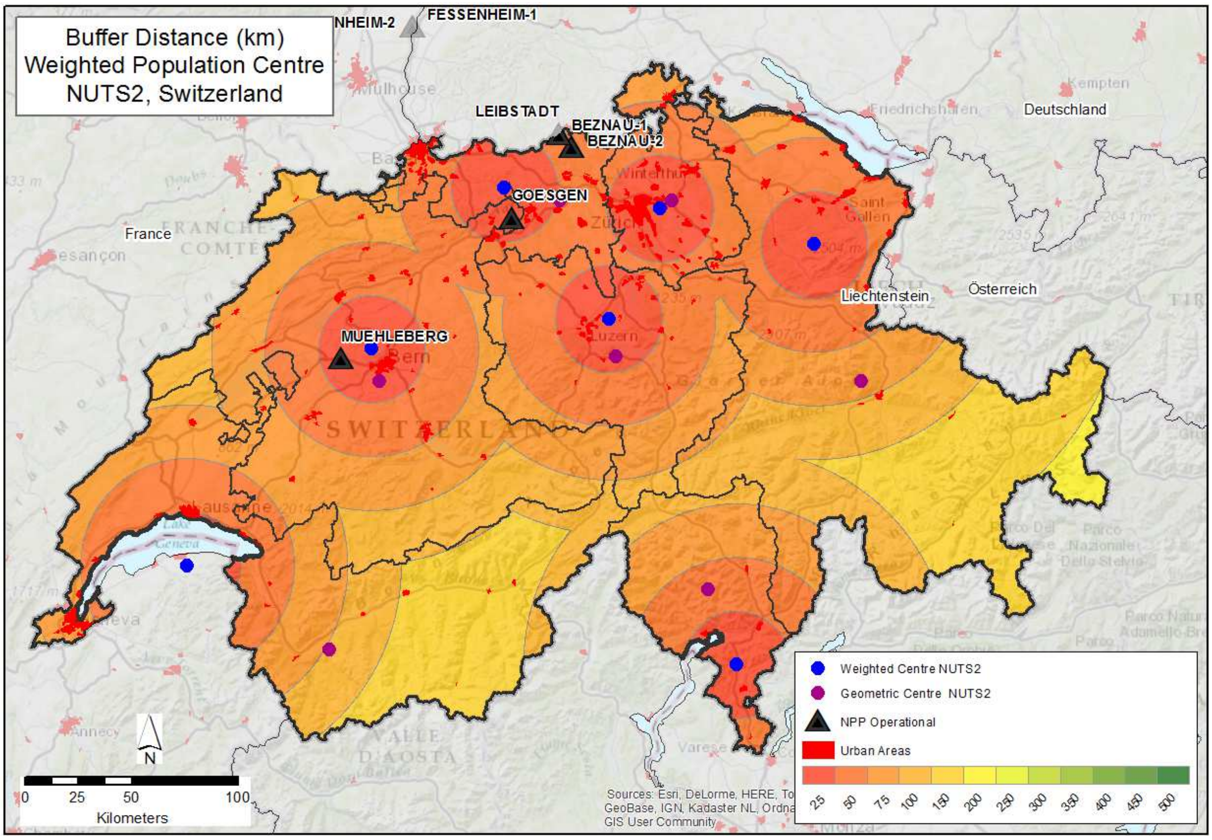

Figure 10: Multiple buffer distances from population weighted centers at NUTS2 level for Switzerland .

Tables 7 and 8 show the differences between the distances calculated using the two methods at NUTS0 and NUTS2 level, respectively.[3] The pattern emerging is that there can be marked differences in distances between population centres and NPPs, depending on the method used in GIS to determine the population centers and the NUTS level. Choosing the appropriate GIS function is crucial to achieving a truly representative result that mimics reality.

Table 7: Distances to NPPs from geometric and weighted populated centres for NUTS0

	Distances to NPPs (in km)			
	Beznau	Leibstadt	Goesgen	Muehleberg
From Population Weighted Center	95	99	57	77
From Geometric Centre	125	132	97	111
Difference in Distances (Geometric – Population Weighted)	30	33	40	34

Table 8: Distances to NPPs from both geometric and populated weighted centres for NUTS2

	Distance Between Geometric & Weighted Population Centers (km)	Distances to NPPs (in km)								Difference in Distances (Geometric - Population Weighted)			
		From Geometric Centre				From Weighted Population Centre							
		B	L	G	M	B	L	G	M	B	L	G	M
CH01 - Région lémanique	78	260	258	217	133	265	262	220	120	-5	-4	-3	13
CH02 - Espace Mittelland	19	140	138	96	23	132	129	88	15	8	9	8	8
CH03 - Nordwestschweiz	28	30	20	25	128	35	35	17	110	-5	-15	8	18
CH04 – Zürich	10	60	52	78	174	57	50	69	165	3	2	9	9
CH05 - Ostschweiz	67	182	175	182	245	129	122	142	227	53	53	40	18
CH06 - Zentralschweiz	20	106	98	80	130	88	81	64	126	18	17	16	4
CH07 – Ticino	38	220	215	195	203	259	251	231	231	-39	-36	-36	-28

Notes: B=Beznau, L=Leibstadt, G=Goesgen, M=Muehleberg

[3] It should be noted that the example of Switzerland was chosen solely to illustrate the methods applied in the preparation of the European NPP data base on the basis of ESS. Our well-being analysis of the proximity to NPPs in Switzerland relies on data from the Swiss Statistical Office which include much more detailed information on the proximity to NPPs (see subsection 6.2).

6 SWB and proximity to energy facilities

This analysis studies the relationship between SWB and proximity to nuclear power plants (NPP). This relationship is assumed to involve a trade-off between economic factors related to the proximity to NPPs (e.g. employment opportunities) and concerns about nuclear safety.
We investigated the relationship between SWB and NPPs both from a European wide perspective, and with respect to Switzerland as a case study. In the European wide analysis we used data from the European Social Survey (rounds 1-5) and GIS matching to distance from NPP from work package1 (see section 5). In the analysis for Switzerland we used data from the Swiss "Statistics on Income and Living Conditions" (SILC) 2009-2011, where survey respondents are characterized by their distance to the nearest NPP in steps of 5 km.

6. 1. SWB and proximity to energy facilities in Europe

This analysis is preliminary and here we present our latest results. More work needs to be conducted to control for unobservable omitted variables that simultaneously correlate with distances to NPP and life satisfaction at the European level, such as urban areas and their amenities, which ultimately may bias our estimates. GIS matching between selected micro variables of the European Social Survey and the geographical coordinates of nuclear power stations in operation leaves us with a usable sample of 107,714 respondents living in 21 European countries and interviewed over the period 2003-2012. The distance to the nearest NPP (from package1, see section 5) was divided into 5 mutually exclusive dummy variables for econometric analysis. The categories are: 0-20 km; 20-50 km; 50-100 km; 100-150 km and finally over 150 km. This variable has the potential advantage of capturing nonlinearities in the relationship between SWB and proximity to the nearest NNP. Table 9 provides frequencies for each distance dummy.

Table 9: Distance to the nearest nuclear power station (dummies).

Distance to the nearest nuclear power station (mutually exclusive dummies)	Freq.	Percent	Cum.
0-20Km	2,838	2.63	2.63
20-50Km	5,184	4.81	7.45
50-100Km	13,249	12.30	19.75
100-150Km	19,109	17.74	37.49
Over 150Km	67,334	62.51	100.00
Total	107,714	100.00	

Table 10 provides an indication of the heterogeneity of the dataset by listing the 21 countries available and by showing the summary statistics of the country dummies (the header 'Mean' of the indicator variable proportion of respondents from each country and the variable takes only two values: 0 or 1).

Table 10: Countries in the sample (country dummies)

Country name	Mean	St. Dev	Min	Max
Belgium	.0613476	.239968	0	1
Switzerland	.0610598	.2394412	0	1
Czech Rep	.0359285	.1861127	0	1
Germany	.0942774	.2922157	0	1
Denmark	.0330412	.178745	0	1
Spain	.0499842	.2179134	0	1
Finland	.0581726	.2340706	0	1
France	.0521845	.2223999	0	1
UK	.0740944	.2619256	0	1
Greece	.0568728	.2316005	0	1
Croatia	.01789	.1325522	0	1
Hungary	.0311009	.1735912	0	1
Ireland	.048898	.2156558	0	1
Italy	.0151512	.1221549	0	1
Luxemburg	.0167109	.1281867	0	1
Netherlands	.0655532	.2475006	0	1
Norway	.0673636	.2506518	0	1
Poland	.059723	.236974	0	1
Portugal	.0372004	.1892533	0	1
Slovakia	.0264497	.1604691	0	1
Ukraine	.0029894	.0545939	0	1

Our preliminary econometric results can be found in Table 11. Standard errors are clustered at regional level to account for potential correlation within areas. The first column of Table 11 reports the estimated coefficients of a life satisfaction regression on distance to NPP dummies only. Each regression controls for individual characteristics and country and year fixed effects. Each coefficient has to be estimated with respect to "over 150 km" dummy. Perhaps surprisingly, the sign of each coefficient is positive, indicating a positive association between proximity and life satisfaction. These results may be affected by omitted variables that correlate with distances and habituation effects. Further work is needed to disentangle these aspects.

Table 11: SWB regression on distance to the NPP (showing distance dummies only)

	(1)
Ref cat: "over 150Km"	Proximity to NPP
0-20Km	0.174*
	(0.094)
20-50Km	0.173***
	(0.048)
50-100Km	0.129**
	(0.060)
100-150Km	0.095**
	(0.046)
Individual characteristics	Yes
Year fixed effects	Yes
Contry fixed effects	Yes
Observations	107,745
R-squared	0.203

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. Regressions include micro controls (sex, age, marital status, household size, employment status, education and household income), and country and quarter fixed effects

6. 2. SWB and proximity to energy facilities: the case of Switzerland

This analysis is based on a version of the SILC database for 2009-2011 that includes information on people's distance to the nearest domestic NPP in steps of 5 km (<5, …, >85) and which was created and supplied on purpose by the Swiss Statistical Office. As a downside of this useful feature, person identifiers were randomized in this data base for purposes of data protection (anonymity). Therefore, though SILC is in principle a panel, we were unable to use person fixed effects in our analysis. Another issue is that foreign NPPs were not considered, even though some (e.g. NPP Fessenheim in France) are close to the Swiss border.

Empirical background

As it was shown in Figure 5, especially when seen by comparison with Figure 11, NPPs in Switzerland are concentrated in the German-speaking part of the country. With regard to concerns about nuclear safety, it can thus be assumed that individuals in the Italian-speaking region may feel protected by the Alps from any radioactivity originating in NPPs. Similarly, people in the French-speaking region may feel protected by the prevailing wind direction (westerly wind at most of the time). This suggests that from a nuclear safety perspective "distance" (or proximity) is not a homogenous factor in the relationship between SWB and the location of NPPs.
With respect to the economic dimension of the SWB-NPP relationship, the data suggest that unemployment rates vary with distance to NPP. As illustrated in Figure 12, in the case of NPP Mühleberg the unemployment rate at more than 85 km distance is almost twice as high as within a radius of 15 km.
It follows from these considerations that in identifying a relationship between SWB and proximity to NPP, language regions and unemployment rates should be accounted for. We note that information on survey respondents' language region is available only for 2010 and 2011.

Figure 11: Language regions in Switzerland

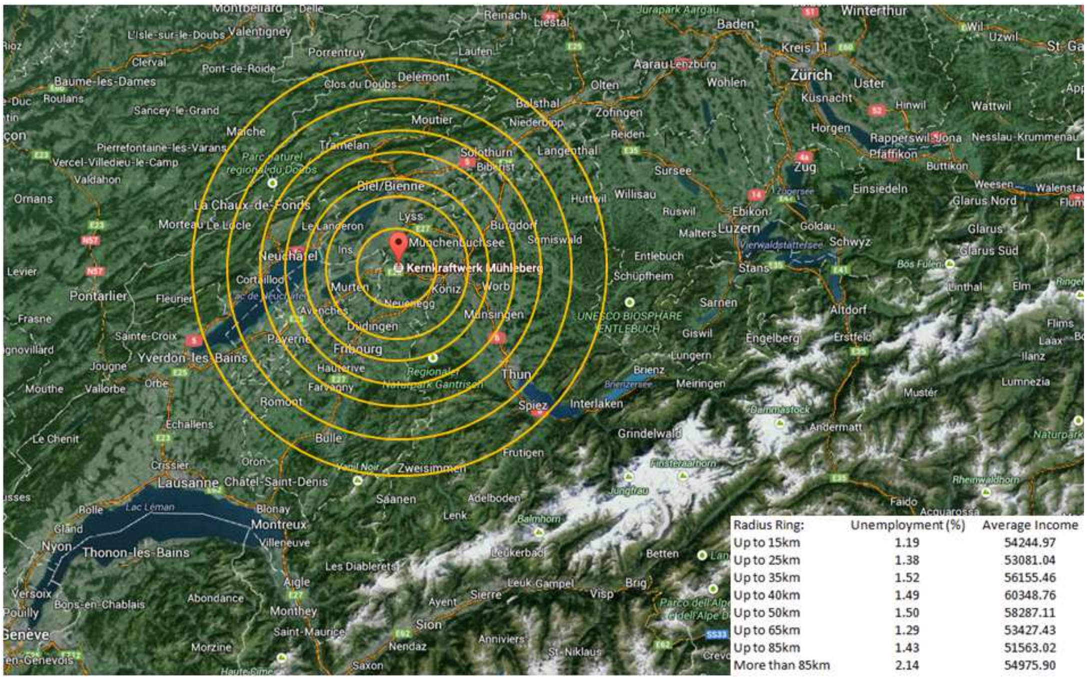

Figure 12: Economic significance of distance from NPP

Theoretical model and research strategy

As the conceptual basis for our empirical analysis, we propose the following theoretical framework. This framework encompasses two specifications which alternatively treat proximity to NPPs as an endogenous variable (choice variable) or an exogenous variable.

We assume that utility of individual *i* at location *s* depends on location-specific benefits B_s (such as employment opportunities), location-specific perceived nuclear risk R_s and individual-specific factors X_i. We specify location as proximity to NPP and assume that both benefits and perceived nuclear risk are increasing functions of proximity: $B_s = B(prox)$ with $B' > 0$ and $R_s = R(prox)$ with $R' > 0$. We obtain the following model:

$$u_{is} = U(B(prox), R(prox), X_i)\,, \qquad (1)$$

where the derivatives of *U*(.) with respect to the first and second arguments are positive and negative, respectively.

If we assume proximity to be a choice variable, the 'effect of proximity on utility' is not a meaningful issue. Under the locational-choice assumption, the issue is whether individuals make utility-maximizing location choices. Under the appropriate concavity conditions, a utility maximum, or spatial equilibrium, is characterized by the following first-order condition:

$$\frac{du_{is}}{dprox} = \frac{\partial U}{\partial B} B'(prox) + \frac{\partial U}{\partial R} R'(prox) = 0. \qquad (1a)$$

Condition (1a) tells us that in spatial equilibrium individuals are indifferent between alternative locations because the associated benefits and perceived risks just balance each other.

Alternatively, one can treat proximity as an exogenous variable in the sense that location choice is disregarded. Then, location-specific benefits are fixed, and we have:

$$u_{is} = U(B_s, R(prox), X_i)\,. \qquad (2)$$

In this framework, the 'effect of proximity on utility via perceived nuclear risk' is a meaningful concept. It is the derivative of utility with respect to proximity at given proximity-specific benefits:

$$\frac{\partial u_{is}}{\partial prox} = \frac{\partial U}{\partial R} R'(prox) . \qquad (2a)$$

Empirically, we use life satisfaction (*LS*) as a proxy for *u*, location-specific unemployment rates (*unemp*) as an (inverse) proxy for *B* and distance to the nearest NPP (*dist*) as an (inverse) indicator of proximity. The analogs to models (1) and (2) are then stated as

$$LS_{is} = \beta \cdot dist_i + \gamma \cdot X_i + \varepsilon_i . \qquad (1')$$

$$LS_{is} = \alpha \cdot unemp_s + \beta \cdot dist_i + \gamma \cdot X_i + \varepsilon_i , \qquad (2')$$

In model (1') the parameter on *dist* indicates whether the spatial equilibrium condition (1a) is satisfied under the maintained (untestable) hypothesis that proximity is endogenous. Spatial equilibrium requires that this coefficient is not significantly different from zero. A significant coefficient (of either sign) indicates less than perfect mobility. In model (2') the parameter on *dist* measures the 'effect of proximity' under the maintained (untestable) hypothesis that proximity is exogenous, see equ. (2a).

Results

As a preliminary step, we ran a regression of 11-point life satisfaction (LS) on the socio-demographic characteristics usually included in SWB regressions. The results, reported in Table 12, are that life satisfaction is U-shaped in age, greater for females than for males, increasing in income, lowest for unemployed persons and increasing in health. The results are similar to those for other industrialized countries (see Dolan et al. 2008). We conclude from this that we may have confidence in the adequacy of the data base for SWB analyses.
In addition, we note that the relationship between life satisfaction and those factors is very similar for German-speaking persons and for the Swiss population overall. This suggests that regional identifiers, to be included in the following analysis, reflect geographic rather than psychological factors.

Table 12: Life satisfaction in Switzerland - socio-demographics only

	(1)	(2)		(1)	(2)		(1)	(2)
	All	DE-spk		All	DE-spk		All	DE-spk
Age	-0.0469***	-0.0483***	Self	0.151**	0.216***	Other	-1.035***	-0.727
	(0.00750)	(0.00818)		(0.0652)	(0.0726)		(0.307)	(0.446)
Age^2	0.000598***	0.000617***	Self prt	0.0578	0.0452	Married	0.244***	0.228***
	(0.0000761)	(0.0000835)		(0.111)	(0.120)		(0.0546)	(0.0620)
Female	0.125***	0.146***	Un-emp	-0.773***	-0.914***	Sepa-rate	-0.773***	-0.898***
	(0.0383)	(0.0413)		(0.173)	(0.227)		(0.161)	(0.217)
HH size	0.0271	0.0396**	Schoo l	0.00828	0.0110	Widow	-0.0268	0.187**
	(0.0176)	(0.0177)		(0.0874)	(0.100)		(0.0884)	(0.0928)
Income	0.296***	0.249***	Re-tired	0.160**	0.0839	Divorce	-0.109	-0.0511
	(0.0329)	(0.0378)		(0.0729)	(0.0815)		(0.0761)	(0.0830)
Sec edu	0.112*	0.0495	Sick	-0.0970	-0.0359	Health	0.637***	0.647***
	(0.0609)	(0.0663)		(0.268)	(0.402)		(0.0264)	(0.0299)
Tert edu	0.0527	-0.00303	Milit	-0.0193	-0.195	Const	6.513***	7.134***
	(0.0654)	(0.0727)		(0.353)	(0.393)		(0.392)	(0.445)
Empl part	0.0390	-0.00182	House	0.142**	0.0906	Obs	12264	9054
	(0.0544)	(0.0552)		(0.0659)	(0.0725)	R^2	0.170	0.172

Notes: Methods: least squares. (Estimates from ordered probit were robust). *p>0.1, **p<0.05, ***p<0.01.

As a next step, we considered the relationship between SWB and the distance to the nearest NPP. Preliminary analysis showed that 3 sets of 5-km-distance rings differ significantly from each other while not presenting significant within-differences: <40 km, 40-85 km and >85 km. We based the subsequent analysis on these categories, referring to them as Ring 1, Ring 2 and Ring 3. They represent about 45, 40 and 15 percent, respectively, of the sample.

Table 13 reports the results for equation (1') from the preceding subsection, which omits characteristics related to location (distance from NPPs). LS is significantly lower in Ring 3 than in Ring 1 and Ring 2 while there is no significant difference between the latter two. These results apply to all three years, 2009-2011. The indifference between Rings 1 and 2 suggests that the hypothesis of locational equilibrium cannot be rejected for these categories. With respect to Ring 3, by contrast, there appear to be barriers to mobility which prevent people from moving from Ring 3 to Rings 1 or 2.

Given our discussion of location-specific SWB factors other than perceived nuclear risk, we next introduced *distance specific unemployment* and *language regions* into or regressions. These regressions correspond to equation (2') from the preceding subsection and are meant to measure the effect of distance on LS that are not accounted for by economic or socio-linguistic factors. Table 14 reports the results. It is seen that LS is significantly greater in Ring 2 than in both Ring 1 and Ring 3. For the year 2011 and for German speaking Switzerland in 2010, LS in Ring 3 is greater in than in Ring 1, though not significantly so. In comparison with Table 13, both Ring 2 and Ring 3 have 'improved' their position relative to Ring 1.

Table 13: SWB and distance to NPP

	2009	2010	2011
Distance < 40km (Ring1)	Omitted	Omitted	Omitted
Distance 40-85km (Ring2)	0.0240	0.0258	0.00487
	(0.0328)	(0.0334)	(0.0340)
Distance >85km (Ring3)	-0.0889**	-0.0768*	-0.0955**
	(0.0412)	(0.0439)	(0.0473)
Socio Demographics	Included	Included	Included
Observations	12480	12440	12264
R-squared	0.166	0.188	0.171

Notes: Each column corresponds to a different regression. Each regression includes micro controls (omitted from the table). Methods: least squares (Estimates from ordered probit were robust). *p>0.1, **p<0.05, ***p<0.01.

Table 14: Impact of distance to NPP on SWB

	All_2010	DE_2010	All_2011	DE_2011
Distance <40km (Ring1)	Omitted	Omitted	Omitted	Omitted
Distance 40-85km (Ring2)	0.0703**	0.0715*	0.0695**	0.0934**
	(0.0357)	(0.0387)	(0.0344)	(0.0373)
Distance >85km (Ring3)	-0.0284	0.0960	0.0573	0.217
	(0.0518)	(0.0617)	(0.134)	(0.143)
Unemployment rate	-0.0298	-0.0117	-0.105	-0.161
	(0.0735)	(0.0815)	(0.173)	(0.178)
German language region	Omitted		Omitted	
Italian language region	-0.0464		-0.0468	
	(0.101)		(0.114)	
French language region	-0.188***		-0.243***	
	(0.0397)		(0.0413)	
Socio-Demographics	Included	Included	Included	Included
Observations	12440	9128	12264	9054
R-squared	0.190	0.199	0.174	0.173

Notes: Each column corresponds to a different regression. Each regression includes micro controls (omitted from the table). Methods: least squares (Estimates from ordered probit were robust). *p>0.1, **p<0.05, ***p<0.01.

Discussion and conclusions

The results for Rings 2 and 3 in Table 14 are consistent with the idea that people more remote from NPP enjoy a feeling of greater nuclear safety: Controlling for possible benefits from proximity to NPP, people in Ring 2 are significantly more satisfied than in Ring 1, as are people in Ring 3 (except for overall Switzerland 2010), though not significantly so. The idea that this is related to perceived nuclear risk is supported by the findings that the coefficient on ‘Ring 3’ is greater (a) in German-speaking Switzerland than in the country overall and (b) in 2011 than in 2010. In addition, the coefficient on ‘Ring 2’ in German-speaking Switzerland is also greater in 2011 than in 2010.

Finding (a) is consistent with the idea that concern for nuclear safety is more salient in the German-speaking area, whereas people in the Italian-speaking area may feel protected by the Alps and people in the French-speaking area may feel protected by the prevailing wind direction. Finding (b) is consistent with the idea that the SWB-NPP relationship in 2011 may reflect the Fukushima nuclear accident. The latter is an issue that we will address in more detail in the next section.

Before turning to that we observe that the geographic features of Switzerland (Alps and wind direction) represent an important source of identification for an effect of NPP on SWB. This could have been explored more thoroughly if we had more detailed information on the location of individuals other than distance to NPP and language region. Using the latter variable as a crude indicator of geography beyond distance nevertheless yields results that are indicative of an NPP-SWB relationship.

Our results tentatively suggest that this relationship involves a trade-off between socio-economic factors and safety concerns. The intermediate distance category may be viewed as offering an optimal balance between prosperity and socio-cultural amenities on the one hand and perceived nuclear safety on the other.

From a spatial economics perspective, the results reported in Table 13 suggest the existence of barriers to moving from Ring 3 to Rings 1 and 2.

7. SWB and the Fukushima accident

The purpose of this analysis is to study whether SWB in Europe in general and in Switzerland in particular was affected by the nuclear accident at Fukushima on March 11, 2011. More specifically, we also study whether a ‘Fukushima effect’ (if any) was mediated by the proximity to nuclear power plants (NPP) in Europe and in Switzerland.
As in the analysis reported in the preceding section, the European wide analysis used data from the European Social Survey (rounds 1-5) and GIS matching to distance from NPP from work package 1. In the analysis for Switzerland we used data from the Swiss “Statistics on Income and Living Conditions” (SILC) 2009-2011, where survey respondents are characterized by their distance to te nearest NPP in steps of 5 km.

7. 1. The Fukushima accident and SWB in Europe*

This work builds on the estimation in work package 5 and analyzes whether there was a ‘Fukushima effect’ that varied with distance to NPPs. The hypothesis is that the Fukushima accident acted like an information shock making the risk of nuclear power more salient to those in close proximity to NPPs. Proximity to NPPs is defined by using the distance variables calculated in work package 1.
However, in a broader sense, at the national level the perceived distance may depend on the share of nuclear energy in a particular country. While regression analysis involving the distance variables from work package 1 is in a preliminary state, we have analyzed the relationship between European citizens’ SWB and the share of nuclear power before and after the Fukushima nuclear disaster. As detailed below, we found that European citizens’ SWB was statistically unrelated to the share of nuclear power before the Fukushima nuclear disaster, but that SWB was negatively related to the nuclear share after the disaster. In the sense of section 3, this suggests the existence of an induced preference change.

Hypotheses

The Fukushima nuclear accident may have changed European citizens’ relationship between nuclear power and SWB through several channels:

- The subjective assessment of accident probabilities,
- The subjective assessment of the damage potential of an accident,
- The utility weights people place on nuclear safety relative to other attributes of electricity supply.

These potential changes may have altered the relationship between SWB and the share of nuclear power. Put differently, a hypothesized effect of Fukushima on a country’s SWB may be positively related to this country’s nuclear power share.

Empirical Approach: Difference-in-Difference Specification

Using survey data for 123,675 individuals *i* in 23 European countries *c* in 10 years *t*, we estimated the following life satisfaction regression

$$LS_{ict} = \alpha * nuke_{ct} + \beta * post_{ict} + \gamma * post_{ict} * nuke_{ct} + \delta * controls_{ict} + country_{c} + time_{t} + \varepsilon_{ict}$$

where *nuke* denotes the percentage share of nuclear power by country-year and *post* is a dummy variable taking the value 1 if LS was elicited after the date of the accident (11 March 2011) and 0 otherwise. In this formulation, α is the SWB-nuclear relationship pre-Fukushima, β is the change of SWB (after-

* The discussion in this section is partially based on the working paper “Fukushima and the Preference for Nuclear Power in Europe: Evidence from Subjective Well-Being Data” by Heinz Welsch & Philipp Biermann (2014.), produced as a deliverable for this project within work package 5. See appendix to this report.

before) in nuclear-free countries, and γ is the change of SWB (after-before) differentiated by nuclear share (difference-in-difference) or, likewise, the SWB-nuclear relationship post-Fukushima. The estimation period is 2002-2011 (where LS is identified by calendar date). The regressions control for country fixed effects and for quarter fixed effects (2002.II – 2011.IV) to account for seasonal mood patterns.

Results

Table 15 presents the estimation results. The following results stand out (column A):

- Pre-Fukushima, SWB was not significantly related to the nuclear share.
- Post-Fukushima, SWB increased in nuclear-free countries.
- Post-Fukushima, SWB is negatively related to the nuclear share.

The second of these results may indicate an increased awareness and appreciation of people in nuclear-free countries of not being subject to nuclear hazard.

According to columns B – D of Table 15 these relationships apply to men and women, to all age groups, and to environmentalists and non-environmentalists (though somewhat more strongly to the former).

Table 15: The SWB-nuclear relationship

	A	B	C	D
Nuke	0.00379	0.00397	0.00339	0.00484
	(0.00692)	(0.00689)	(0.00693)	(0.00672)
Post	0.481***			
	(0.169)			
Nuke*Post	-0.0127***			
	(0.00324)			
Post*male		0.622***		
		(0.178)		
Post*female		0.403**		
		(0.156)		
Nuke*post*male		-0.0130***		
		(0.00323)		
Nuke*post*female		-0.0129***		
		(0.00316)		
Post*(13-32)			0.477***	
			(0.175)	
Post*(33-47)			0.364**	
			(0.173)	
Post*(48-62)			0.425**	
			(0.171)	
Post*(>62)			0.687***	
			(0.178)	
Nuke*post*(13-32)			-0.0110***	
			(0.00356)	
Nuke*post*33-47)			-0.0117***	
			(0.00328)	
Nuke*post*(48-62)			-0.0138***	
			(0.00322)	
Nuke*post*(>62)			-0.0129***	
			(0.00363)	
Post*environmentalist				0.598***
				(0.157)
Post*non-environmentalist				0.385**
				(0.154)
Nuke*post* environmental-ist				-0.0140***
				(0.00306)
Nuke*post*non-environmentalist				-0.0117***
				(0.00299)
Observations	123675	123675	123675	123675
R-squared	0.202	0.202	0.203	0.203

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. Regressions include micro controls (sex, age, marital status, household size, employment status and household income), macro controls (GDP per capita and the rates of unemployment and inflation) and country and quarter fixed effects.

Preliminary results using distance to the nearest NPP

As mentioned above, the analysis of proximity using distances calculated in work package 1 is still preliminary. In what follows we use the sample of individuals presented in section 6.1. This sample is composed by about 107,000 respondents interviewed across 21 countries over the period 2003-2012. We use a difference-in-difference approach, where the treatment group consists of individuals living closer to the NPP and the treatment is Fukushima. In other words, we study the effect of Fukushima on life satisfaction by interacting each distance to NPP dummy with a Post Fukushima indicator, which takes the value of 1 if the respondent has been interviewed after the 11th March and 0 otherwise. As in section 6.1, our reference category is the dummy indicating whether the respondent lives more than 150 km from a NPP. Results are shown in Table 16. The first column is the basic specification whereas the second column includes month fixed effects to take into account seasonal effects in life satisfaction as Fukushima occurs at the onset of spring. Results show that living closer to NPP is negatively correlated with life satisfaction *after* the Fukushima accident. The same results can be found if one uses happiness instead of life satisfaction.

Table 16: Fukushima, distance to NPP and Life Satisfaction in Europe (showing distance dummies and interactions only)

	(1)	(2)
Ref cat: (“Over 150Km”)	Fukushima effect and proximity to NPP	
0-20Km	0.166*	0.167*
	(0.095)	(0.095)
20-50Km	0.155***	0.156***
	(0.050)	(0.049)
50-100Km	0.119*	0.120*
	(0.062)	(0.062)
100-150Km	0.086*	0.086*
	(0.047)	(0.047)
Post Fukushima	-0.414***	-0.450***
	(0.137)	(0.153)
(0-20Km)*(Post Fukushima)	-1.650***	-1.557***
	(0.154)	(0.176)
(20-50Km)*(Post Fukushima)	0.516***	0.573***
	(0.189)	(0.200)
(50-100Km)*(Post Fukushima)	0.408**	0.416**
	(0.175)	(0.178)
(100-150Km)*(Post Fukushima)	0.217	0.257
	(0.172)	(0.178)
Individual characteristics		
Year fixed effects	Yes	Yes
Country fixed effects	Yes	Yes
Month fixed effects	No	Yes
Observations	107,745	107,714
R-squared	0.203	0.204

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. Regressions include micro controls (sex, age, marital status, household size, employment status, education, and household income), and country and year fixed effects

7. 2. SWB and the Fukushima accident: the case of Switzerland

Using Switzerland as a case study, this analysis uses data from SILC to study whether the SWB-NPP relationship considered in subsection 6.2 has changed after the Fukushima nuclear accident of March 11, 2011. We note that this research suffers from the circumstance that person identifiers were randomized in the data base supplied by the Swiss Statistical Office (see subsection 6.2). We are therefore unable to investigate changes in SWB on a person-by-person basis. In addition, as illustrated in Figure 13, data in 2009 and 2010 were collected only in the first quarter of the respective year. We therefore must confine this analysis to data from 2011; using the combined data set for 2009-2011 would require controlling for seasonality of mood (which we did in the European wide analysis described in subsection 7.1). Since LS typically rises in spring, this means, however, that if we find an indication of a drop in mood after the event, this effect would probably be more rather than less marked if we were able to account for the seasonal mood pattern.

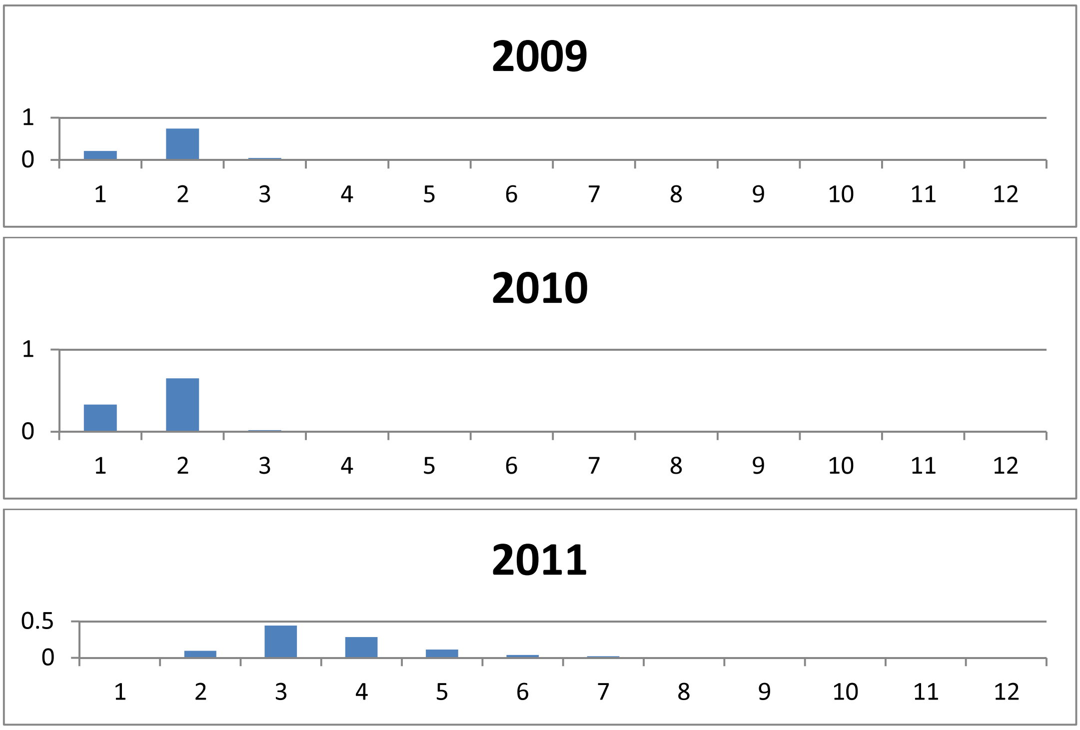

Figure 13: Timing of the SILC – Percentage of observations per month

Empirical Strategy

Our empirical strategy involves the following estimating equation:

$$LS_i = \boldsymbol{\alpha}'\mathbf{micro_i} + \boldsymbol{\beta}'\mathbf{macro_i} + \gamma \ postevent + \varepsilon_i$$

In addition to the usual micro controls (Table 12) and macro controls (language region and distance-specific unemployment rate), this specification includes a *postevent* dummy which takes the value 1 after the event and 0 otherwise. We estimated this equation on data for 2011, differentiated by radius rings around the nearest NPP.
With respect to the *postevent* dummy, we note that any effect of the Fukushima accident on LS in Switzerland must be understood as an information shock concerning accident probability and/or damage potential of an accident. It is not clear *a priori* at what time the information shock became effective. We therefore experimented with alternative choices of the *postevent* date and checked how the results from this experimentation relate to media coverage in Switzerland.

Figure 14 shows the results for alternative choices of the *postevent* date. As can be seen, the *postevent* coefficient became negative after March 12 in German-speaking Switzerland and a few days later in Switzerland overall; and the coefficient became significant (at the 10 percent level) from March 27 in German-speaking Switzerland and, again, a few days later in Switzerland overall.

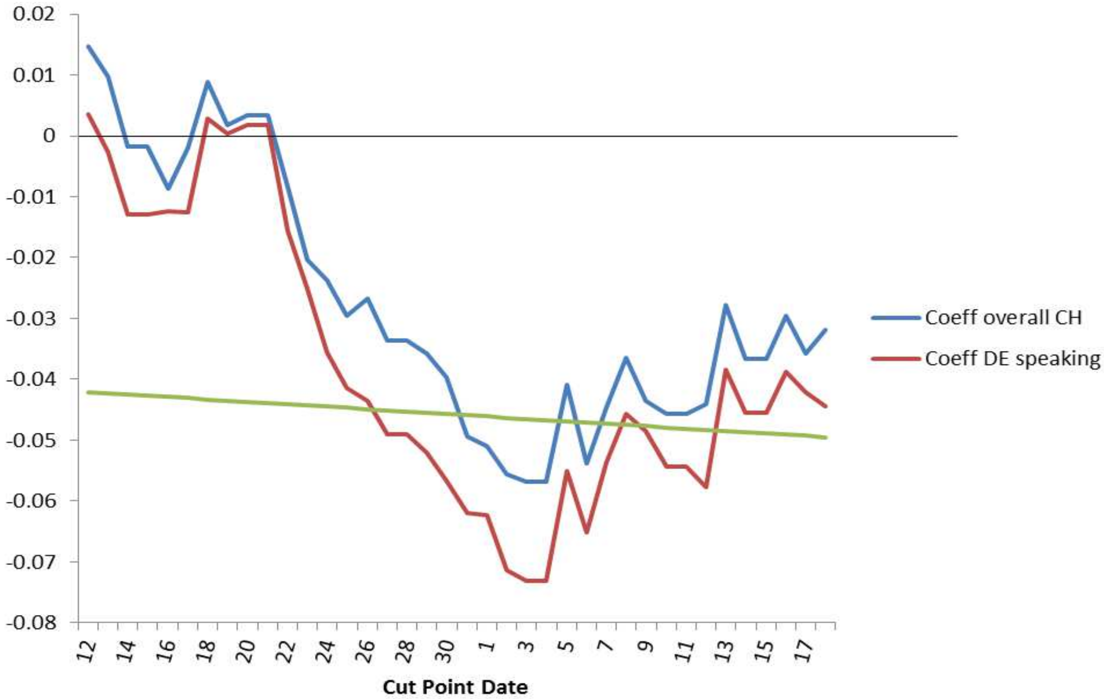

Figure 14: Coefficient estimates for alternative *postevent* dates (all distance categories)

As illustrated in Table 17, the dynamics of the *postevent* coefficient broadly corresponds to media coverage of nuclear energy in Switzerland after March 11, 2011.

Table 17: Media coverage of nuclear energy after March 11, 2011 (Aargauer Zeitung)

17.03.2011	– German Social Democratic Party SPD willing to set up an initiative against nuclear power together with Austrian SPÖ – Swiss Disaster Task Force does not evaluate the situation as a threat for CH – Tokyo nearly faces a blackout – Fear of radioactive contaminated food from Japan arises
18-24.03.2011	– Swiss NPPs do not participate in stress test of the EU – Japan: successful cooling in reactor 3 of Fukushima – Japan: discovery of radioactive drinking water – Operators of Swiss NPPs to declare security status of their NPPs to the federal security inspectors (Ensi) → insecure NPPs should be shut down – Fukushima NPP will be permanently shut down – Aargau canton parliament (Großer Rat) rejects to exit nuclear electricity generation – Concern about radiation in Japan increases
25-31.03.2011	– Switzerland to rely on nuclear energy – Extreme contamination of water in block 3 of Fukushima – EU- Heads of State and Government demand stress test for Europe NPPs – European wide demonstrations against nuclear power, inter alia in Geneva – Japanese NPP-Operator TEPCO revises previous statements of radiation level – Letter bomb at Swissnuclear

Results

Using March 27 as the start date of the *postevent* period, we estimated the equation stated above, differentiated by radius rings around the nearest NPP, as introduced in subsection 6.2. Table 18 presents the results. It is seen that there is no effect of Fukushima in Ring 1 (<40 km) and in Ring 3 (>85 km), but a highly significant negative effect in Ring 2 (40-85 km). This applies to both the German-speaking region and Switzerland overall. Interestingly, the effect size is somewhat smaller in the German-speaking region. This may suggest that the information shock (concerning damage potential, say) at an intermediate distance from NPP was greater in the non-German speaking part of the country.

Table 18: Estimation results by radius rings

	Overall Switzerland				German Language Region			
	all	0-40km	40-85km	>85km	all	0-40km	40-85km	>85km
Postevent	-0.0330	0.00546	-0.147***	0.0521	-0.049*	-0.027	-0.137***	0.054
(27mar2011)	(0.0250)	(0.0348)	(0.0432)	(0.064)	(0.028)	(0.036)	(0.0515)	(0.09)
Unemployment rate	-0.0666	-0.190	0.0347	Omitted	0.0339	-0.161	-1.124	Omitted
	(0.0468)	(0.137)	(1.232)		(0.055)	(0.138)	(1.557)	
German region	Omitted	Omitted	Omitted	Omitted	Omitted	Omitted	Omitted	Omitted
Italian region	-0.00461	-	-	-0.143				
	(0.0893)			(0.093)				
French region	-0.196***	-0.0513	-0.244***	-0.41***				
	(0.0324)	(0.0646)	(0.0532)	(0.0695)				
Socio De-mographics	Included	Included	Included	Included	Included	Included	Included	Included
Observations	12264	6264	3821	2179	9054	5660	2467	927
R-squared	0.171	0.172	0.188	0.171	0.170	0.177	0.182	0.135

To complement this analysis, we estimated life satisfaction regressions including radius rings (as in section 6.2), differentiated by the pre- and post-event period. Table 19 reports the results. It is seen that pre-Fukushima people in German speaking Switzerland were *less satisfied* in Ring 3 than in Ring 2 and equally satisfied in Ring 3 as in Ring 1. Post- Fukushima people in German speaking Switzerland were *more satisfied* in Ring 3 than in Ring 1 and Ring 2, and there was no statistically significant difference between Ring 1 and Ring 2. Similar, though less marked, results apply to Switzerland overall. The more pronounced effects in German speaking Switzerland are consistent with the concentration of the NPPs in that region.

Table 19: Estimation results pre- vs. post-event (March 27, 2011)

	Overall Switzerland		German language region	
	Pre-event	Post-event	Pre-event	Post-event
Distance <40km (Ring1)	Omitted	Omitted	Omitted	Omitted
Distance 40-85km (Ring2)	0.168***	-0.00218	0.158***	0.0478
	(0.0408)	(0.0400)	(0.0444)	(0.0440)
Distance >85km (Ring3)	0.0240	0.161	0.108	0.315**
	(0.149)	(0.150)	(0.157)	(0.160)
Unemployment Rate	-0.0541	-0.206	-0.0929	-0.242
	(0.188)	(0.193)	(0.191)	(0.197)
German region	Omitted	Omitted		
Italian region	-0.0347	-0.0233		
	(0.138)	(0.117)		
French region	-0.269***	-0.176***		
	(0.0482)	(0.0466)		
Observations	5881	6383	4256	4798
R-squared	0.177	0.170	0.177	0.170

Discussion

It can be concluded that life satisfaction dropped in Switzerland after the Fukushima nuclear accident. This drop increased over time and became significant with some delay, due to accumulating information on the effects of the accident. The effect is heterogeneous with respect to both distance from the nearest NPP and the language region. With regard to the former, a strongly significant effect occurred only at the intermediate distance category (Ring 2 = 40-85 km). This suggests that the information shock regarding nuclear safety was most pronounced in that distance range. With regard to that particular distance category, the effect was somewhat stronger in Switzerland overall than in the German-speaking regions. This may suggest that people in German-speaking Ring 2 areas were less “surprised” by the damage potential facing that distance category than people in non-German speaking areas of equal distance.

Due to the heterogeneous effect by distance category, the Fukushima accident also changed the ranking of the distance categories in terms of life satisfaction. Whereas the most distant category in German-speaking Switzerland ranked lower than in the intermediate range before the accident (even controlling for economic factors), it ranked first after the accident. Similar, though less marked, changes apply to Switzerland overall.

To put those results in perspective, it should be noted that the differentiation into a pre- and a post-Fukushima period refers only to the year 2011. It remains to be seen whether the changes in SWB identified extend beyond that year.

8. Conclusions

This project has shown that the production of energy does affect individual welfare, operationalized as subjective well-being (SWB), through the hypothesized dimensions of costs, security, safety and pollution. Using regression analysis, the project has estimated the relationship between SWB and those dimensions of the energy system for European citizens between 2002 and 2011. The relationships unveiled by the econometric analysis seem intuitive and plausible, which lends support to the use of subjective indicators of well-being for policy analysis. This is in line with recent efforts to expand the measurement of economic and social progress to include subjective (as well as objective) indicators of well-being. Quantitative measures of SWB to measure quality of life and its determinants are growing in importance; and in some countries such as the UK have almost reached the point to become part of the tool kit for proposal appraisal and evaluation in social benefit-cost analysis.

Regarding specific findings, the results indicate a preference of European citizens for a safe and environmentally benign electricity supply. They also indicate that it is important to differentiate between energy sources: neither electricity from fossil fuels (coal, oil, gas) nor from renewable sources (hydro power, solar & wind power, biofuels) are homogeneous from an SWB perspective. While electricity from biofuels is less preferred than any other supply technology, electricity from gas as well as solar & wind power are preferred over nuclear power. The latter applies at all levels of income, but not surprisingly the intensity of that preference is less when the level of electricity prices is higher. This hints to another finding of the project that can inform policy strategies designed to mitigate energy poverty: energy prices affect SWB negatively and significantly specially at low incomes and at times when energy requirements and/or bills are high.

Our results suggest the existence of a change in experienced preference concerning nuclear power following the Fukushima nuclear accident. Fukushima seems to have acted a shock affecting the relationship between SWB and the energy supply. After Fukushima, the preference for solar & wind power over nuclear power has risen drastically. Preliminary results also show that proximity to nuclear power plants has a negative impact on SWB but only after the Fukushima accident.

Regarding caveats and future directions, a number of points can be mentioned. One point is that the analysis of the relationship between SWB and proximity to NPPs is preliminary in several ways. With respect to Switzerland, it would be desirable to include foreign NPPs. For instance, the Fessenheim NPP in France is only 40 kilometers away from Basel. In addition, the randomization of SILC respondents performed by the Swiss Statistical Office for confidentiality reasons prevented including individual fixed effects in the analysis. This feature of the data also prevented a more advanced, difference-in-difference analysis of the effects of the Fukushima accident on Swiss citizens' SWB. At the European level, the localization of ESS respondents is relatively crude, which provides a serious limitation to the analysis of the relationship between SWB and the proximity to NPPs.

Our analysis of energy facilities has focused on NPPs. This focus is mainly due to issues of data availability. It is not meant to imply that other electricity generation technologies are free from any SWB impacts. For instance, wind turbines are controversial due to visual and acoustic impairments in the surrounding areas. Analysis of such effects is an obvious candidate for future research. Such analyses can be carried out using spatially disaggregated data bases, which can be constructed at national levels (for instance for Germany). Since, in contrast to most NPPs, renewable energy facilities were expanded over the time for which SWB data are available, it is possible in this case to study dynamic aspects of the relationship between SWB and energy facilities, in particular the question whether habituation (hedonic adaptation) exists in that relationship.

9. Dissemination

9.1 Deliverables

The following deliverables were produced as part of the project's dissemination strategy.

- „Electricity Supply Preferences in Europe: Evidence from Subjective Well-Being Data" (Heinz Welsch & Philipp Bierman 2013), working paper, publicly available at http://ideas.repec.org/p/old/dpaper/359.html. The paper has been published in the journal *Resource and Energy Economics* 38 (2014), pp. 38-60. DOI information: 10.1016/j.reseneeco.2014.05.003.
- "Induced Transnational Preference Change: Fukushima and Nuclear Power in Europe" (Heinz Welsch & Philipp Biermann 2013), working paper, publicly available at http://ideas.repec.org/p/zen/wpaper/27.html..
- "Well-Being Effects of a Major Negative Externality: The Case of Fukushima" (Katrin Rehdanz, Heinz Welsch, Daiju Narita & Toshihiro Okubo 2013), working paper, publicly available at http://ideas.repec.org/p/kie/kieliw/1855.html.
- "GIS Methodology in Determining Population Centers and Distances to Nuclear Power Plants" (Tine Ningal & Finbarr Brereton 2013), technical report, publicly available at http://www.uni-oldenburg.de/energy-for-well-being/
- "Environment, Well-Being, and Experienced Preference" (Heinz Welsch & Susana Ferreira 2014), working paper, publicly available at http://ideas.repec.org/p/old/dpaper/367.html. This paper has been accepted for publication in the *International Review of Environmental and Resource Economics.*
- "Energy Prices, Energy Poverty, and Subjective Well-Being" (Heinz Welsch & Philipp Bierman 2014), working paper, publicly available at http://ideas.repec.org/p/old/dpaper/369.html.

9.2 Presentations

Preliminary results of the project were presented at the following events.

- Second Workshop in Applied Economics, Hanover, May 17, 2013.
- Annual Meeting of the Swiss Society for Economics and Statistics, Neuchatel, June 20-21, 2013.
- Energy 2013 Conference of the Center for European Economic Research (ZEW), June 24, 2013.
- Seminar: University College Dublin, June 8, 2013
- Poster Session at 15th workshop of GEE Student Chapter in Berlin, November 29, 2013.
- Panel discussion: The future of renewable energy and sustainability, Oldenburg, April 5, 2014.
- *Energy 2014 Conference* of the Center for European Economic Research (ZEW), May 5-6, 2014.
- Workshop "Energy, Environment, and Well-Being", Institute of Advanced Studies (HWK), Delmenhorst, June 5-6, 2014.
- Poster presentation at the *World Conference of Environmental and Resource Economists* (WCERE), Istanbul, June 28 - July 2, 2014.

9.3 Website

A project website has been created. It is accessible at http://www.uni-oldenburg.de/energy-for-well-being/.

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Appendix: Working papers

Environment, Well-Being, and Experienced Preference*

Heinz Welsch [a)] and Susana Ferreira [b)]

Recent years have seen a sharp increase in the use of subjective well-being data in environmental economics. This article discusses the conceptual underpinnings of using such data as a tool for preference elicitation and non-market valuation. Given the connection of those data to the notion of experienced utility, we refer to this approach as the experienced preference method and discuss recent methodological advances and applications of the approach to subject areas not previously reviewed. In addition, we discuss insights concerning environmental behavior that can be gained with the help of subjective well-being data.

JEL classification: Q51, D60, D03, I31, B4

Keywords: Non-market valuation; Environmental behavior; Experienced utility; Happiness; Life satisfaction; Subjective well-being.

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*Appendix to chapter 2. Forthcoming in *International Review of Environmental and Resource Economics.*

1. Introduction

Recent years have seen economists increasingly use data on subjective well-being to study the consequences of economic and social phenomena for human welfare. As noted by Levinson (2013), the number of peer-reviewed economics articles referencing well-being, happiness or life satisfaction quadrupled from 153 to 651 in 2001-2011, and the proportion in the total number of articles indexed by EconLit doubled.

While large portions of this literature are concerned with economic variables in the narrow sense – such as income and unemployment – institutions and public goods or bads have also received considerable attention in these works. In particular, environmental quality and environment-related events have been matters of concern, and the relevant literature, though small, has seen an even more rapid expansion than the economics of well-being literature overall. While 4 papers were published in journals indexed by the ISI Web of Science Journal Citation Reports in 2002- 2005, the number increased to 13 in 2006-2009, and 23 in 2010-2013.[4]

Explicitly or implicitly, an aim of practically all of those papers has been the elicitation of environmental preferences and the monetary valuation of environmental goods. As it will be discussed below, the conceptual underpinnings of this method of preference elicitation rest on the notion of "experienced utility", whereas the more conventional revealed and stated preference methods are closely connected to "decision utility". To highlight this distinguishing feature of preference elicitation by means of happiness or life satisfaction data, we will refer to this approach as the *experienced preference method* (EPM).[5]

The literature that we discuss is concerned with global self-reports of subjective well-being (SWB), as opposed to well-being in specific life domains (e.g. financial well-being). The concept of SWB encompasses both happiness and life satisfaction, where the former primarily refers to the affective and the latter to the evaluative aspect of SWB. Happiness data and life satisfaction data are usually highly correlated with each other, and using one or the other in economic analysis typically yields the same qualita-

[4] A subset of those articles is indexed by EconLit. The corresponding numbers are 3 in 2002-2005 and 16 in 2010-2013.

[5] The terminology up to this point has been inconsistent, referring to the happiness approach (Welsch and Kühling 2009), the life satisfaction approach (Luechinger 2009, Luechinger and Raschky 2009, Frey et al. 2010), or the well-being valuation approach (Powdthavee and van den Berg 2011).

tive insights (see, e.g., Frey and Stutzer 2002). Economists mostly use the terms SWB, happiness, and life satisfaction interchangeably, and we follow this practice unless stated otherwise.

Though the use of subjective well-being data in environmental economics is a relatively new area of research, there exist at least three previous survey papers on this subject (Welsch and Kühling 2009, Frey et al. 2010, MacKerron 2012). In addition, important methodological aspects were discussed in Ferreira and Moro (2010) and Levinson (2013), whereas Smith (2008) offers a critical view on this literature. Against this background, this paper contributes in the following ways. First, we offer a discussion of the theoretical underpinnings of this new method of preference elicitation and its conceptual relation to other approaches. Specifically, we introduce a general utility theoretical framework for non-market valuation which allows us to put the EPM in perspective and to compare it with other preference elicitation methods (Section 2). Second, we discuss advances and extensions of the empirical methodology used. We describe how recent EPM studies have improved over early studies by refining the spatial and temporal matching of environmental conditions to well-being data at the level of the individual (Section 3). Third, we describe applications to subject areas not previously surveyed. These include land use, energy supply systems, and natural disasters (Section 4). Fourth we discuss lessons from well-being research concerning environmental behavior. These refer to the hedonic spatial equilibrium model and the hypothesis of utility-maximizing environmental consumer choice (Section 5). We conclude by indicating directions for future research (Section 6).

2. Non-Market Valuation

In contrast to marketable goods, whose value can be inferred from observed market data under some mild assumptions, the public-good characteristics of many environmental goods prevent their value from being identified directly from observation. Since environmental valuation constitutes a basic ingredient to the benefit-cost analysis of environmental policy, researchers and environmental agencies use a number of standard tools for non-market valuation. In this section, we discuss the conceptual underpinnings of non-market valuation and the relationship between the various methods employed.

2.1 Experienced Utility as a Standard of Valuation

In an influential paper entitled “Back to Bentham?” Kahneman et al. (1997) introduced the distinction between decision utility and experienced utility, which will be important for putting non-market valuation techniques in perspective. These concepts can be defined as follows.

Definition 1. Experienced utility is the *ex post* hedonic quality associated with an (economic) outcome. Decision utility describes the *ex ante* expectation of experienced utility.

Experienced utility thus entails a retrospective (or contemporaneous) assessment of outcomes whereas decision utility involves a prospective assessment. Ideally, decision utility and experienced utility would coincide, but evidence from behavioral economics casts doubt on the general validity of their equivalence. Specifically, deviations between decision utility and experienced utility (and the associated decision errors) may arise because of failures in affective forecasting, that is, in figuring out the utility consequences of one's choices (Loewenstein and Adler 1995, Loewenstein and Schkade 1999, Loewenstein et al. 2003, Wilson and Gilbert 2003).[6]

Based on the concepts of decision utility and experienced utility, a natural definition of economic value follows.

Definition 2. The value of a good is its contribution to experienced utility.[7]

Different non-market valuation methods capture the value of environmental goods in different ways. Revealed and stated preference methods generically refer to decision utility. For instance, people's willingness to pay for a given house – which reveals their valuation of the associated environmental amenities – depends on their expectations as to how those amenities will affect their utility. Likewise, people's stated willingness to pay for a hypothetical improvement in environmental conditions depends on their

[6] Failures in affective forecasting (utility misprediction) are a psychological phenomenon and may arise even if people hold perfect information about the objective characteristics of choice alternatives (goods). From the point of view of standard economics, an additional reason for decision utility to deviate from experienced utility is that at the time a decision is taken individuals may be imperfectly informed about those characteristics. Implications of utility misprediction with regard to environmental behavior will be discussed in subsection 5.2.

[7] Kahneman and Sugden (2005) argue that goods have value by virtue of their capacity to create pleasurable affect states. This view is consistent with the subjective theory of value of, e.g., Jevons and Menger, which implies that the value of a thing reflects the utility or enjoyment experienced by the individual. While this assumption may be questionable in some cases of pure existence value, experienced utility can be considered a source of value for most environmental goods.

expectations of the utility consequences of that improvement. To capture the value of non-market goods, both revealed and stated preference methods thus require that individuals are able to accurately predict the utility implications of (actual or hypothetical) choices.

Non-market valuation using SWB data, conversely, does not rely on choices, but on the statistical association between individuals' SWB and indicators of environmental quality. Provided that reports of SWB are good proxies for experienced utility (see subsection 2.3), we propose to refer to non-market valuation using well-being data as the *experienced preference method* (EPM). Different from previous terminology (see footnote 2) this term does not limit the dependent variable to either happiness or life satisfaction, and it fits with the language used for existing conventional non-market valuation approaches.

The immediate *conceptual* conformity to Definition 2 should, of course, not be construed to imply *practical* superiority of the EPM. Practical strengths and weaknesses of the main revealed and stated preference methods and the EPM will be discussed in subsection 2.4.

2.2 A Framework for Non-Market Valuation

In this subsection we present a general framework for non-market valuation. Since this framework is intended to formally encompass several particular valuation methods, for simplicity it disregards the possibility that decision utility deviates from experienced utility.

Consider an economy with one environmental good and two marketable goods, housing and a numeraire. An individual derives utility from those three goods. Her indirect utility function specifies the maximum utility she can attain by allocating income optimally to the marketable goods at a given housing price. The indirect utility function takes the following form:

$$u = v(p, y, q), \qquad (1)$$

where p, y and q denote the price of housing, income, and the quantity of the environmental good (level of environmental quality), respectively. The indirect utility function is decreasing in the first and increasing in the second and third argument.

The hedonic model assumes that houses are heterogeneous in terms of the environmental quality prevailing in the places where they are located and that the price of housing is an increasing function of environmental quality: $p = p(q)$. It also assumes that wages (and thus income) decrease in environmental quality: $y = y(q)$. Substituting these relationships in (1) gives

$u = v(p(q), y(p), q)$. (2)

In a simple hedonic model with homogeneous agents, people choose their location in such a way as to balance the benefit from better environmental quality against the cost of more expensive housing and lower income so that the utility in different locations is equalized (otherwise individuals would have an incentive to move). Under the appropriate concavity conditions this spatial equilibrium condition can be expressed as follows:

$$\frac{dv}{dq} = \frac{\partial v}{\partial p}\frac{dp}{dq} + \frac{\partial v}{\partial y}\frac{dy}{dq} + \frac{\partial v}{\partial q} = 0 \qquad (3)$$

The hedonic model thus predicts that in spatial equilibrium dv/dq is zero. This implies that the marginal utility derived from environmental quality, $\partial v/\partial q$, is exactly offset by the marginal disutility from higher housing prices in cleaner places, $(\partial v/\partial p)*(dp/dq)$, and the marginal disutility from lower income, $(\partial v/\partial y)*(dy/dq)$.

An important insight from this discussion is that the EPM and the hedonic model are conceptually consistent with each other.[8] While the latter attempts to measure the value of environmental amenities in an indirect way, through the disutility from higher housing prices and lower wages, the former aims at a direct measurement of the utility from environmental quality. In spatial hedonic equilibrium, both can yield the same result: $\frac{\partial v}{\partial q} = -\frac{\partial v}{\partial p}\frac{dp}{dq} - \frac{\partial v}{\partial y}\frac{dy}{dq}$. If, however, the spatial equilibrium condition fails to be satisfied, results may differ. Specifically, environmental quality may be incompletely capitalized in housing or labor markets, in which case the marginal utility of environmental quality is the sum of what is capitalized in the

[8] An implicit assumption in this comparison between methods, however, is that there are no affective forecasting errors, that is, decision and experienced utility coincide.

respective markets and a non-capitalized residual value, $\frac{dv}{dq}$. In this case, results from hedonic pricing studies may be inappropriate as standards against which to assess the "plausibility" of EPM results.[9]

With regards to stated preference methods, their conceptual background may be considered to be the same as in equation (1), but the practical way of eliciting the (monetized) utility of non-market goods is different (see subsection 2.4).

The discussion up to this point has been in terms of utility. To convert the marginal utility-value of the environmental good into monetary units, it must be divided by the marginal utility of income. This yields the marginal utility-constant monetary value of the environmental good, that is, the marginal rate of substitution (MRS) of income for the environmental good:

$$MRS = \frac{\partial v / \partial q}{\partial v / \partial y}. \tag{4}$$

The MRS represents the amount of income necessary to compensate people for a marginal change in environmental quality while keeping utility constant. Diagrammatically, the MRS is the slope of an indifference curve at a given (y, q) configuration, as illustrated in Figure 1. With strictly convex indifference curves, the MRS depends on the point of measurement and can be large at large values of y/q (see, e.g., point D in Figure 1).

If non-marginal changes in environmental quality are to be valued, the compensating surplus (*CS*) and the equivalent surplus (*ES*) can be used. The compensating surplus is the amount by which – *ex post* of an environmental improvement – income would need to be reduced to fix utility at its *ex ante* level, that is, $v(p, y, q) = v(p, y - CS, q + \Delta q)$. The equivalent surplus is the amount by which income would need to

[9] By using SWB data as a proxy for utility, in principle, it is possible to check the spatial equilibrium condition $dv/dq = 0$ in Roback's (1982) representative agent model or its analog for non-marginal instead of marginal differences in environmental quality, $\Delta v / \Delta q = 0$, that is, the proposition of equality of utility across locations in spite of differences in environmental quality (see subsection 5.1 below).

be raised to attain the level of utility *ex post* of an environmental improvement – did the improvement not take place: $v(p, y, q+\Delta q) = v(p, y+ES, q)$.

CS and *ES* are illustrated in Figure 1. For an environmental improvement that takes the individual from point A to B, we have *CS* = F – E and *ES* = G – F. As shown by, e.g., Johansson (1987) and illustrated in Figure 1, strictly concave indifference curves imply *ES* > *CS*, and *ES* is theoretically unbounded.[10]

2.3 The Experienced Preference Method

Application of the EPM involves using survey data on SWB as a proxy for the left-hand side variable in equation (1), that is, for experienced utility *u*, and specifying and estimating the indirect utility function *v*(.).

The survey questions pertaining to SWB may refer to "happiness" or to "life satisfaction", and the categories may be purely verbal or may combine verbal with numerical features. For instance, the *General Social Surveys* use a three-point verbal happiness scale. It asks the question: "Taken all together, how would you say things are these days – would you say that you are very happy, pretty happy, or not too happy?" In the *World Values Surveys*, people are offered a scale from 1 (dissatisfied) to 10 (satisfied) to respond to the question: "All things considered, how satisfied are you with your life as a whole these days?"

In using SWB data for econometric analysis, some important assumptions have to be imposed on the information content of those data. As discussed by Ferrer-i-Carbonell and Frijters (2004), necessary assumptions are (a) a positive monotonic relationship between SWB and the underlying true utility *u* (if $SWB_{it} > SWB_{is}$, then $u_{it} > u_{is}$ for individual *i* at times *t* and *s*) and (b) ordinal interpersonal comparability (if $SWB_{it} > SWB_{jt}$, then $u_{it} > u_{jt}$ for individuals *i* and *j*). Validation research has produced a variety of supporting evidence of those assumptions (see Diener et al. 1999, Frey and Stutzer 2002, Ferrer-i-Carbonell and Frijters 2004).

Under ordinal comparability an ordered discrete choice model of the following form can be estimated:

$$u_{ilt} = \alpha \ln y_{ilt} + \beta q_{lt} + x_{ilt}'\gamma + \varepsilon_{ilt} \qquad (5)$$

$$SWB_{ilt} = 1 \Leftrightarrow u_{ilt} < \theta_1, \quad SWB_{ilt} = 2 \Leftrightarrow \theta_1 \le u_{ilt} < \theta_2, \quad \ldots \quad , \quad SWB_{ilt} = K \Leftrightarrow \theta_{K-1} < u_{ilt} \qquad (6)$$

[10] The concepts of *CS* and *ES* can likewise be applied to environmental deteriorations. In this case, the *CS* is unbounded.

In equation (5), u_{ilt} is unobserved true utility of individual i at location l surveyed on date t. The variables y_{ilt} and q_{lt} are income and environmental quality (at location l and date t), respectively. The vector x_{ilt} comprises the individual's socio-economic characteristics, and possibly location and time fixed effects, and ε_{ilt} is a disturbance term. Equation (6) establishes the association between true utility and SWB. It states that the SWB scores take values 2, …, K (rather than 1) if utility exceeds certain thresholds θ_k, k = 1, …, K-1. The parameters in (5) and the thresholds in (6) are estimated simultaneously.

Equation (5) is a typical specification in that it includes income in logarithmic form to account for decreasing marginal utility of income. As discussed above, monetary valuation relies on the MRS of income for environmental quality, that is, the ratio of the marginal utilities of environmental quality and income (equation (4)). In the case of specification (5) the MRS is $\beta/(\alpha/y)$. In order for this approach to capture the marginal utility of environmental quality (i.e. the partial derivative), the vector of controls x_{ilt} should include the price of housing. Otherwise, compensation of poor environmental quality through lower house prices (if any) may introduce a downward bias into the coefficient on environmental quality.

If, more restrictively than ordinal comparability, it is assumed that $SWB_{it} - SWB_{jt}$ is proportional to $u_{it} - u_{jt}$, SWB can be treated as a cardinal variable.[11] In this case, least squares can be applied to equation (5) with u on the left-hand side being replaced with the respective SWB scores. Ferrer-i-Carbonell and Frijters (2004) and many others found that assuming the data to be ordinal or cardinal and applying the corresponding estimation methods has little effect on qualitative results. In particular, the ratios of coefficients are similar which, as seen above, is important for monetary valuation. Importantly, individual fixed effects can be included in this case in a straightforward way (if data availability allows doing so) whereas there is no consensus on how to implement a fixed effects estimator for ordered discrete choice models (Ferrer-i-Carbonell and Frijters 2004, Baetschmann et al. 2013).

In applications of the EPM it has sometimes been observed that the valuations obtained, that is, the MRS of income for the public good under study, are "too high" (e.g. Frey et al. 2007, MacKerron and Mourato 2009, Ferreira and Moro 2010), in particular in comparison with results from hedonic pricing studies.[12] As discussed in the preceding subsection, however, hedonic pricing need not capture the full

[11] Cardinality amounts to assuming that the difference between an SWB score of, say, 8 and 9 is the same as the difference between a 4 and a 5 (Ng 1997).

[12] For example, Frey et al. (2007) report that for the period 1975–1998 an average Northern Ireland resident would be willing to pay 41% of her income to reduce terrorist activity to the

value of environmental quality because the condition of spatial equilibrium may not be satisfied. Another reason why hedonic pricing studies may be an inappropriate standard against which to assess the plausibility of EPM results is the disjunction between decision and experienced utility. In addition, as we also discussed above, being the slope of an indifference curve, the MRS can be large at the point of measurement if the indifference curve is sufficiently convex. A high MRS of income for environmental quality can thus arise when environmental quality is poor and should not *per se* be dismissed as implausible. Similar considerations apply to the equivalent surplus of an environmental improvement and the compensating surplus of an environmental deterioration.

Though expectations as to “reasonable” magnitudes for the value of environmental quality may be misleading, a bias can nevertheless arise from a biased estimate of the marginal utility of income, the denominator of the MRS in formula (4).[13] One source of bias can be endogeneity of income (due to reverse causality, omitted variable bias and measurement error). In addressing this issue, Powdthavee (2010) finds that the income coefficient in an instrumental-variables specification of the well-being regression is larger than in a least-squares specification, suggesting that equation (4) would otherwise overstate the MRS of income for the environmental good. Ambrey and Fleming (2014) also provide evidence of an overstatement of the MRS due to endogeneity of income.

In addition to issues of endogeneity, it is important to be clear about exactly how to include income and what that implies for the interpretation of results. One important point is that specifications of well-being regressions often fail to control for the disutility from income generation (working hours, commuting and stress) and thus tend to deliver less than the “full” marginal utility of income (Luechinger 2009).[14]

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level seen in the Republic of Ireland. MacKerron and Mourato (2009) estimated that a 1% increase in NO_2 levels is equivalent, in life satisfaction terms, to a 5.3% drop in income, and they note that „[n]otwithstanding that the NO_2 variable here may indicate more general pollution levels, this figure is unrealistically high, both intuitively and in comparison with results from revealed and stated preference studies. Although this result may be due in part to the high incomes of the survey sample, surprisingly high values seem to be a fairly common finding in LS research to date.“

[13] In specification (5) the marginal utility of income is α / y.

[14] However, instrumenting income helps address this concern.

Another relates to relative income effects. Specifically, there exists a large literature which finds that, due to habituation and social comparison, it is income relative to one's past income and the income of others rather than absolute income which matters for well-being (see Clark et al. 2008 for a review).

The findings on relative income effects might suggest to include in the well-being regression not only current own income but also lagged own income and the income of others. Because lagged own income and the income of others affect well-being negatively but both are likely to be positively correlated with current own income, omission of those controls is expected to lead to a smaller coefficient on current own income than their inclusion. It is however open to debate whether this constitutes a bias or whether both specifications yield meaningful, though different insights: When lagged own income and the income of others are controlled for, the coefficient on current own income captures utility gains from short-term improvements in relative socio-economic status, that is, the short-term private marginal utility of income. When lagged own income and the income of others are omitted, the coefficient on current own income incorporates the negative "internality" of past income and the negative externality of others' income. The coefficient can thus be interpreted as capturing the long-term social marginal utility of income, which is less than the short-term private marginal utility of income (Layard 2006).

Following this reasoning, standard EPM studies, which include only current own income, should be taken as delivering the value of environmental quality in terms of the long-term social value of income. The value of environmental quality so obtained may be larger than its counterpart in terms of the short-term private value of income.[15] To the extent that individuals fail to account for negative consumption (income) "internalities" and externalities in making (actual or hypothetical) choices (as argued, e.g., by Frank 1985), conventional revealed and stated valuation approaches may be thought of as relying on the short-term private value of income.

It follows from this discussion that obtaining an unbiased estimate of the monetary value of environmental goods requires including both housing prices, and working and commuting time in the well-being regression. Omitting the former can lead to a downward bias in the estimation of the marginal utility of environmental quality, whereas omitting the latter can lead to a downward bias in the estimation of the marginal utility of income. In addition, it arguably is the long-term social value of income rather than its

[15] Regarding habituation, Menz and Welsch (2010) experiment with including lagged income and find it to enter negatively and to considerably raise the coefficient on current income. Habituation could, however, affect not only income but also environmental quality, see subsection 3.3.

short-term private value that should be the basis for environmental valuation. This suggests omitting own past income and others' income in the regressions.

2.4 Comparison of Valuation Methods

As discussed in subsection 2.1, the main *conceptual* difference between the standard revealed and stated preference methods and the experienced preference method is that the former relate to decision utility whereas the latter aims at a direct measurement of environmental goods' contribution to experienced utility. In addition, they differ at a *practical* level, and these differences constitute their respective strengths and weaknesses. Since these strengths and weaknesses have been discussed in previous review papers (Welsch and Kühling 2009, Frey and Stutzer 2010, MacKerron 2012), we give only a brief account and limit ourselves to the hedonic pricing method and the contingent valuation method as the most important varieties of revealed and stated preference approaches, respectively.

From a methodological point of view, the strength of the hedonic pricing method (HPM) is that it relies on observations of objective data, such as housing prices and wages. In terms of scope, it can potentially capture all effects of environmental conditions that are linked to the location and that are capitalized in housing or labor markets. It is problematic, however, as it relies on assuming equilibrium (optimal) adjustment of market behavior to environmental conditions. The method thus neglects information asymmetries as well as transaction and moving costs which may prevent optimal adjustment.[16] It also presumes perfect functioning of markets, especially the absence of regulation, while in fact regulation is a characteristic of housing and labor markets in many countries. Finally, the hedonic method may be subject to sorting bias, as people most averse to poor environmental conditions choose to live in more favorable locales.[17] A test of the HPM by Ferreira and Moro (2010) finds that the predictions of the HPM are not satisfied in data from Ireland (see subsection 5.1).

[16] Bayer et al. (2009) show that when moving is costly, the variation in housing prices and wages across locations may no longer reflect the value of differences in local amenities. Controlling for impediments to moving raises their HPM valuation results for particulate matter considerably.

[17] Over the past decade, a new "equilibrium sorting" framework has developed to characterize preference heterogeneity (Kuminoff et al. 2013). In their equilibrium sorting model, Bayer and McMillan (2012) show that as distance to work matters relatively less than other considerations

The contingent valuation method (CVM) rests on subjective data as to the stated willingness to pay (WTP) or willingness to accept (WTA) for changes in environmental conditions. Its main strength is that, in principle, it can be applied to all kinds of environmental conditions and can capture both use and existence values. In practice, however, several issues need careful consideration. In the first place, contingent valuation is concerned with hypothetical changes in environmental conditions. To place a monetary value on such changes presents people with an unfamiliar and cognitively complicated task of affective forecasting which may result in elicitation of attitudes rather than preferences (Kahneman and Sugden 2005). Contingent valuation is subject to framing effects and context effects. In particular, it matters whether valuation questions are formulated in terms of WTP for gains or WTA for losses in environmental quality. While the difference should be small according to standard models of consumer choice, behavioral economists have consistently shown that, due to the so-called endowment effect, the valuation of losses is systematically larger than the valuation of gains (Knetsch 2005). Moreover, strategic responses may further widen the gap. See Hausman (2012), Kling et al. (2012) and Haab et al. (2013) for recent contributions to the still ongoing intellectual debate over CVM.

Similar to the CVM, the EPM rests on subjective data, but is cognitively less demanding than the CVM because individuals are simply asked about their SWB rather than being requested to place monetary values on hypothetical environmental conditions. In addition, less knowledge on the physical effects of those conditions is required than in both the HPM and CVM. In fact, the EPM is able to capture all effects of environmental conditions (ranging from non-monetized health to aesthetic values, ecological effects, altruism, and income losses), even though the individual may not be consciously aware of them. For instance, exposure to pollution can damage health through a process unnoticed by the individual, but which nevertheless affects subjective well-being. From the point of view of mainstream economics, a weakness of the EPM is the assumption of interpersonal comparability of utility, as discussed above, especially when using cross-national surveys. Another issue is that the measurement of utility using reported well-being involves measurement error. Identification of the relationship between utility and environmental conditions may be biased if errors in the measurement of utility through SWB are correlated with environmental conditions (Bertrand and Mullainathan 2001), but it is not clear why such correlations should

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in the household location choice, neighborhood stratification on the basis of local public goods consumption increases.

exist.[18] Finally, similar to the HPM, the EPM may be subject to sorting bias as individuals can move according to their environmental preferences; and because SWB data are gathered in surveys, similar to the CVM it may be subject to framing and context effects and social desirability bias, especially if advanced questionnaire and survey design methods, as developed in sociology and psychology, are not applied.

3. **Methodological Advances**

In relation to studies reviewed in earlier survey articles on the EPM, there have been advances with respect to methodology, and growth in the areas of application. This section is concerned with methodological advances. They mainly refer to the spatial and temporal resolution of the data and the matching between the well-being and environmental quality data.

3.1 First-Generation Studies

We start with a brief account of some early EPM studies. They are characterized by using indicators of environmental quality and SWB at the country or country-year level. Using average SWB (by country or country-year) as the dependent variable implies assuming cardinality of the underlying individual-level well-being data. By averaging SWB, this approach sidesteps the problem of unobserved heterogeneity of individuals *within* countries or country-years, whereas unobserved heterogeneity *between* countries and years can be captured by country and year fixed effects. Country fixed effects control for unobserved between-country heterogeneity, while year fixed effects control for year-to-year heterogeneity. The main disadvantage of this approach is that inference is made based on country-level characteristics. In particular, environmental conditions are captured in a crude way: Only their cross-country and year-to-year variation is used as a source of identification; any regional, within-country variation is neglected.

An early EPM paper by Welsch (2002) studies the impact of air pollution (average levels of ambient sulfur dioxide, nitrogen dioxide, and total suspended particles) on country-average happiness for a cross-section of 54 countries around 2000. He finds that larger nitrogen dioxide concentrations are statistically associated with lower average happiness whereas higher per capita income is associated with higher average happiness. The implied MRS of per capita income for nitrogen dioxide suggests a considerable

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[18] Li et al. (2014) propose to treat utility as a latent variable built from several indicators of satisfaction, in a structural equation model as a way to reduce measurement error.

monetary value of reducing the latter.[19] Welsch (2006) addresses the problem of unobserved between-country heterogeneity by using country and year fixed effects in a panel comprising annual data (1990-1997) for 10 European countries. He finds that nitrogen dioxide and lead are both negatively and significantly related to average life satisfaction.

Rehdanz and Maddison (2005) study the relationship between SWB and climate for a panel of 67 countries in the 1990s. They control for between-country heterogeneity by means of social and macroeconomic indicators (such as life expectancy, literacy rate, religion, unemployment, inflation etc.) but do not include country or year FE in their regressions. They find that a country's average happiness is significantly raised by higher minimum temperatures and reduced by higher maximum temperatures as well as by an increased frequency of dry conditions.

3.2 Spatial Resolution

As noted above, using mean SWB and mean environmental quality indicators at the country level has the advantage that unobserved heterogeneity across individuals is evened out. However, SWB and environmental quality levels are assessed only at a highly aggregated scale. Ideally, data on environmental conditions would be matched to happiness data at the spatial level of disaggregation at which individuals actually experience their surroundings. This can be facilitated by the use of geographical information systems (GIS), for example to define buffers around point data or to measure distances between points. In the case of climate or pollution data, in order to match the readings from a limited number of monitoring stations to individual SWB data, spatial interpolation techniques (such as kriging or inverse distance weighting) can be applied to the available data to provide climate or environmental quality information between monitoring stations. Alternatively, when possible, air pollution models can be used to model the dispersion of pollutants.

In one of the first applications of GIS analysis to happiness studies, Brereton et al. (2008) find that the explanatory power of their life-satisfaction regression for Ireland substantially improves after accounting for environmental amenities. By controlling for a broad range of spatial variables, they reduce the risk of omitted variable bias, present in studies that focus on only one amenity. The matching between individual

[19] We abstain from reporting and commenting on monetary values of environmental conditions if previous review papers (Welsch and Kühling 2009, Frey et al. 2010, MacKerron 2012) have already done so.

happiness data and spatial amenities in their study is at the Irish electoral district level (ranging between 17 and 6,189 ha). A more precise matching of environmental amenities to individual data is done at the zip-code area level in Van Praag and Baarsma's (2005) study of aircraft noise around Amsterdam Schiphol airport. They find that although individuals' perceived noise nuisance is negatively related to SWB, the objective noise burden is not statistically significant.[20] MacKerron and Mourato (2009) also use the postcode to match annual average concentrations of nitrogen dioxide (which is found to have a large negative impact) and PM10 to individual life satisfaction in their small, convenience sample of Londoners.

Although data at the zip-code level are generally not available, practically all the recent (post 2008) studies that have analyzed the impact of environmental amenities on individual-level SWB have relied on sub-national (regional or local) data. For example, Smyth et al. (2008) link SO_2 emissions, environmental disasters, traffic congestion and access to parklands to SWB for 30 cities in China. Cuñado and Perez de Gracia (2012) study the impact of a wide range of regional amenities (NO_2, PM10 concentrations, CO_2 emissions, and indicators of precipitation and temperature) on SWB in Spain. Ferreira et al. (2013) find a negative and significant relationship between SO_2 concentrations at the regional level and life satisfaction in Europe. Murray et al. (2013) analyze the impact of regional climate variability in Europe. Ambrey et al. (2014) focus on PM10 concentrations at the collection-district level (similar to a US census block group) in South-East Queensland, Australia.

Luechinger (2009) also combines individual-level data with high resolution SO_2 data (at the county level for Germany). Unlike other studies, however, he is able to control for individual fixed effects as he uses data from the German Socio-Economic Panel Study (SOEP), a large panel survey. Moreover, he uses the estimated improvement in air quality caused by the mandated installation of scrubbers at power plants as a novel instrument for air pollution. In a subsequent study, Luechinger (2010) uses pollution from foreign sources (estimates of the contribution of SO_2 emissions from other countries to the concentration in a given country) as an instrument for mean annual SO_2 country-level concentrations across Europe. In both cases, instrumenting for pollution results in it having a larger impact on SWB.

[20] Similarly, Weinhold (2013) finds *perceived* noise levels across Europe to be negatively associated with SWB. Li et al. (2014) study the role of perceptions of air pollution for SWB as well as the formation of such perceptions using a system of equations framework.

3.3 Time Scale

In addition to the spatial dimension, an important issue is the temporal dimension of the link between well-being and environmental quality. While this is of less importance in the case of environmental amenities that do not change over a longer period of time, it may be highly relevant for flow pollutants, especially if their amounts are volatile.

Levinson (2012) merged data on local air quality and individual observations to estimate SWB as a function of air quality on the day the well-being question was asked. He finds a statistically significant negative coefficient on the daily concentration of PM10, whereas the coefficient on the annual average concentration of the same pollutant is negative but statistically indistinguishable from zero. He concludes from these results that long-term average pollution levels may be of little importance for well-being, due to habituation.

Since several papers find significant effects of annual levels of other air pollutants, such as nitrogen dioxide, lead, and sulfur dioxide (Welsch 2002, 2007, Luechinger 2009, 2010), the general validity of this proposition is unclear. Moreover, by differentiating survey respondents by birth cohort, Menz and Welsch (2012) find the well-being effect of nitrogen dioxide to be greater in people who likely were exposed to high pollution loads in early childhood.[21] This finding is consistent with epidemiological evidence of greater susceptibility to current air pollution in people whose lung functions were impaired by early exposure to that pollution. Moreover, even with respect to PM10, Menz (2011) finds the pollution levels of both the current year and the preceding year to have significant negative coefficients in life satisfaction regressions, which suggests the existence of long-term effects rather than habituation.

We conclude from these results that the dynamics of the relationship between pollution and well-being are likely to depend on specific aspects of the type of pollution and are an area for further investigation.

3.4 Instantaneous Well-Being

All the studies reviewed so far relate indicators of environmental quality to global self-reports of subjective well-being (happiness or life satisfaction). Although the use of high resolution spatial data is expected to yield a better match between the survey respondent and the environmental conditions she experiences, the match between the two is done using the location of the residence. Even in Levinson's (2012) study in which air quality is measured at the day of the interview, the pollution concentrations might not reflect the

[21] For details on how the identification problem (differentiating year-of-birth effects from age effects) is addressed the reader is referred to Menz and Welsch (2012).

individual's actual exposure to pollution on that day if, for example, the respondent spent most of the day indoors or at a different location (e.g. at work).

In a path breaking study, MacKerron and Mourato (2013) use an alternative approach to the measurement of the impact of environmental amenities on SWB. They develop and apply a smartphone app that signals participants at random moments during their daily lives and asks them to report the extent to which they are feeling "Happy". Although longitudinal study designs in which participants provide ongoing reports of their momentary, experienced SWB are not new, the novelty of their application of the Experience Sampling Method is the use of satellite positioning (Global Positioning System, GPS) to determine the precise geographical coordinates that then can be associated to objective spatial data (the matching can be done at a square of area 25x25 m.). Three environmental indicators are collected: land cover type, weather conditions and daylight status. On average, study participants report to be significantly and substantially happier outdoors in natural habitat types than they are in urban environments.

4. Areas of Application

As seen in Table 1, the EPM has been applied to issues such as air pollution, noise, climate parameters, and the presence of local environmental (dis)amenities. Some more recent papers have dealt with land use, energy supply systems and environmental disasters. In addition, the EPM has been applied in the context of an explicit benefit-cost analysis of environmental policy. This section reviews some of the more recent applications.

4.1 Benefit-Cost Analysis

Though an important rationale for environmental valuation is benefit-cost analysis, the results from EPM studies have rarely been applied in a policy context to date. However, as reflected in the newest version of the UK's Treasury Green Book providing guidance for proposal appraisal and evaluation, EPM "may soon be developed to the point where it can provide a reliable and accepted complement to the market based approaches" for direct use in social benefit-cost analysis. "In the meantime, the technique will be important in ensuring that the full range of impacts of proposed policies are considered, and may provide added information about the relative value of non-market goods compared with each other, if not yet with market goods" (HM Treasury, 2014, p.58).

With regards to the explicit application of EPM for benefit-cost analysis in the economics academic literature, and beyond its incipient use for non-market valuation, an initial step in this direction was taken by Welsch (2002) by comparing the monetized benefit from air pollution abatement estimated by the EPM (see subsection 3.1) with estimates of marginal abatement costs from the literature. The result of this comparison was that the marginal benefit from abatement exceeds the corresponding marginal costs up to considerable degrees of abatement.

That analysis was extended by Welsch (2007) to compute optimal pollution levels. Using the same basic data set and happiness function as Welsch (2002), the model is augmented by a concave production function for per capita GNP. In the production function, air pollution plays the role of a quasi-input, other inputs being physical and human capital. In this set-up the net marginal value of pollution, that is, the marginal product (from the production function) minus the monetized marginal disutility (from the happiness function) can be computed. The net marginal value at observed pollution levels is found to be negative for most countries in the sample. By computing that level of pollution at which the marginal product and the marginal monetized disutility are equalized, optimal pollution levels are determined. In the case of several less developed and transition economies with weak environmental regulation there is a large disparity between actual and optimal pollution levels.

4.2 Land Use, Biodiversity, and Scenic Amenities

A number of recent studies use the EPM to provide insights on the value of natural environments or specific attributes associated with those natural environments (biodiversity and scenic amenity). As noted in MacKerron and Mourato (2013), there are at least three reasons for thinking that natural environments will have a positive impact on individual well-being. First, the biophilia hypothesis suggests that there is an instinctive bond between human beings and other living systems which is a product of biological evolution (Wilson 1984). Second, environmental quality may be higher in natural environments. Third, natural environments may encourage behaviors (such as exercise, recreation and social interaction) that are physically and psychologically beneficial. The psycho-evolutionary theory predicts that restorative influences of nature involve a shift towards a more positively toned emotional state, positive changes in physiological activity levels and that these changes are accompanied by sustained attention/intake. (Ulrich et al., 1991, Kaplan, 1995, pp.173-174).

Kopmann and Rehdanz (2013) relate regional land-use data to SWB in a cross-section of 31 European countries, and find that natural land cover (encompassing both cultivated and natural varieties) is positively associated with SWB, regardless of region, with higher values for scarce land categories (those with the lowest shares). White et al (2013) also report a beneficial effect of green space on both mental well-being and life satisfaction in England, but unlike Kopmann and Rehdanz (and like MacKerron and Mourato) they use a much higher level of spatial disagregation (their land-use classification is for an area of 4 km^2, on average) and by using panel data between 1991 and 2008, they are able to control for individual fixed effects. Overall, these three studies provide compelling evidence that natural environments have a positive impact on SWB, but fall short of identifying what specific attributes of the landscape matter most.

Ambrey and Fleming (2011 and 2013) point at scenic amenity and biodiversity as potential channels through which natural environments increase SWB, at least for the residents of South East Queensland (SEQ), Australia. They measure scenic amenity (in a 1-10 scale) by combining, at the Australian collection-district level, scenic preference maps (based on surveys of public preferences for scenery) with maps showing the degree of landscape visibility in SEQ. Ecosystem biodiversity for the SEQ bioregion is measured at a similarly high spatial resolution via Simpson's (1949) diversity index. Both variables are found to have a large impact on the life satisfaction of SEQ residents.

4.3 Energy Supply Systems

A recent area of application of the EPM is the supply of energy, specifically the supply of electricity. Though electricity *per se* is a private, marketable good, different supply technologies differ in terms of attributes such as cost, environmental impacts, and safety and security of supply. Given those differences, the question arises as to people’s preferences over those attributes and whether they manifest themselves in a relationship between the energy mix and SWB.

This issue is studied by Welsch and Biermann (2014). They merged survey data for about 140,000 individuals in 25 European countries, 2002-2011, with the supply shares of nuclear power and several types of fossil-based and renewable power in the respective country-years. Controlling for the usual individual and macro-level factors as well as country and year fixed effects, they find that individuals’ life satisfaction varies systematically and significantly with differences in the electricity mix across countries and across time. Among other results, they find that a greater share of solar and wind power relative to nuclear power is associated with greater life satisfaction. This relationship exists at all levels of income. Moreover, the respective coefficient has risen drastically after the Fukushima nuclear accident. Since a higher share of solar and wind power is associated with higher electricity prices, the authors interpret those results as evidence of a preference for a clean and safe electricity supply in spite of higher costs. In addition, the preference for oil-based electricity dropped at the time of political unrest in oil-exporting countries in North Africa (“Arab Spring”), which they take to indicate increased concern about supply security.

4.4 Environmental Disasters.

Natural disasters caused by *inter alia* earthquakes, volcanic eruptions, tsunamis, hurricanes, floods and droughts occur frequently across the world and can have profound environmental, political, and social consequences. The interest of economists in studying the impacts of natural disasters on human welfare is not new, but has intensified in recent years due to an increase in their incidence and damages. Some estimates put *ex post* disaster relief spending between 2011 and 2013 as high as $40 to $50 billion per year only in the US (Weiss and Wideman 2013). Disasters can have an impact on life satisfaction through the financial losses associated with property damages and fiscal consequences of reconstruction. Moreover, they can cause stress and other psychic costs (grief for the bereaved, individual and collective traumas). It is not surprising then that a number of recent studies have used the EPM to assess the impact of disasters on SWB.

In one of the first studies linking global self-reports of SWB to natural disasters, Kimball et al. (2006) find that reported happiness dipped significantly after the seriousness of the damage done by hurricane Katrina along the US Gulf coast from central Florida to Texas, became clear. The impulse response of happiness is stronger in the South Central region, closest to the devastation of Katrina. Interestingly, a remote event (the October 2005 earthquake in Pakistan) is also found to affect happiness, albeit to a lesser extent. Subsequent studies have analyzed the impacts of flood disasters on the life satisfaction of Europeans (Luechinger and Raschky 2009) and of droughts on the life satisfaction of Australians (Carroll et al 2009). Both studies estimate a large willingness to pay to avoid hydrometeorological disasters: $6,505 to prevent a sure flood event, and A$18,000 for residents in rural areas to prevent a spring drought, respectively.

Kountouris and Remoundou (2011) estimate the impact of fire frequency and extent on the life satisfaction of residents of the European Mediterranean region (Italy, France, Spain and Portugal).[22] As ex-

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[22] Because fires are correlated with pressures from local economic activity which are not included as regressors in the life satisfaction equation, they instrument their fire indicator with mean daily precipitation from April to September, which does not overlap with the period of survey fieldwork. Although this ensures that the instrument does not have a direct influence on SWB through weather conditions on the day of the interview, many studies (Rehdanz and Maddison 2005, Maddison and Rehdanz 2011, Murray et al. 2013) have shown that climate conditions do have an impact on SWB.

pected, the negative impact of forests incidents is larger for larger-scale fires and more pronounced for rural residents, but even in this case, the WTP to prevent an additional forest fire incident is estimated at only €0.26, which the authors attribute to a possible hedonic adaptation to forest fires, which are a seasonal and widespread phenomenon in the region, and to analyzing mainly small fires that burnt less than 100ha of forest.

In the aftermath of the earthquake, tsunami and subsequent meltdown of the reactors of a nuclear plant in Fukushima, Japan on March 11, 2011, German Chancellor Angela Merkel proclaimed an acceleration of the phase-out of nuclear power in Germany, a country more than 5,000 miles apart from Japan. Is it possible that the effects of a disaster in Japan reverberate on the German electorate? Kimball et al's results suggest that yes, an environmental disaster can have impacts on the SWB of individuals far removed from the directly affected area. In addition, nuclear energy in Germany has been controversial for years (leading to a phase-out decision already in 1999 which was revised 10 years later). Using data from the German SOEP, Berger (2010) shows that a previous nuclear accident, at Chernobyl's nuclear power plant on April 26, 1986 boosted environmental concerns among the German population. However, she does not find evidence that the accident had a significant effect on general life satisfaction. Goebel et al. (2013) find similar results for the Fukushima accident, the meltdown significantly increased environmental concerns in Germany (by 20%), but did not have an effect on global reports of life satisfaction, only on an affective well-being measure: sadness.

The accident in Fukushima did have a marked impact on SWB in Japan. Rehdanz et al. (2013) find that after the disaster people living in a place affected by the tsunami or close to the Fukushima Dai-ichi power plant experienced a drop in life satisfaction (measured as "satisfaction with life in the previous year"), while the well-being effects declined with distance to the place of the event. The drop in life satisfaction in areas affected by the tsunami is equivalent to 72 percent of annual income and goes up to 110 percent in areas where fatalities were reported. However, in contrast to satisfaction with life in the previous year, no effect on people's satisfaction with their entire life can be found among those affected by the disaster. A possible explanation, discussed by the authors, is a stoic life attitude characteristic of Japanese culture. In addition, no change in well-being is detectable in people living close to nuclear facilities in general. This is consistent with the idea that the well-being effects of the disaster are strongly related to physical effects and mental distress actually experienced rather than general concern about nuclear safety.

5. Well-Being and Environmental Behavior

In addition to offering a tool for environmental valuation, well-being data permit to test assumptions on environmental behavior made in mainstream economics. One such assumption refers to people's location choices in response to differences in environmental conditions which, according to the hedonic model, are expected to result in equalization of utility across locations (at least for people of a similar type). Another assumption is that individuals correctly anticipate the utility consequences of environmentally relevant consumption choices and balance the benefits and costs of those choices in such a way that utility is maximized.

5.1 Spatial Equilibrium and Hedonic Pricing

In a hedonic spatial equilibrium wages and rents must adjust to equalize utility across locations. Otherwise some individuals would have an incentive to move to locations where they could attain a higher utility. However this equilibrium relies on strong assumptions that are not likely to hold in practice. For example, hedonic models typically assume that people have perfect information and move freely among locations when they buy homes and choose jobs. Even in a country such as the US where costs to mobility are assumed to be low, Bayer et al. (2009) show that the great majority of household heads (from 58 to 79%) reside in the region of their birth.

Other than by observing violations of its implicit assumptions, a test of the hedonic spatial equilibrium requires a comparison of utility across locations. This is precisely the test that Ferreira and Moro (2010) propose. Using SWB as a proxy for utility, in statistical terms, the differences in reported SWB should not be significant across different locations. Assuming that personal traits are averaged out, they perform both parametric and non-parametric statistical tests and find that even in a small country such as Ireland, SWB varies across all the geographical levels considered (regions, local authorities and electoral divisions). In addition to the unconditional tests, they conduct another, conditional test to account for potential structural differences across locations that may lead to personal traits not averaging out. That is, socio-demographic characteristics may also vary spatially, and result in differing proportions of different types of individuals across locations. They run a SWB regression with region dummies controlling for individual characteristics (sex, age, education level, marital status, family size, employment status, income and housing prices), and find that the regression-adjusted life satisfaction in different regions (the estimated location dummies) are also statistically different. They interpret these findings as evidence that the equilibrium condition required by the hedonic approach in Irish markets does not hold.

Ferreira and Moro (2010) use cross-sectional data for Ireland. Using data from the German socio-economic panel, Maddison and Rehdanz (2007) find that, although in any year there may be large differences in average utility between German regions even when stratifying by different individual types, these utility differences tend to be eliminated over time, especially for highly educated individuals.

The question begs whether regional differences in utility are related to regional differences in environmental amenities. Results in Moro et al. (2008) suggest that for Ireland, they are. They find that three alternative rankings of quality of life (QoL): the simple unconditional average of SWB across location, a conditional average that differs only in terms of the environmental amenities, and a QoL index that weights environmental amenities by their MRS with income, are highly correlated (r=0.61 to 0.98). This suggests that the spatial variation of SWB across locations is not random but driven by their endowments of amenities. Because hedonic price data on wages and rents in Ireland are not readily available, Moro et al. (2008) cannot compare their rankings with “objective” QoLs rankings (where the weights for environmental amenities are derived from hedonic regressions). Oswald and Wu (2010), using data for the US, do. They find a strong correlation (r=0.6) between the conditional average/regression adjusted life satisfaction and objective QoL rankings, which they take as an objective confirmation that subjective well-being measures are meaningful.

5.2 Environmental Behavior and Rational Choice

Consumer theory maintains that individuals make accurate forecasts as to the utility consequences of their choices (or, equivalently, that decision utility coincides with experienced utility) and make choices that maximize utility. This assumption has been called into question by behavioral economists (see subsection 2.1) but is impossible to test unless a measure of experienced utility is available. SWB data offer such a measure and have been used to test the assumption of utility-maximizing choice, in particular with regard to environmentally relevant choices.

One example of an environmentally relevant choice refers to commuting. Standard theory predicts that people balance the benefits from commuting in terms of higher income against the associated mental distress, loss of time available for social and family interactions, etc. At the optimum, the positive and negative effects of the time spent commuting should just balance, such that the net marginal utility of commuting time should be zero. Stutzer and Frey (2010) use information on individuals’ commuting time and subjective well-being to test whether the optimality condition is satisfied. They estimate a well-being regression that includes commuting time but not income. In such a set-up, a utility maximum would require that the coefficient on commuting time be indistinguishable from zero, but in fact it is found to be significantly negative. This suggests that people ex ante underrate the disutility from commuting relative to the utility from higher income and spend more time commuting than is utility maximizing.

A similar question arises with respect to pro-environmental behaviors, such as recycling, water saving, and the purchase of "green" products. These activities are supposed to yield utility (satisfaction) due to an intrinsic motivation to protect the environment, but also disutility due to inconvenience or high costs. Utility maximization would, again, imply that the positive and negative effects balance, such that that the net marginal utility from these behaviors be zero.

This condition is tested and refuted by Welsch and Kühling (2010). In their life satisfaction regressions the coefficients indicating the net marginal utility from recycling, water saving and purchasing green products are found to be significantly positive. This suggests that people ex ante underrate the satisfaction from pro-environmental behavior relative to other forms of consumption and, consequently, could raise utility by behaving more environmentally friendly. These qualitative findings are confirmed by Welsch and Kühling (2011). In addition, they find that the decision error is smaller in people whose peers display more pro-environmental behavior and in people who have themselves displayed those behaviors for a longer period of time. One interpretation of these findings is that people learn to appreciate the satisfaction from those behaviors, such as to make smaller errors. Another would be in terms of social comparison and habituation effects diminishing the satisfaction from green behaviors.

Another example of an assumption rooted in economic analysis is that people care more about the environment as their income increases. While, in principle, any valuation technique can be used to estimate whether the willingness-to-pay for environmental amenities varies with income, using SWB one can directly analyze whether the marginal utility of environmental amenities varies with income. Ferreira and Moro (2013) find little empirical support for the marginal effects of environmental amenities in Ireland being larger for the richest.

6. Conclusions

Recent years have seen a sharp increase in the use of subjective well-being data in economics in general and environmental economics in particular. This article has discussed the conceptual underpinnings of using such data as a tool for preference elicitation and non-market valuation. Given the connection of those data to the notion of experienced utility, we referred to this approach as the experienced preference method and discussed recent methodological advances and applications of the approach to subject areas not previously reviewed. In addition, we discussed insights concerning environmental behavior that can be gained with the help of subjective well-being data.

The literature reviewed indicates that factors such as air pollution, noise, climate, scenic amenities, biodiversity and natural disasters are correlated with subjective well-being. Though the relationships found are broadly plausible a priori, they largely have the character of reduced-form relationships in which the specific transmission channels at work remain in the background. For example, air pollution may affect people both aesthetically (through reduced visibility) and through its health impacts, but the extant literature has not assessed the relative importance of each of these mechanisms. In some other cases, the specific transmission channels are still highly hypothetical. For instance, the channels through which biodiversity impacts on well-being are as of yet more a matter of philosophical reasoning than of empirical evidence. In order to disentangle channels of influence, systems of structural equations rather than simple reduced-form specifications may be useful.

A specific issue of which a better understanding is desirable is the role of habituation to environmental conditions. As it was discussed above, it is unclear what time scales are relevant in the relationship between air pollution and well-being and to what extent people habituate to air pollution. While impairment by poor visibility is probably a short-term phenomenon, some health effects may depend on long-term exposure. Combining subjective well-being research with epidemiological research might help shed more light on such questions. In addition, the use of complementary approaches (such as the Day Reconstruction Method and the Experience Sampling Method) and new technology (GPS, biophysical monitoring) may help disentangle the immediate and lasting impacts of pollution on mental and physical well-being.

As to geographical coverage, the literature to date has mostly focused on industrialized or emerging economies. To a great extent this is due to a lack of appropriately disaggregated environmental data for developing countries (although for an exception, see Alem and Colmer 2013). It is to be hoped that such data will be forthcoming with more resources and improved tools and technologies. This would then allow investigation of possible differences across development levels and cultures in the relationship between environment and well-being. In addition, geographically disaggregated data in a cross-national setting would facilitate the identification and further exploration of transboundary effects on well-being.

In contrast to other non-market valuation approaches that have been studied and applied for decades, no widely accepted protocol summarizing “best practice” has developed for EPM yet. Developing such a protocol, especially given the possibility of using EPM to complement conventional valuation approaches in benefit-cost analysis, is gaining urgency. From a methodological point of view, establishing causality is particularly challenging in SWB research. Being a broad concept, it is difficult to be sure that SWB is not the cause of another variable and that all important variables correlated with those whose impact on SWB one is trying to estimate are included in the analysis. The use of fixed effects, especially with individual panel data can help in this respect. In addition it is important to control for time-varying factors such as housing prices and the time spent on income acquisition in order to obtain unbiased estimates of the co-efficients of interest, that is, the coefficients on amenities and income, respectively. In the absence of controlled experiments to establish causality, more extensive reliance on quasi-experimental difference-in-difference research designs might be useful. Finally, a comparison of different valuation techniques in a controlled manner (same amenities, same respondents, same moment in time) would shed light on whether EPM results really are different or not.

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Table 1: Articles on Environment and Subjective Well-Being by Year of Publication

Article	Environmental Variables	Geographical Area
Frijters and Van Praag (1998)	Climate	Russia
Welsch (2002)	Air pollution	54 countries
Van de Vliert et al. (2004)	Climate	71 countries
Rehdanz and Maddison (2005)	Climate	67 countries
Van Praag and Baarsma (2005)	Noise	Amsterdam
Venuri and Costanza (2006)	Natural capital	171 countries
Welsch (2006)	Air pollution	10 countries, 1990-1997
Welsch (2007)	Air pollution	54 countries
Brereton et al. (2008)	Environmental amenities	Ireland
Moro et al. (2008)	Environmental amenities	Ireland
Di Tella and MacCulloch (2008)	Air pollution	13 countries, 1975-1997
Rehdanz and Maddison (2008)	Air pollution, noise	Germany
Smyth et al. (2008)	Environmental Amenities	China
Carroll et al. (2009)	Drought	Australia
Engelbrecht (2009)	Natural Capital	58 countries
MacKerron and Mourato (2009)	Air pollution	London
Luechinger (2009)	Air pollution	Germany
Luechinger and Raschky (2009)	Floods	16 countries, 1973-1998
Berger (2010)	Nuclear disaster	Germany
Ferreira and Moro (2010)	Environmental amenities	Ireland
Luechinger (2010)	Air pollution	13 countries, 1979-1994
Menz and Welsch (2010)	Air Pollution	25 countries, 1990-2004
Ambrey and Fleming (2011)	Scenic amenity	Australia
Fischer and Van de Vliert (2011)	Climate	58 countries
Kountouris and Remoundou (2011)	Forest fires	European regions
Maddison and Rehdanz (2011)	Climate	79 countries
Menz (2011)	Air pollution	48 countries, 1990-2006
Cuñado and Perez de Gracia (2012)	Air pollution, climate	Spain
Gandelman et al. (2012)	Air pollution, noise	Uruguay
Levinson (2012)	Air pollution	USA
Menz and Welsch (2012)	Air pollution	10 countries, 1990-1997
Ambrey and Fleming (2013)	Ecosystem diversity	Australia
Ferreira et al. (2013)	Air pollution	European regions
Ferreira and Moro (2013)	Environmental amenities	Ireland
Guardiola et al. (2013)	Water access	Mexico
Koopman and Rehdanz (2013)	Land Use	European regions
MacKerron and Mourato (2013)	Land Use	UK
Sekulova and van den Bergh (2013)	Climate	Barcelona
Urban and Maca (2013)	Noise	Czech Republic
Weinhold (2013)	Noise	28 European countries
White et al. (2013)	Land Use	UK
Ambrey et al. (2014)	Air pollution	Australia
Li et al. (2014)	Air pollution	China
Welsch and Biermann (2014)	Electricity mix	25 countries, 2002-2011

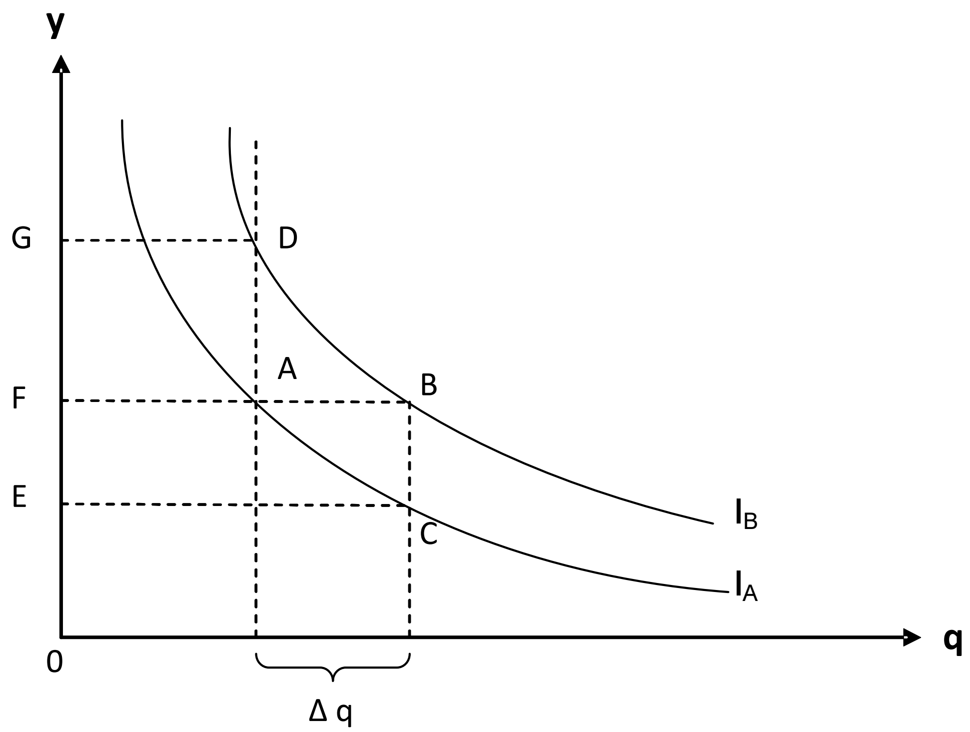

Figure 1: Trade-off between income and environmental quality. If an environmental improvement moves the individual from A on indifference curve I_A to B on indifference curve I_B , the associated equivalent and compensating surplus are G – F and F – E, respectively.

Energy Prices, Energy Poverty, and Well-Being: Evidence for European Countries*

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Abstract
This paper uses data on the life satisfaction of more than 100,000 individuals in 21 European countries, 2002-2011, to study the relationship between subjective well-being and the prices for households of electricity, oil and gas. We find that energy prices have statistically and economically significant effects on subjective well-being. The effect sizes are smaller than but comparable to the effects of important personal factors of well-being. Effects above average are found in individuals from the lowest income quartile. In addition, effects are strongest at times when required energy expenditures can be expected to be high. The empirical results are consistent with the prediction that greater energy poverty implies a greater effect of energy prices on well-being.

Keywords: energy price; energy poverty; fuel poverty, consumer welfare; subjective well-being
JEL classifications: Q41; I31; D12
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*Appendix to chapter 3.

1. **Introduction**

The residential consumption of fuel and power is an important component of household consumption. It contributes to well-being through heating and cooling, lighting, cooking, and the operation of appliances. Different from most other consumer goods, fuel and power consumption is often considered a basic need whose satisfaction is necessary for an acceptable quality of life. Since the access to fuel and power crucially depends on the level of their prices, and given the dependence of those prices on policy choices (for instance choices concerning taxation or the energy mix), the relationship between energy prices and well-being is an important issue both from an academic and a public policy point of view.

From a more specific perspective, the character of energy consumption as a basic need has spurred an interest in studying what has come to be known as energy poverty.[23] In a strict sense, it appears natural to refer to a consumer as energy poor if prevailing prices prevent her from satisfying a minimum requirement of energy (Foster et al. 2000). In a wider sense, it is common to speak of energy poverty if the costs of satisfying the minimum energy requirement exceed a certain threshold level, even if those costs stay within the limits of the budget constraint. A rationale for this wider notion of energy poverty is that a high level of required energy costs constrains the consumption of non-energy goods and thus consumer welfare (Brunner et al. 2011).[24]

Though energy poverty has been discussed for several decades (e.g., Boardman 1991), the issue has recently gained increasing attention in research (e.g., Hills 2012, Moore 2012, Thomson and Snell 2013) and in public policy (EU 2010), not least because of rising energy prices (Neuhoff et al. 2013). The policy relevance of energy poverty is evidenced by policies in several countries to combat it, such as the UK Winter

[23] We use the term “energy poverty” interchangeably with “fuel poverty”.

[24] Energy poverty in the strict sense is discussed in particular with respect to developing countries (Foster et al. 2000) whereas the wider notion may be more relevant in developed economies.

Fuel Payment and national or municipal funds for subsidizing energy costs for low income households in Belgium and Italy, respectively.[25] Energy prices – gas prices in particular – are an increased concern after the recent conflict between Ukraine and Russia.

Measuring and analyzing energy poverty, however, is hampered by ambiguity as to the appropriate definition and measure.[26] In addition, more basically than ambiguity of measurement, an important issue in the study of energy poverty is its welfare significance, however energy poverty is specified. Though it is intuitive to expect a negative effect of energy poverty on consumer welfare, the nature of the relationship is surrounded by considerable vagueness.

Against the background of those practical and theoretical ambiguities, this paper pursues a different approach to energy prices, energy poverty and welfare, focusing on the implications of energy poverty for consumer welfare directly. Based on the insight (to be derived below) that a higher energy poverty ratio – the ratio of required energy costs to income – implies a greater effect of energy price increases on consumer welfare (utility), we identify the degree of energy poverty with the effect of energy prices on utility. According to this conceptualization, energy poverty is greater if consumers suffer greater welfare losses from a price increase. We deem this approach to be in line with the idea that the ultimate rationale for the notion of energy poverty rests on its implications for welfare and the quality of life.

The purpose of this paper thus is to measure the relationship between energy prices and individual welfare, taking the strength of that relationship as an indicator of energy poverty. Empirically, we implement this research strategy by using data on subjective well-being (SWB) as a proxy for utility. Based on data for between 100,908 and

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[25] See European Fuel Poverty and Energy Efficiency Projects: Detailed Report on Different Types of Existing Mechanisms to Tackle Fuel Poverty. Accessible at www.fuel-poverty.org.

[26] For instance, Moore (2012) and Heindl (2013) have shown that applying different measures of energy poverty discussed in the literature implies a large variation in the number of households identified as energy poor as well as in the population subgroups affected by energy poverty.

117,819 individuals in 21 European countries, 2002-2011, we estimate well-being equations that include the prices to households of electricity, gas and light fuel oil among the explanatory variables while controlling for the usual covariates of well-being as well as for county and time fixed effects.

We find that energy prices have statistically and economically significant effects on SWB. On average, a 1-standard-deviation increase in the prices of electricity and gas reduces well-being – measured on an 11-point scale – by about 0.10 and 0.12 points, respectively. In the lowest income quartile a 1-standard-deviation increase in the prices of electricity, oil and gas reduces well-being by 0.14, 0.16 and 0.15 points, respectively. These magnitudes are smaller than but nevertheless comparable to the well-being effects of important personal life circumstances like being unemployed. In addition, effects are seasonally concentrated at times when required energy expenditures can be expected to be high due to, for instance, heating requirements. The empirical results are consistent with the prediction that greater energy poverty implies a greater effect of energy prices on consumer welfare.

Our approach of using SWB regressions for a welfare assessment of energy prices 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). With regard to energy, the SWB approach was used by Welsch and Biermann (2014) in an assessment of electricity supply structures in Europe

The paper is organized as follows. Section 2 presents the conceptual and section 3 the empirical framework. Section 4 reports and discusses the results. Section 5 concludes.

2. **Conceptual Framework**

2.1 Energy Poverty Measures

Measures of energy poverty typically rely on the energy poverty ratio and apply it in various ways to arrive at an assessment of overall energy poverty in society as well as its incidence across subgroups.

The energy poverty ratio (*EPR*) is the ratio between the costs of "required" energy consumption and income:

$$EPR = p^{*}R/Y, \qquad (1)$$

where p, R and Y denote the energy price, required energy consumption and income, respectively.

Definitions of energy poverty usually relate the EPR to some threshold level (poverty line) and identify households as energy poor if their EPR exceeds that threshold. Examples of poverty lines include the 10-percent threshold and the 2-times median or 2-times average expenditure share thresholds. The high-cost/low-income approach (Hills 2012) defines those households as energy poor whose EPR exceeds an energy poverty threshold while their income falls below a general-poverty threshold. In addition, some energy poverty measures refer to the difference rather than the ratio between income and energy expenditures and identify households as energy poor if their income net of energy costs falls short of a specified level.[27]

[27] See Moore (2012) and Heindl (2013) for a discussion of energy poverty measures.

There is thus a diverse set of energy poverty measures which differ by whether they refer to ratios or differences between required energy costs and income, by the threshold they apply, and by whether or not they incorporate general poverty (income poverty). In practice, they are typically computed by replacing "required energy expenditures" by actual energy expenditures because the former are unobserved. Following this practice, Moore (2012) and Heindl (2013) found that applying different measures of energy poverty implies a large variation in the number of households identified as energy poor as well as in the population subgroups affected by energy poverty.

2.2 Energy Poverty and Consumer Welfare

Though the notion of energy poverty seems to be rooted in a concern for welfare, the relationship between energy poverty and its constituents – energy prices, energy requirements, and income – on the one hand, and consumer welfare on the other is usually not made explicit. This subsection discusses the channels through which energy poverty – high required energy expenditures relative to income – affect welfare. As it will be seen, the welfare significance of energy poverty rests on the fact that it makes consumers more vulnerable to energy price increases in the sense that an energy price increase has a greater effect on utility if the level of energy poverty is higher. This insight will motivate our empirical analysis of the relationship between energy prices and well-being.

Consider an individual who derives utility from energy E and a non-energy good N according to a monotonically increasing and strictly concave utility function:

$$u = U(E, N) , \quad (2)$$

Treating the non-energy good as the numeraire and denoting income and the energy price by Y and p, respectively, the consumer's problem is to maximize utility subject to a budget constraint p*E + N = Y. This yields demand functions E(p,Y) and N(p,Y), and substituting these into (2) gives the indirect utility function:

$$u = U(E(p,Y), N(p,y)) =: V(p,Y),$$

The utility effect of an energy price increase, written in elasticity form, is given by:

$$\eta_{Vp} = \eta_{UE}\eta_{Ep} + \eta_{UN}\eta_{Np}, \qquad (3)$$

where $\eta_{XY} := (\partial X / \partial Y)/(X / Y)$ denotes the elasticity of a variable X with respect to Y.

According to (3), the effect of an energy price increase is composed of the changes in energy demand and non-energy demand, each weighted by the corresponding elasticity of utility. Basic microeconomics implies that the total effect is negative. It also implies that the effect on non-energy demand is negative ($\eta_{Np} < 0$) if and only if energy demand is inelastic ($-1 < \eta_{Ep} < 0$).[28]

Against this background, we now address the welfare significance of a "required" level of energy consumption, R, and of energy poverty. It is convenient to refer in this discussion to the Stone-Geary utility function (which underlies the popular linear expenditure system) because it directly focuses on a minimum required level of energy consumption.[29] Hence we consider:

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[28] Intuitively: If energy demand is inelastic, the income effect dominates the substitution effect in the response of non-energy demand to energy price increases.

[29] To be concise, we consider a consumption minimum for energy only.

$$u = U(E, N) = a(E - R)^{\alpha} N^{1-\alpha} \qquad (4)$$

where the scaling parameter *a* is positive if E – R is non-negative, and zero otherwise. The demand functions associated with (4) are $E = R + \alpha(Y/p - R)$ and $N = (1-\alpha)(Y - pR)$, and it is easy to compute that $\eta_{UE}\eta_{Ep} = -\alpha Y/(Y - pR)$ and $\eta_{NE}\eta_{Np} = -(1-\alpha)pR/(Y - pR)$. Hence, under (4) the utility effect of an energy price increase, equation (3), takes the following form:

$$\eta_{Vp} = \eta_{UE}\eta_{Ep} + \eta_{UN}\eta_{Np} = \frac{-\alpha Y}{Y - pR} + \frac{-(1-\alpha)pR}{Y - pR} = -\frac{\alpha + (1-\alpha)EPR}{1 - EPR}, \qquad (5)$$

where EPR = p*R/Y is the energy poverty ratio, see equation (1).

From equation (5) several insights can be gained:

Proposition 1. Given the utility function (4) with 0 < R < Y/p, the following holds:

(a) A greater energy poverty ratio implies greater marginal disutility from a rise in the energy price: $\partial|\eta_{Vp}|/\partial EPR > 0$.

(b) A rise in the energy price implies a decrease in the consumption of both energy and non-energy: $\eta_{Ep} < 0, \eta_{Np} < 0$.

(c) A greater energy poverty ratio implies that a greater share of the overall disutility effect of energy price increases accrues to the reduction in non-energy consumption: $\partial(\eta_{UN}\eta_{Np} / \eta_{UE}\eta_{Ep}) / \partial EPR > 0$.

Result (a) demonstrates that the welfare effect of energy poverty consists in raising the effect of energy price increases on consumer utility while results (b) and (c) clarify the channels through which this effect operates.

Considering the constituents of energy poverty, a corollary of result (a) is that the disutility from an energy price increase is greater if (i) income is lower, (ii) the energy price is higher, and (iii) the energy requirement is higher.

Against the background of Proposition 1, studying the effect of energy prices on utility is not only important per se; it also permits to shed light on the welfare implications of energy poverty. In addition to its conceptual motivation, a practical advantage of such an approach is that it does not involve a measure of "required energy expenditures" which, in view of their unavailability, are usually replaced with observed energy expenditures in conventional analyses of energy poverty.

3. **Empirical Framework**

3.1 Data

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 variable used to capture 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 dissatisfied and 10 means extremely satisfied, and we use the answers on the 11-point scale as our dependent variable. In robustness checks we use 11-point happiness instead of life satisfaction as the dependent variable.[30]

[30] The happiness question is: "Taking all things together, how happy would you say you are?"

The explanatory variables at the individual level include socio-demographic and socio-economic factors that have been found to be related to SWB (sex, age, marital status, household size, employment status and household income), see, e.g., Dolan et al. (2008).[31] In addition, our regressions include macroeconomic control variables (quarterly data for GDP per capita and the rates of inflation and unemployment), taken from the OECD online data base (www.oecd.org).

Our main variables of interest are the prices of electricity, gas and light fuel oil for households, which we take from the IEA Energy Prices and Taxes database, see www.iea.org. The data for the gas price refer to natural gas, which – similar to oil and unlike electricity - mainly serves heating purposes. The prices of electricity and gas are average unit values, which are obtained either from utilities as average revenue per unit delivered to households or from households as average expenditure per unit purchased. Energy price data are reported by country and quarter and we matched each observation from the ESS with the respective energy price variable (real unit energy prices for households at PPP-corrected USD) on a country-quarter level.

The five-wave cumulative dataset of the ESS includes about 240,000 observations from 33 countries. Because energy price data are unavailable for some countries, our analysis refers to the following 21 countries in the case of electricity: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Sweden, Switzerland, Turkey and the UK. In the case of oil the set of countries includes Luxembourg and Spain in addition whereas Hungary and the Slovak Republic are missing. In the case of gas the set of countries corresponds to the one for electricity plus Spain minus Italy and Norway. Due to missing price data and a small number of non-responses in

[31] With respect to household income, the ESS includes a 12-point scale where 1 corresponds to less than 1,800 Euro annually and 12 corresponds to more than 120,000 Euro. For steps 3 to 8 each step corresponds to 6,000 Euro.

the ESS the final samples for econometric analysis include observations for 100,908 individuals (electricity), 117,819 individuals (oil) and 101,937 individuals (gas).[32]

Tables A1 and A2 in the Appendix contain the variable descriptions and the summary statistics of the main variables. The average electricity price is 0.189 USD per kWh and varies between 0.064 (minimum) and 0.343 (maximum). The average oil price is 0.856 USD per liter (minimum = 0.260, maximum = 2.767) and the average gas price is 0.068 USD per kWh (minimum = 0.018, maximum = 0.162). Energy prices can thus be considered to exhibit sufficient variation to permit identification of their effect on well-being.

3.2 Discussion of Subjective Well-Being Data

In using SWB data for economic analysis it is important to understand the assumptions to be imposed on the information content of those data. As discussed by Ferrer-i-Carbonell and Frijters (2004), necessary assumptions are (a) a positive monotonic relationship between SWB and the underlying true utility u (if $SWB_{it} > SWB_{is}$, then $u_{it} > u_{is}$ for individual i at times t and s) and (b) ordinal interpersonal comparability (if $SWB_{it} > SWB_{jt}$, then $u_{it} > u_{jt}$ for individuals i and j). Validation research has produced a variety of supporting evidence of those assumptions (see Diener et al. 1999, Frey and Stutzer 2002, Ferrer-i-Carbonell and Frijters 2004). Under ordinal interpersonal comparability SWB can be treated as an ordinal variable. If, more restrictively, cardinal interpersonal comparability is assumed ($SWB_{it} – SWB_{jt}$ is proportional to $u_{it} – u_{jt}$), SWB can be treated as a cardinal variable.[33] Ferrer-i-Carbonell and Frijters (2004) and many others found that assuming the data to be ordinal or cardinal and applying the corresponding estima-

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[32] If we were to consider a common sample for all types of electricity the number of observations would be reduced to 80,068.

[33] Cardinal interpersonal comparability amounts to assuming that the difference between an SWB score of, say, 8 and 9 is the same as the difference between a 4 and a 5 (Ng 1997).

tion methods has little effect on qualitative results. In the empirical analysis we will check the robustness of our results to those assumptions.

Another issue with SWB data is that they are bounded from below and from above. This implies that one can neither observe a decline in SWB if it was in the lowest category in the preceding period, nor an increase if it was in the highest category. A way of addressing this problem is by collapsing the information of SWB variables in two categories (high/low), and we will do so in an additional robustness check.

3.3 Empirical Strategy

We estimated a micro-econometric SWB function in which the self-reported life satisfaction (*LS*) of individual *i*, in country *c* and time *t* depends on a set of individual socio-demographic and socio-economic indicators ($\boldsymbol{micro}_{ict}$), macroeconomic indicators ($\boldsymbol{macro}_{ct}$), residential energy prices (pen_{ct}), and country and time dummies ($country_c$, $time_t$, respectively). The general form of the estimating equations reads as follows:

$$LS_{ict} = \boldsymbol{\alpha}'\boldsymbol{micro}_{ict} + \boldsymbol{\beta}'\boldsymbol{macro}_{ct} + \gamma \; pen_{ct} + country_c + time_t + \varepsilon_{ict} \,. \quad (6)$$

In this specification, time *t* refers to the quarters 2002.I to 2011.IV; ε_{ict} denotes the error term. The *micro* controls are sex, age, marital status, household size, employment status, and household income. The *macro* controls are quarterly GDP per capita, inflation rates, and unemployment rates. In addition to those controls, we account for unobserved country- and time-invariant factors with country and quarter fixed effects. The *country* fixed effects account for unobserved time-invariant country characteristics (like climate or cultural attitudes) that may affect both the energy prices and well-being whereas the *time* fixed effects (2002.II to 2011.IV) account for unobserved time-specific confounding factors that are common to all countries (e.g. common global shocks). We extend equation (6) to include interactions of the price variables with several factors that may affect the relationship between energy prices and well-being.

Based on the results of Ferrer-i-Carbonell and Frijters (2005) we treat the dependent variable, 11-point life satisfaction, as a cardinal variable in our main analysis and estimate equation (6) using least squares. As a robustness check we estimate an ordered probit model. We report robust standard errors adjusted for clustering at the county-quarter level.

4. **Results**

4.1 Main Estimation Results

Table 1 presents the main estimation results for equation (6).[34] Panel A refers to energy prices without interactions. The coefficients of the electricity, oil and gas prices are negative, and they are (at least weakly) significant for electricity and gas. Quantitatively, an increase of the electricity price by 1 USD per MWh (0.1 cent per kWh) is associated with a drop in life satisfaction by 0.00155 points (on the 11-point scale). In the case of gas the drop in life satisfaction for a corresponding price increase is 0.00459 points.

We thus find that the well-being effect of a 1-USD-per MWh increase of the electricity price is considerably smaller than that of the same increase of the gas price. In the light of the framework from subsection 2.2, an explanation for this difference in effect sizes may rely on different cost shares for (required) electricity and gas. For in-

[34] 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 various energy prices 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 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). As indicated by the estimates for the country dummies, Iceland, Switzerland, Norway and Denmark have the highest “generic” (that is, unexplained) levels of reported well- being, which is also consistent with the literature.

stance, German data reveal that in 2011 the mean expenditure share of electricity was 3.2 percent, whereas the share of expenditures for space heating (which includes gas) was 5.0 percent (Heindl 2013).

Panel B of Table 1 reports results differentiated by household income, where income groups approximately correspond to income quartiles. The coefficients for electricity are negative, but significant only for the lowest income quartile. For this group, the coefficient is considerably greater (in absolute terms) than the coefficients for the other groups and for the average household (as reported in panel A). In the case of oil, coefficients are now significant except for the second lowest group, and the one for the highest group is greater than those for the other. In the case of gas, the coefficients are significant for all income groups and the coefficient for the lowest group is the greatest, whereas the coefficient for the highest income group is the second greatest. Overall, the results for electricity and gas are consistent with the expectation that energy price increases have the largest well-being effect at low levels of income. In the cases of oil and gas we find, in addition, a u-shaped relationship between the price and well-being. A possible explanation for the large coefficient at high income is that high income may be a proxy for larger homes and, hence, greater heating requirements.

While income represents the denominator of the energy poverty ratio, the energy price and required energy consumption represent the numerator and hence are expected to raise the disutility from energy price increases according to the framework of subsection 2.2. Both the price and required consumption can be expected to vary across the quarters of the year. On the one hand, heating requirements imply that the demand for oil is high in autumn when tanks need to be filled for the winter season. On the other hand, high and inelastic seasonal demand may translate into high seasonal prices. In fact, as some complementary regressions show, the price not only of oil but also of gas is highest in the third quarter (Table A4) Thus, one or both components of required energy expenditures, price and quantity, can be expected to be high in the third quarter. In the case of electricity, prices are highest in the fourth quarter (Table A4) while payment of arrears for the preceding year may drive up electricity expenditures in the first quarter.

To check for seasonal differences in the relationship between well-being and energy prices, we included in the well-being regressions interactions with quarter dummies. Panel C of Table 1 reports the results. In the case of electricity we find a significant negative coefficient in the first and a weakly significant negative coefficient in the fourth quarter, whereas coefficients are insignificant in the second and third quarter. The coefficient in the first quarter is substantially greater than the year-average reported in panel A. The result for the first quarter may arise because of high “involuntary” electricity expenditures due to payments of arrears for the preceding year.

In the cases of oil and gas we get the interesting results that coefficients are significant only in the third quarter but not at other times of the year. This is consistent with the circumstance that both the “required” demand and the price of oil are high before the start of the winter season, implying a high expenditure share of oil. Similarly, high gas prices in the third quarter increase the expenditures for gas and the well-being effect of the price. Indeed, the coefficient for the gas price is substantially greater in the third quarter than the year-average (panel A).

Table 1: SWB and Energy Prices

Prices in PPP Dollar per Unit	Electricity (USD/MWh)	Oil (USD/1000 liter)	Gas (USD/MWh)
Panel A			
Price	-0.00155* (0.000916)	-0.000354 (0.000229)	-0.00459** (0.00196)
Constant	9.494*** (0.705)	7.156*** (0.561)	8.293*** (0.564)
R-squared	0.208	0.182	0.190
Panel B			
Price*Income<6k	-0.00231** (0.000962)	-0.000397* (0.000228)	-0.00590*** (0.00198)
Price*Income6k-24k	-0.00122 (0.000925)	-0.000299 (0.000234)	-0.00397** (0.00201)
Price*Income24k-60k	-0.00114 (0.000913)	-0.000382* (0.000228)	-0.00413** (0.00206)
Price*Income>60k	-0.00118 (0.000933)	-0.000492** (0.000228)	-0.00500** (0.00211)
Constant	9.494*** (0.705)	7.156*** (0.561)	8.293*** (0.564)
R-squared	0.209	0.182	0.191
Panel C			
Price*QI	-0.00207** (0.00104)	-0.000378 (0.000272)	-0.00247 (0.00247)
Price*QII	-0.00190 (0.00176)	-0.000427 (0.000286)	-0.00173 (0.00672)
Price*QIII	-0.00121 (0.00114)	-0.000736** (0.000286)	-0.00717*** (0.00317)
Price*QIV	-0.00158* (0.000933)	-0.000288 (0.000224)	-0.00324 (0.00213)
Constant	6.623*** (0.343)	7.266*** (0.617)	6.268*** (0.273)
R-squared	0.208	0.182	0.190

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. Regressions include micro controls (sex, age, marital status, household size, employment status and household income), macro controls (GDP per capita and the rates of unemployment and inflation) and country and quarter fixed effects (2002.II to 2011.IV). N = 100,908 (electricity), N = 117,819 (oil), N = 101,937 (gas).

4.2 Discussion

Our estimation results so far suggest several insights. First, electricity and fuels (oil and gas) differ in that a significant relationship between well-being and the electricity price exists only at low levels of income, whereas well-being is significantly related to the prices of fuel at all income levels except for the second quartile in the case of oil. A likely explanation of the difference between electricity and oil/gas is the lower amount that needs to be spent on required electricity consumption in comparison to expenditures for space heating using oil and gas.

Second, the strength of the relationship between well-being and energy prices depends on household income. As was just mentioned, in the case of electricity the relationship is significant only in individuals with low income. In the case of gas, the sensitivity of well-being to the price is greatest at low income. Both of this is consistent with the idea that the well-being effect of energy prices is increasing in the degree of energy poverty through an income effect, holding required expenditures constant.

Third, though electricity and gas prices affect well-being on average over the year, the effects are actually significant only in those seasons (quarters) in which required expenditures are high. In addition, though the oil price has no significant effect in the average of seasons, a significant negative effect exists at the time when expenditures can be expected to be higher than average. The finding that effects are greater when "forced" expenditures are high is consistent with the idea that the well-being effect of energy prices is increasing in the degree of energy poverty through required expenditures, holding income constant. In general, these findings yield the insight that the well-being effects of energy poverty are predominantly of a seasonal character.

In quantitative terms, a 1-standard-deviation change in the electricity price is associated with a change in 11-point life satisfaction by 0.096 for the average person and

0.144 for a person from the lowest income group. For a 1-standard-deviation change in the gas price, the effects are 0.119 (average) and 0.153 (low income). For the oil price the effect is 0.157 at low income. To put those figures in perspective, note that one of the strongest negative factors for well-being consists in being unemployed. In our data the well-being difference between an employed and an unemployed person is between 1.0 and 1.1 (see Table A3). The well-being effects of a 1-SD difference in energy prices can thus be considered to be of a non-negligible magnitude.

4.3 Robustness

We checked the robustness of our results to a number of factors, including the use of control variables and the treatment of the dependent variable. Results are reported in Table 3.

One factor that may impact on results is inclusion of the inflation rate. When the latter is included, as is the case in the specifications discussed so far, the measured effect of an energy price change is that which goes beyond the effect of a change in the general price level. As panel A of Table 3 shows, the conclusions on the significance of energy prices from panel A of Table 1 stay largely intact when the inflation rate is omitted, except that the significance level of the gas price increases. As for magnitudes, it is seen that, consistent with expectations, the coefficients of the electricity and gas price are greater (in absolute terms) than when the inflation rate is included. The increase in coefficient size amounts to 11.0 percent in the case of electricity and 9.6 percent in the case of gas.

To account for the possible non-cardinality of life satisfaction data, panel B in Table 3 reports the results from estimating the models from panel A of Table 1 using an ordered probit instead of least squares. In this case, the prices of electricity and gas become more significant, whereas the oil price remains insignificant. The coefficient sizes are of course not comparable to those from least squares, but the *ratios* of the significant coefficients are very similar: While under least squares the coefficient of the electricity price is 33.8 percent that of the coefficient of the gas price, it is 39.8 percent in the ordered probit model.

To account for the fact that life satisfaction data are bounded from below and from above (see subsection 3.2) we collapsed them into a “low” and a “high” category (each accounting for about one half of the observations) and estimated a probit model on these data. As panel C in Table 3 shows, the prices of electricity and gas are now more significant than in Table 1 and the oil price is weakly significant. This suggests that the boundedness of the life satisfaction scale tends to mask some of the well-being effects of energy prices

Finally, we replace the dependent variable, 11-point life satisfaction, with 11-point happiness and revert to least squares as the estimation method. The electricity price is now more significant whereas the gas price is less significant than with life satisfaction. The oil price is insignificant as it is in the case of life satisfaction. The magnitude of the electricity price coefficient is practically the same as with life satisfaction whereas the gas price coefficient is now 38 percent smaller.

5 Conclusions

This paper has used data on the life satisfaction of more than 100,000 individuals in 21 European countries, 2002-2011, to study the relationship between subjective well-being and the prices for households of electricity, oil and gas. We find that energy prices have statistically and economically significant effects on subjective well-being. The effect sizes are smaller than but comparable to the effects of important personal factors of well-being. Effect sizes above average are found in individuals from the lowest income quartile. In addition, effects are strongest at times when required energy expenditures can be expected to be high. The empirical results are consistent with the prediction that greater energy poverty implies a greater effect of energy prices on well-being.

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Appendix

Table A1: Description of Data

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 (quarterly)	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
Household Energy Prices (quarterly)		
Electricity Price		Electricity End Use Prices for Households (PPP-adjusted)
Light Fuel Oil Price		Light Fuel Oil End Use Prices for Households (PPP-adjusted)
Gas Price		Gas End Use Prices for Households (PPP-adjusted)

Table A2: Summary Statistics of Main Variables

		Sample Electricity			
Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Life Satisfaction	100908	7.01979	2.244549	0	10
GDPPC_Q_ppp	100908	7.607159	3.006035	0.3460003	14.61596

Inflat_Q	100908	.4327715	.6313537	-1.43013	3.879408
Unemp_Q	100908	7.447661	3.512062	2.533333	20.26667
Unemp_invol	100908	0.0340607	0.1813861	0	1
NetHousehold Income	100908	5.748831	2.720912	1	12
Elecprice	100908	189.0693	62.1076	64.36095	342.8068

Sample Light Fuel Oil (LFO)

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Life Satisfaction	117819	7.151368	2.164312	0	10
GDPPC_Q_ppp	117819	8.000223	2.924847	.3460003	17.27039
Inflat_Q	117819	0.4084959	.5947207	-1.650163	3.879408
Unemp_Q	117819	7.634302	3.539856	2.533333	22.03333
OCC_Unemp_invol	117819	0.0350283	.1838521	0	1
Net_HouseholdIncome	117819	5.976956	2.643891	1	12
LFO_Price	117819	856.5338	394.7213	259.7072	2767.4

Sample Gas

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Life Satisfaction	101937	6.91378	2.25876	0	10
GDPPC_Q_ppp	101937	7.113523	2.381947	.3460003	11.00873
Inflat_Q	101937	0.4378295	0.645011	-1.650163	3.879408
Unemp_Q	101937	8.391749	3.692231	3.033333	22.03333
OCC_Unemp_invol	101937	0.038308	0.1919397	0	1
Net_HouseholdIncome	101937	5.615949	2.626459	1	12
Gas_Price	101937	68.9154	25.98495	18.41632	162.3365

Table A3: Detailed Estimation Results

	(1) LFO	(2) Electricity	(3) Gas
Male	omitted	omitted	omitted
Female	0.122***	0.120***	0.120***
	(0.0128)	(0.0145)	(0.0153)
Age	-0.0613***	-0.0668***	-0.0659***
	(0.00439)	(0.00482)	(0.00474)
Age^2	0.000606***	0.000659***	0.000646***
	(0.0000430)	(0.0000468)	(0.0000464)
Household Size	-0.0140*	-0.0236***	-0.0229***
	(0.00732)	(0.00825)	(0.00800)
Single	omitted	omitted	omitted
Married	0.360***	0.339***	0.346***
	(0.0262)	(0.0291)	(0.0297)
Divorced	-0.160***	-0.190***	-0.211***
	(0.0347)	(0.0385)	(0.0390)
Separated	-0.492***	-0.519***	-0.512***
	(0.0620)	(0.0662)	(0.0666)
Widowed	-0.179***	-0.163***	-0.182***
	(0.0324)	(0.0360)	(0.0358)
Paid Work	omitted	omitted	omitted
In_school	0.185***	0.190***	0.243***
	(0.0349)	(0.0411)	(0.0407)
Voluntary_Unempl	-0.794***	-0.824***	-0.837***
	(0.0765)	(0.0866)	(0.0828)
Sick_empl	-1.189***	-1.151***	-1.156***
	(0.0562)	(0.0527)	(0.0578)
Retired	0.00438	-0.0394	-0.0120
	(0.0342)	(0.0361)	(0.0359)
Civil_Military	0.0997	0.131	0.0212
	(0.162)	(0.170)	(0.196)
Housework	-0.0740***	-0.0530*	-0.0716**
	(0.0280)	(0.0294)	(0.0289)
Other_empl	-0.242***	-0.172**	-0.153**
	(0.0645)	(0.0679)	(0.0696)
Invol_Unempl	-1.066***	-1.034***	-1.080***
	(0.0616)	(0.0551)	(0.0653)
Household_Income	0.132***	0.133***	0.145***
	(0.00655)	(0.00712)	(0.00691)
Austria	1.113**	-0.870***	-0.534***
	(0.545)	(0.254)	(0.106)
Belgium	1.186**	-0.769***	-0.582***
	(0.567)	(0.225)	(0.107)

Switzerland	1.635**	-0.188	
	(0.636)	(0.172)	
Czech_Republic	0.337	-1.930***	-1.321***
	(0.354)	(0.422)	(0.287)
Germany	0.719	-0.957***	-0.834***
	(0.545)	(0.232)	(0.0978)
Estionia	omitted	omitted	omitted
Denmark	2.125***	0.251	0.488***
	(0.511)	(0.229)	(0.0969)
Spain	1.340**		-0.231*
	(0.516)		(0.118)
Finland	1.692***	-0.310	-0.0441
	(0.519)	(0.278)	(0.139)
France	0.0682	-1.975***	-1.579***
	(0.511)	(0.288)	(0.131)
United_Kingdom	0.872	-1.007***	-0.800***
	(0.559)	(0.218)	(0.0811)
Greece	0.112	-2.126***	-1.450***
	(0.455)	(0.383)	(0.218)
o.Hungary	0	-2.699***	-2.135***
	(.)	(0.422)	(0.297)
Ireland	1.310**	-0.542***	-0.404***
	(0.591)	(0.208)	(0.0854)
Italy	0.877**	-1.338***	
	(0.419)	(0.322)	
Luxembourg	1.808*		
	(0.923)		
Netherlands	1.327**	-0.546***	-0.361***
	(0.529)	(0.202)	(0.0667)
Norway	1.707**		
	(0.729)		
Poland	0.672**	-1.626***	-0.927***
	(0.317)	(0.413)	(0.291)
Portugal	-0.617	-2.664***	-2.020***
	(0.399)	(0.361)	(0.239)
Sweden	1.779***	-0.250	0.133
	(0.531)	(0.186)	(0.115)
Slovenia	0.540	-1.875***	-1.086***
	(0.380)	(0.433)	(0.300)
Slowak_Republic	omitted	-1.874***	-1.332***
		(0.374)	(0.253)
Turkey	omitted	-2.914***	-1.889***
		(0.594)	(0.487)
Q1_02	omitted	omitted	omitted
Q2_02	-0.683***	-0.272***	-0.298***
	(0.258)	(0.0333)	(0.0331)

Q3_02	0.387	0.812***	0.899***
	(0.257)	(0.0665)	(0.0724)
Q4_02	0.410	0.884***	0.960***
	(0.257)	(0.0590)	(0.0587)
Q1_03	0.533**	1.071***	1.069***
	(0.260)	(0.108)	(0.0735)
Q2_03	0.211	0.672***	0.673***
	(0.264)	(0.121)	(0.0722)
Q3_03	0.692**	1.371***	1.375***
	(0.282)	(0.108)	(0.0860)
Q4_03	0.480	1.205***	1.233***
	(0.330)	(0.0405)	(0.0411)
Q3_04	0.503*	0.919***	1.070***
	(0.263)	(0.0863)	(0.0861)
Q4_04	0.543**	0.975***	1.026***
	(0.256)	(0.0679)	(0.0708)
Q1_05	0.541**	1.049***	1.044***
	(0.264)	(0.109)	(0.0906)
Q2_05	0.684**	1.204***	1.195***
	(0.267)	(0.0915)	(0.0829)
Q4_05	1.392***	1.742***	1.798***
	(0.283)	(0.144)	(0.139)
Q1_06	1.418***	1.799***	1.836***
	(0.274)	(0.114)	(0.109)
Q2_06	1.422***	1.707***	1.763***
	(0.287)	(0.126)	(0.121)
Q3_06	0.514*	1.036***	1.066***
	(0.278)	(0.118)	(0.125)
Q4_06	0.609**	1.065***	1.108***
	(0.266)	(0.102)	(0.110)
Q1_07	0.587**	1.111***	1.165***
	(0.268)	(0.109)	(0.124)
Q2_07	0.732**	1.276***	1.356***
	(0.287)	(0.144)	(0.174)
Q3_07	0.775***	1.336***	1.288***
	(0.279)	(0.127)	(0.125)
Q4_07	0.714**	1.243***	1.194***
	(0.283)	(0.123)	(0.112)
Q3_08	0.940***	1.333***	1.338***
	(0.302)	(0.105)	(0.124)
Q4_08	0.653**	1.127***	1.176***
	(0.280)	(0.0985)	(0.124)
Q1_09	0.561**	1.051***	1.125***
	(0.279)	(0.108)	(0.134)
Q2_09	0.796***	1.383***	1.481***
	(0.266)	(0.144)	(0.158)
Q3_09	0.569	1.017***	1.276***
	(0.346)	(0.243)	(0.266)

Q4_09	0.828**	1.366***	1.366***
	(0.323)	(0.202)	(0.208)
Q1_10	1.054***	1.603***	1.541***
	(0.326)	(0.196)	(0.204)
Q3_10	0.934***	1.350***	1.435***
	(0.279)	(0.0930)	(0.116)
Q4_10	1.006***	1.494***	1.521***
	(0.285)	(0.108)	(0.120)
Q1_11	0.921***	1.408***	1.453***
	(0.296)	(0.124)	(0.132)
Q2_11	1.576***	1.435***	2.042***
	(0.328)	(0.139)	(0.198)
Q3_11	1.179***		1.633***
	(0.328)		(0.206)
GDPPC_Q_ppp	-0.0717	-0.139***	-0.0499
	(0.0533)	(0.0496)	(0.0518)
Inflat_Q	-0.109***	-0.102***	-0.121***
	(0.0344)	(0.0371)	(0.0348)
Unemp_Q	-0.0484***	-0.0521***	-0.0502***
	(0.00998)	(0.0105)	(0.00979)
LFO_Price	-0.000354		
	(0.000229)		
Electr_Price		-0.00155*	
		(0.000916)	
Gas_Price			-0.00459**
			(0.00196)
Constant	7.207***	9.431***	8.265***
	(0.557)	(0.712)	(0.553)
Observations	117819	100908	101937
R-squared	0.182	0.208	0.190

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01.

Table A4: Seasonality of Energy Prices

	Electricity (USD/MWh)	Oil (USD/1000 liter)	Gas (USD/MWh)
Quarter 1	Omittted	Omitted	Omitted
Quarter 2	1.15*** (5.89)	-9.55*** (10.03)	3.35*** (31.33)
Quarter 3	0.10 (0.44)	145.66*** (125.97)	12.62*** (94.74)
Quarter 4	2.19*** (9.59)	70.40*** (60.25)	8.85*** (66.27)
Constant	78.42*** (121.32)	1250.45*** (333.22)	29.25*** (77.31)
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Method: least squares. t-statistics in parentheses. ***p<0.01.

Electricity Supply Preferences in Europe: Evidence from Subjective Well-Being Data*

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Abstract: We use survey data for 139,517 individuals in 25 European Countries, 2002-2011, to estimate the relationship between subjective well-being (SWB) and production shares of various electricity generation technologies. 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 and electricity from coal and oil is associated with greater SWB at all levels of income and that the implied preference for solar and wind power over nuclear power has risen drastically after the Fukushima nuclear accident.

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

JEL classification: Q42; Q48

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1. Introduction

Several European countries are currently undertaking fundamental revisions of their energy policies, 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 25 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 fielded, we are able to investigate whether the relationship between the electricity mix and SWB in Europe has changed after the Fukushima accident of March 11, 2011.

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 has been referred to as experienced preference (Welsch and Ferreira 2014). In contrast to stated preference methods, the experienced preference approach is not subject to biases stemming from strategic response or the warm-glow effect.[35] Even though survey data on SWB may be an imperfect approximation of experienced utility, there is no reason to expect that imperfections in the measurement of utility vary systematically with the structure of the electricity system, thus biasing the results.[36]

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. [37] 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, provided they affect SWB.[38]

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. The identified relationships between SWB and the electricity mix imply that solar and wind power and electricity from gas are preferred over nuclear power

[35] 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, due to the warm glow from stated environmental awareness.

[36] For a discussion of the use of SWB data and pertinent methodological issues, see section 2.

[37] This statement should not be construed to mean that other approaches (say willingness to pay surveys) require better-informed respondents.

[38] An attribute of electricity supply systems that is probably not captured by SWB is electricity generation's effect on future climate change.

and electricity from coal and oil. In spite of evidence suggesting a preference for low-cost supply, the preference for solar and wind applies at all levels of income. In addition, the 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.

In our well-being regressions we use country and year fixed effects to control for unobserved factors (for instance climate or cultural differences), in addition to controlling for national per capita income and other macroeconomic indicators usually included in well-being regressions. This way we minimize the risk of the preference structure identified to be affected by omitted variable bias. In particular, as we shall discuss in detail, country fixed effects rule out that the preference for solar and wind power is an artifact of a higher presence of these technologies in "generically" happier countries. Similarly, controlling for macroeconomic conditions rules out that this preference is spurious due to a possibly higher share of these technologies under conditions of good economic performance.

In addition to those methodological safeguards, 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. 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 and the sharp rise of the oil price.

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. Theoretical 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

$$U = f(A). \quad (1)$$

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.

The above 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.[39]

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 con-

[39] 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).

flicts, and power generation from bio fuels may lead to nuisance from odor pollution.[40] 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 SWB. Similar as has been done with other societal factors of well-being (ranging from macroeconomic conditions to institutional or environmental quality), we study the statistical relationship between SWB 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 SWB and S, we take them to be meaningful (non-spurious) if they can be rationalized in terms of (i) plausible relationships between U (utility) and A (costs, pollution etc.) and (ii) existing or perceived relationships between A and S, as outlined above.

In using SWB data for preference elicitation and monetary valuation it is important to understand the assumptions to be imposed on the information content of those data. As discussed by Ferrer-i-Carbonell and Frijters (2004), necessary assumptions are (a) a positive monotonic relationship between SWB and the underlying true utility U (if $SWB_{it} > SWB_{is}$, then $U_{it} > U_{is}$ for individual i at times t and s) and (b) ordinal interpersonal comparability (if $SWB_{it} > SWB_{jt}$, then $U_{it} > U_{jt}$ for individuals i and j). Validation research has produced a variety of supporting evidence of those assumptions (see Diener et al. 1999, Frey and Stutzer 2002, Ferrer-i-Carbonell and Frijters 2004). Under ordinal interpersonal comparability SWB can be treated as an ordinal variable. If, more restrictively, cardinal interpersonal comparability is assumed ($SWB_{it} - SWB_{jt}$ is proportional to $U_{it} - U_{jt}$), SWB can be treated as a cardinal variable.[41] Ferrer-i-Carbonell and Frijters (2004) and many others found that assuming the data to be ordinal or cardinal and applying the corresponding estimation methods has little effect on qualitative results. In particular, the ratios of coefficients are similar, which is important for monetary valuation (see section 5.6).

Another issue with SWB data is that they are bounded from below and from above. This implies that one can neither observe a decline in SWB if it was in the lowest category in the preceding period, nor an

[40] 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. On associated nuisance see footnote 15.

[41] Cardinal interpersonal comparability amounts to assuming that the difference between an SWB score of, say, 8 and 9 is the same as the difference between a 4 and a 5 (Ng 1997).

increase if it was in the highest category. A way of addressing this problem is by collapsing the information of SWB variables in two categories (high/low).

As a final issue, Bertrand and Mullainathan (2001) have expressed general doubts on the use of subjective data as dependent variable to the extent that they are subject to measurement error (misreporting) that is correlated with explanatory variables. Though the examples they offer relate to attitudes and opinions, misreporting may exist in the case of SWB too. However, we consider this to be less of a problem because misreporting of SWB, if any, is not likely to be correlated with our variables of interest, electricity supply shares.

Getting back to our approach more specifically, we note that it 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.[42]

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.

[42] 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 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.

The variable used to capture 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 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 be related to 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.

The five-wave cumulative dataset of the ESS includes about 240,000 observations from 33 countries. Because the electricity supply data are unavailable for some countries, our analysis refers to the following 25 countries: Austria, Belgium, Czech Republic, Denmark, 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 electricity data and a small number of non-responses in the ESS (1,454) the final sample for econometric analysis includes 139,517 data points.

Tables A1 to A3 in the Appendix contain the variable descriptions and the descriptive statistics. Table A3 reveals that the variation in supply shares necessary for identification comes not only from cross-country differences (as indicated by the country-specific mean values) but also from inter-temporal variability (indicated by the country-specific minimum and maximum values). For instance, the share of coal varies between 39 and 55 percent in Denmark, 13 and 33 percent in Portugal, and 9 and 34 percent in Spain. While nuclear power is constantly absent in Austria, Denmark, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Norway, Poland, Portugal and Turkey, its share varies, for instance, between 25 and 33 percent in the Czech Republic, 18 and 28 percent in Germany, 18 and 26 percent in Spain, 38 and 51 percent in Sweden, and 14 and 23 percent in the UK. As regards the less prevalent and more recent renewable technologies, the share of solar & wind power is in the range of 12 to 28 percent in Denmark, 1 to 19 percent in Portugal, and 4 to 18 percent in Spain. Inter-temporal variation is gradual in some cases (like the substitution of solar & wind power for coal and nuclear power in Germany) whereas more discrete changes can be found in others (e.g. an increase of the gas share by about 10 percentage points in the UK in 2006-2008). Overall, we expect that the inter-country and inter-temporal variation of supply shares provides a strong enough source of identification of the relationship between the electricity mix and well-being.

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.[43] As expected, there exists a positive and sizeable correlation between air pollution and the shares of coal and oil. Household electricity prices are most strongly and positively correlated with the share of solar & wind power, while being negatively 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 & wind power), we expect the preference weights people attach to pollution and prices to translate into preferences regarding the underlying electricity supply structures. Similar considerations are expected to apply to (perceptions of) supply security and the safety of electricity facilities, though we do not have indicators to capture these.

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. The general form of the estimating equation reads as follows:

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

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

where, alternatively, $k \in \{f, r\}$, $k \in \{n, r\}$, and $k \in \{n, f\}$; ε_{ict} denotes the error term. The *micro* controls are sex, age, marital status, household size, employment status, and household income. The *macro* controls are GDP per capita, the inflation rate, and the unemployment rate. In addition to those controls, we account for unobserved country- and time-invariant factors with country and year fixed effects. The *country* fixed effects account for unobserved time-invariant country characteristics (like climate or cultural attitudes) that may affect both the electricity mix and well-being whereas the *year* fixed effects account for unobserved time-specific confounding factors that are common to all countries (e.g. common global shocks).

The coefficients of interest in this specification are the γ_k's. Because of adding-up of the share variables, a positive (negative) relationship between SWB and one of the included share variables implicitly indicates a negative (positive) relationship between SWB and the respective 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 (negative) and significant coefficient is taken to mean that the corresponding type is preferred to (less preferred than) the omitted one. 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. Furthermore, statistically significant differences in coefficient size can be taken to represent a preference relationship among included technologies. If two coefficients are not statistically different, individuals can be considered to be indifferent between the technologies. This way, a complete preference ordering over each pair of technologies can be established.[44]

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. In some of those regressions we include interactions of the supply

[44] The preference ordering is not transitive: If individuals prefer X over Y and are indifferent between Y and Z, this does not imply that they prefer X over Z. The relationship between X and Z must be tested explicitly.

shares with the electricity price and with income to study the influence of those variables on supply preferences, given the technologies' different cost characteristics.

Finally, we will study whether the relationship between SWB and the electricity mix may have changed after a set of events in 2011 (the Fukushima nuclear accident and the political unrest in North Africa). 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:

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

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.

In our main analysis, we treat the dependent variable, 11-point life satisfaction, as an ordinal variable and 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 5.5). In addition, to address the fact that life satisfaction is bounded from below and from above, we collapse life satisfaction into a low (0-7) and high (8-10) category (each of which represents about one half of the observations) and apply a probit model. We report robust standard errors adjusted for clustering at the county-year level.[45]

5. Results

We first present our estimation results for the aggregate supply structure (nuclear, fossil and renewable power) before disaggregating fossil-based electricity and renewable power into more detailed categories. Without loss of generality, we treat nuclear power as the omitted technology. While starting with qualitative results (sign and statistical significance of coefficients), their economic significance (effect sizes) will

[45] Because each wave of the ESS represents a new random sample, it is unlikely that a respondent appears repeatedly over the years covered, which might induce equicorrelation in the disturbances. Our data base does not permit to check whether a person appears repeatedly.

be discussed in a separate subsection towards the end of this section. We also address possible channels of influence and the robustness of our findings.

5.1 Aggregate Supply Structure

Column A in Table 2 presents the main estimation results for equation (4).[46] 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 electricity is thus associated with significantly greater life satisfaction whereas switching to renewable power has no such effect.[47] A Wald test shows that the coefficient of fossil-based electricity is statistically greater (at the 5 percent level) than the coefficient on renewable power. Switching from renewable power to fossil-based electricity goes with greater life satisfaction.[48]

To address the issue that life satisfaction data are bounded from below and from above (see section 2), column B reports the results for an otherwise identical probit model in which the dependent variable,

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[46] More detailed results concerning the micro and macro controls are presented in Table A4 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). As indicated by the estimates for the country dummies, Iceland, Switzerland, Norway and Denmark have the highest "generic" (that is, unexplained) levels of reported well- being, which is also consistent with the literature.

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

[48] Equivalently to testing for difference between included technologies one can systematically vary the omitted technology. We do not present results from these exercises for considerations of space.

11-point life satisfaction, is replaced with a dummy variable that takes the value one if satisfaction is in the categories 8-10 and zero otherwise. The qualitative results are as in column A: Switching from nuclear power and from renewable power to fossil-based electricity goes with greater life satisfaction whereas a switch from nuclear to renewable power or vice versa is associated with no significant change in satisfaction.

We thus 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 power (or vice versa) is not significantly correlated with SWB.

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

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 individuals are indifferent between renewable and nuclear electricity.

5.2 Disaggregate Supply Structure: Main Results

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 A4.

We continue to take a significantly positive (negative) coefficient to indicate that the corresponding technology is preferred to (less preferred than) the omitted technology, whereas insignificant coefficients indicate indifference. Likewise, significant (insignificant) differences between coefficients indicate preference (indifference).

From column A it is seen that nuclear power is preferred to electricity from bio fuels and less preferred than electricity from gas and solar & wind power. No statistically significant preference can be established between nuclear power and electricity from oil, coal and hydro power. Furthermore, not all of the differences in coefficient size among the non-nuclear technologies are statistically significant. Wald tests suggest that, at a confidence level of 10 percent or better, (a) coal-based electricity is preferred to electricity from bio fuels, (b) oil-based electricity is preferred to electricity from bio fuels, (c) gas-based electricity is preferred to nuclear power (as already stated) and to electricity from bio fuels, (d) solar & wind power is preferred to nuclear power (as already stated) and to electricity from bio fuels, (e) hydro power is preferred to electricity from bio fuels, and, consequently, (f) electricity from bio fuels is less preferred than are all other generation technologies.

Column B presents the results for an otherwise identical probit model in which 11-point life satisfaction is replaced with a dummy variable that takes the value one if satisfaction is in the categories 8-10 (about half of the observations) and zero otherwise. The qualitative results from column A are preserved but the preference of gas-based and of solar & wind power over nuclear power is more significant than in column A. In addition oil is now significantly preferred over nuclear power.

Based on the results in column A of Table 3 we are able to identify a preference ordering over the various technologies that 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. Individuals are indifferent between gas and solar & wind power and between nuclear, coal, oil and hydro power.

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. In particular, they prefer gas over nuclear power, whereas no preference over nuclear power can be established in the case of coal and oil. One reason may be that gas is less polluting than are the other fossil fuels. Similarly, people prefer solar & wind power over nuclear power, but a preference over nuclear power of the other renewable energies cannot be identified. In addition, electricity from bio fuels is less preferred than other renewable energies and in fact is the most disliked type of electricity generation.[49]

[49] A reason for this may be the nuisance from odor pollution that is associated with power generation from organic waste. In a survey among regional stakeholders in a rural region of

Before we proceed to possible channels of influence, we would like to discuss the validity of our results with regard to unobserved variables that are correlated with both reported well-being and the supply mix and might explain the estimated relationships. A possible argument might be, in particular, that the preference for solar & wind power is an artifact of a higher presence of these technologies in countries that are "generically" happier due to unobserved factors. In our sample, solar & wind power have the highest share by far in Iceland (23.1 percent average share) and in Denmark (17.6 percent), and these countries happen to be among those with the highest SWB scores according to all international surveys. We note, however, that our estimates control for this fact by means of country fixed effects. As seen in Table A4 and noted in footnote 11, the estimates of the country fixed effects are among the highest in Iceland and Denmark (along with Norway and Switzerland), capturing unobserved well-being factors in these countries. Any relationship between solar & wind power and well-being is thus not an artifact of unobserved country-level factors of well-being.

More generally than in the case of solar & wind power in Iceland and Denmark, country fixed effects minimize the risk that the preference structure we found is affected by omitted unobserved factors at the country level whereas year fixed effects account for confounding time specific effects like common global shocks. In addition to this, controlling for macroeconomic conditions rules out that the preference structure identified is spurious due to a possibly higher share of these technologies under conditions of good economic performance.

5.3 Disaggregate Supply Structure: Channels of Influence

We now turn to the question of what factors may drive the preferences established so far. Noting that solar & wind power are free from air pollution and gas is less polluting than are coal and oil (as reflected in the correlations between generation shares and SO_2 emissions shown in Table 1), one potential driver of the preference ordering stated in Result 3 is environmental friendliness.

To study the potential influence of the cleanness of power generation, we consider SO_2 emissions per capita as an additional control. We note, however, that emissions may not be an adequate measure of the level of ambient pollution to which a country's residents are exposed, because considerable portions of SO_2 are subject to trans-boundary transport. Since for geographic reasons trans-boundary transport is potentially larger in smaller countries, emissions may be a better proxy for ambient pollution if a country's

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Germany, Gerdes (2013) found odor to be mentioned as a top concern with regard to a potential expansion of power generation from bio fuels.

area is larger. To account for this phenomenon, we include SO_2 per capita along with SO_2 per capita multiplied with land area.

Including emissions reduces the number of observations to 129,795. Estimating the original model (without emissions and land area) on the reduced sample (column C in Table 3) does not lead to great changes in results. One notable exception is that the coefficient on solar & wind increases whereas that on coal is reduced. The difference between these coefficients is now almost significant (p = 0.11), indicating at least some weak form of preference. When we add the emission variables (column D) the coefficient on solar & wind becomes insignificant, and the difference to the coefficient on coal also becomes insignificant (p = 0.20). The weak preference for "clean" solar & wind over "dirty" coal thus vanishes once we control for pollution. In addition, the *distaste* for biofuels, which are also free from SO_2, becomes *stronger* when controlling for emissions. The results for solar & wind and for biofuels are consistent with the idea that differences in pollution intensity are a driver of the preference among electricity generation technologies.

Another potential factor for electricity supply preferences is cost. As seen in Table 1, household electricity prices vary with the supply structure. In particular, a high share of solar & wind power is correlated with higher prices whereas a high share of hydro power is correlated with lower prices. To study the role of costs we include household electricity prices and interactions of the price with the supply shares. Since standard errors may be biased in an ordered probit with interaction terms (Ai and Norton 2003), columns A and B in Table 4 report results both from an ordered probit and least squares, respectively. The result that gas-based electricity and solar & wind power are preferred over nuclear power is preserved in the ordered probit model (column A in Table 4). The coefficient on the solar & wind share is now slightly larger than in the original specification (column A in Table 3) and the coefficient on the price is negative (though insignificant). Interestingly the interaction of solar & wind with the price is negative and significant (whereas the other interactions are insignificant). The preference for solar& wind power is thus smaller when electricity prices are higher.

Another aspect of the influence of cost on electricity supply preferences relates to income. With respect to this, one can expect a greater preference for low-cost supply when income is low. To study this issue, columns C and D in Table 4 report results with income interactions. As regards the un-interacted supply shares, the signs of the coefficients are the same as in the original specification (column A in Table 3). In addition, un-interacted gas and solar & wind remain significant, suggesting that these technologies are preferred over nuclear power even at low levels of income. A major difference to the original specification is that the coefficient on hydro power quadruples and becomes significant. When we consider the interactions with income, we see that their coefficients are all negative, but only those of gas and hydro power are significant. All of this applies to both the ordered probit (column C) and the least squares estimates (column D).

Considering that hydro power is the least expensive technology, the results concerning hydro power suggest that people with low income have a preference for inexpensive electricity supply and that this preference declines with income. In addition, results suggest that the preference for gas and solar & wind stated above applies not just to the average person, but to people at all income levels. Since solar & wind power is correlated with higher costs, concern over the (perceived) safety problems of nuclear power and over pollution associated with coal and oil seems to be more important than concern over the costs of supply of solar & wind power even at low levels of income.

The overall impression from these results – in particular the preference for gas and for solar & wind – 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 power and coal-based electricity in spite of the higher cost of the former.

5.4 Results for the Post-3/11 Period

To further explore the relationship between well-being and the electricity supply structure, we tested whether events that may have affected people's electricity supply preferences are associated with corresponding changes in the well-being equation. 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.[50] In addition, the Arab Spring went along with a much recognized rise in the price of oil.[51]

[50] In this sense, all residents within the database were "treated" by those events. The issue to be studied, however, is whether a change in people's well-being, if any, differs by the supply structure in their countries. Specifically, with regard to Fukushima, individuals in countries with higher nuclear shares may have felt "treated" more intensively and may have experienced greater mental distress because they became more attentive to nuclear risks. This effect is expected to be lacking in nuclear-free countries.

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

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.[52] 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 SWB through increased concern about nuclear safety, the latter may have spurred worries about oil supply from North African countries.

Column E in Table 4 reports the ordered probit results for the model with interactions between the supply shares and a post-Fukushima dummy and column F reports the corresponding least squares results. 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. The post-Fukushima dummy itself is negative but insignificant, which indicates that individuals in nuclear-free countries experienced no significant decline in well-being.

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.[53]

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[52] Post-Fukushima observations account for about 4.5 percent (6220/139517) of all observations. They refer to the countries Belgium, Switzerland, Spain, France, Greece, Israel, Netherlands, Portugal and Slovenia, which have considerably different nuclear shares (see Table A3).

[53] 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.

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.[54]

5.5 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 above (subsection 5.2), 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.

5.6 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

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[54] Another event that may have affected the saliency of different supply attributes is the gas dispute between Russia and the Ukraine in January 2009, which led to an interruption of Russian gas supplies to Europe for two weeks. Experimentation with a dummy capturing this event produced no significant changes in the relationship between SWB and the electricity mix, presumably due to the extent and duration of the supply cut relative to the size of buffer stocks in the gas importing countries.

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 (0.00828) along with the coefficient on income (0.0625), 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 increase in annual household income by 790 Euros.[55] A 1-percentage point substitution of solar & wind power for nuclear power corresponds to 0.18 steps (0.0112/0.0625) on the income scale, which is equivalent to an increase in annual household income by 1,075 Euros.

Using the estimation results from column E 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)/ 0.0625), 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 (0.0314/0.0625), which is equivalent to 3,000 Euros. Using the results from column F 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).[56] The similarity of the least squares valuations to those in the ordered probit model suggests considerable robustness not only of our qualitative but also of our quantitative results.

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. Yet these results suggest the existence of considerable monetary equivalents to having a safe and environment-friendly electricity supply.

6. Conclusions

This paper has used survey data for 139.517 individuals in 25 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 the usual individual and macro-level fac-

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[55] 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 A5 in the Appendix shows how the 12-point income scale matches with income brackets.

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

tors as well as unobserved country and year characteristics, 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 & wind power relative to nuclear power and coal-based electricity is associated with greater SWB.

These estimation results can be taken to represent a preference ordering which reflects differences between the technologies in terms of costs, cleanness, safety and supply security. The results indicate, in particular, that solar & wind power is preferred over nuclear power and electricity from coal and oil. In spite of evidence suggesting a preference for low-cost supply, the preference for solar & wind applies even at low levels of income. In addition, there exists evidence that the preference for solar & 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 (costs, safety and security, 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 warm-glow effects that may arise when people are explicitly *asked* about their opinions and preferences.

In spite of their statistical nature, we believe that the identified relationships are plausible and meaningful. The rise in preference for solar & wind power over nuclear power after the Fukushima accident supports this idea. In addition, from a methodological point of view, inclusion of country and year dummies in our regressions rules out that the established relationships are driven by unobserved factors at the country or year level. Similarly, inclusion of macroeconomic controls rules out that the relationships reflect the possibly higher share of the preferred technologies under conditions of good economic performance.

An aspect of electricity supply preferences that is probably *not* captured by correlations between well-being and the electricity mix is electricity generation's effect on future climate change. If a preference for climate-friendly electricity – in addition to electricity free from traditional air pollution – exists, this will probably not affect the preference of solar & wind over nuclear power since both are free from greenhouse gases. It may, however, imply a preference over fossil-based electricity that our well-being analysis did neither support nor refute.

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.

As to future directions, more specific insights concerning channels of influence could be expected from incorporating a spatial dimension into the well-being analysis of electricity supply structures. In particular, including indicators of people's proximity to electricity facilities of different types and of local or regional electricity-related pollution may contribute to clarifying the roles of (perceived) nuclear safety and of pollution for electricity supply preferences.

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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). *** p<0.01.

Table 2: Estimation Results for Aggregate Supply Structure

	A	B
Nuclear share	omitted	omitted
Fossil share	**0.00719****	**0.00956****
	(0.00335)	(0.00392)
Renewable share	**0.00118**	**0.00408**
	(0.00400)	(0.00508)
Micro controls	Yes	Yes
Macro controls	Yes	Yes
Country dummies	Yes	Yes
Year dummies	Yes	Yes
Observations	139517	139517
(Pseudo) R2	0.0488	0.1157

Column A: dependent variable = life satisfaction (0-10), method = ordered probit. Column B: dependent variable = life satisfaction high (=1 if LS>7), method = probit. Robust standard errors in parentheses corrected for clustering at the country-year level. * p<0.1, ** p<0.05, *** p<0.01.

Table 3: Estimation Results for Disaggregate Supply Structure

	A	B	C	D
Nuclear	omitted	omitted	omitted	omitted
Coal	**0.00410**	**0.00541**	**0.00207**	**0.00212**
	(0.00359)	(0.00408)	(0.00266)	(0.00271)
Oil	**0.00788**	**0.0135****	**0.0109***	**0.00907**
	(0.00575)	(0.00628)	(0.00660)	(0.00671)
Gas	**0.00828****	**0.0103*****	**0.00323**	**0.00231**
	(0.00350)	(0.00382)	(0.00276)	(0.00322)
Solar&Wind	**0.0112***	**0.0209*****	**0.0140****	**0.0112**
	(0.00671)	(0.00760)	(0.00713)	(0.00698)
Hydro	**0.00224**	**0.00292**	**-0.000777**	**-0.00134**
	(0.00437)	(0.00526)	(0.00362)	(0.00363)
Biofuels	**-0.0199***	**-0.0238****	**-0.0284*****	**-0.0278*****
	(0.0102)	(0.0117)	(0.00901)	(0.00862)
SO2pc			**0.00298**	**0.00434**
			(0.00225)	(0.00293)
SO2pc*area				**-0.00760**
				(0.00863)
Micro controls	Yes	Yes	Yes	Yes
Macro controls	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes
Observations	139517	139517	129795	129795
R-squared	0.0489	0.1160	0.0489	0.0494

Columns A, C, D: dependent variable = l life satisfaction (0-10), method = ordered probit. Column B: dependent variable = life satisfaction high (=1 if LS>7), method = probit. Robust standard errors in parentheses corrected for clustering at the country-year level. * p<0.1, ** p<0.05, *** p<0.01. Area is the countries' area in $km^2 x 1000000^{-1}$.

Table 4: Estimation Results with Price, Income, and Post-3/11 Interactions

	Interaction with electr. price		Interaction with income		Interaction with post-3/11	
	A (ordered probit)	B (least squares)	C (ordered probit)	D (least squares)	E (ordered probit)	F (least squares)
Nuclear	omitted	omitted	omitted	omitted	omitted	omitted
Nuclear *Interaction	omitted	omitted	omitted	omitted	omitted	omitted
Coal	**0.00158**	**0.000141**	**0.00645***	**0.01055**	**0.00670***	**0.0100**
	(0.00425)	(0.00892)	(0.00388)	(0.00807)	(0.00363)	(0.0072)
Coal *Interaction	**0.000000462**	**0.00000251**	**-0.00017**	**-0.00033**	**0.00699****	**0.0209*****
	(0.00000334)	(0.00000700)	(0.00012)	(0.00023)	(0.00336)	(0.0070)
Oil	**0.0184*****	**0.0368*****	**0.0102**	**0.01925**	**0.00430**	**0.0063**
	(0.00648)	(0.0133)	(0.00637)	(0.01316)	(0.00528)	(0.0107)
Oil *Interaction	**-0.0000149**	**-0.0000291**	**-0.00013**	**-0.00013**	**-0.0615*****	**-0.1771*****
	(0.0000102)	(0.0000203)	(0.00047)	(0.00098)	(0.0107)	(0.0222)
Gas	**0.00812****	**0.0149***	**0.0105*****	**0.03110*****	**0.00863*****	**0.0152****
	(0.00384)	(0.00808)	(0.00362)	(0.00744)	(0.00332)	(0.0067)
Gas *Interaction	**0.00000418**	**0.0000103**	**-0.0008*****	**-0.0018*****	**0.00444****	**0.0033**
	(0.00000391)	(0.00000825)	(0.0001)	(0.0003)	(0.00217)	(0.0046)
Solar&Wind	**0.0133***	**0.0230**	**0.0165****	**0.03333***	**0.00141**	**-0.0018**
	(0.00754)	(0.0157)	(0.00608)	(0.01700)	(0.00608)	(0.0120)
Solar&Wind *Interaction	**-0.0000130****	**-0.0000244***	**-0.00055**	**-0.00164**	**0.0314*****	**0.0755*****
	(0.00000597)	(0.0000126)	(0.00056)	(0.00117)	(0.00784)	(0.0166)
Hydro	**0.00466**	**0.00920**	**0.00934****	**0.02112****	**0.000272**	**0.0000**
	(0.00469)	(0.00968)	(0.00452)	(0.00989)	(0.00403)	(0.0081)
Hydro *Interaction	**0.00000199**	**0.00000519**	**-0.0007*****	**-0.0018*****	**0.00682*****	**0.0176*****
	(0.00000294)	(0.00000595)	(0.0001)	(0.0002)	(0.00188)	(0.0039)
Biofuels	**-0.0156**	**-0.0290**	**-0.00916**	**0.00456**	**-0.0127**	**-0.0205**
	(0.0174)	(0.0367)	(0.0108)	(0.02160)	(0.0102)	(0.0199)
Biofuels *Interaction	**0.0000156**	**0.0000360**	**-0.00083**	**-0.0041*****	**-0.0152**	**-0.0263**
	(0.0000113)	(0.0000244)	(0.00055)	(0.0011)	(0.0225)	(0.0475)
Electricity Price	**-0.000184**	**-0.000486**				
	(0.000238)	(0.000501)				
Income			**0.103*****	**0.234*****		
			(0.00782)	(0.0181)		
Post 3/11					**-0.201**	**-0.124**
					(0.201)	(0.435)
Micro controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro controls	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	126206	126206	139517	139517	139517	139517
(pseudo-) R2	0.0502	0.199	0.0493	0.1968	0.0489	0.1956

Dependent variable: Life satisfaction (0-10). Method: ordered probit/OLS. Post-3/11 is a dummy variable that takes the value 1 if life satisfaction was measured after March 11, 2011, and 0 otherwise. Robust standard errors in parentheses corrected for clustering at the country-year level. * p<0.1, ** p<0.05, *** p<0.01.

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
SO_2 per capita		Emission of SO_2 in 1000t. Refers to man-made emissions
Electricity Prices		Electricity End Use Prices for Households (PPP-adjusted)
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
Electricity Price	158328	1409.304	4886.851	42.56678	43136.02
SO_2 per capita	188139	14.40602	14.63994	1.28642	128.9047

Table A3: Supply Structure (Summary Statistics by Country)

		Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Greece	Hungary	Iceland	Ireland	Israel	Italy	Luxembourg	Netherlands	Norway	Poland	Portugal	Slovak Republic	Slovenia	Spain	Sweden	Switzerland	Turkey	United Kingdom
Coal	Mean	12.3	10.4	62.4	47.3	24.9	4.8	48.3	57.4	20.6	0.0	28.8	68.9	15.9	0.0	26.1	0.1	91.5	27.1	17.9	34.4	22.1	1.8	0.0	26.4	32.9
	Min	7.6	6.2	57.2	38.6	16.6	4.1	44.0	53.0	17.0	0.0	22.5	58.5	14.6	0.0	21.8	0.1	87.0	13.2	14.9	31.3	8.8	1.1	0.0	22.9	28.0
	Max	16.4	15.6	68.5	54.8	32.4	5.4	53.2	64.1	27.1	0.0	35.8	77.4	17.2	0.0	30.7	0.1	95.1	33.3	20.7	37.0	34.1	3.2	0.0	29.1	38.2
Oil	Mean	2.3	1.3	0.3	3.9	1.1	1.1	1.3	14.2	2.1	0.0	14.2	11.9	15.3	0.0	1.9	0.1	1.7	11.8	2.3	0.2	7.6	1.2	0.3	3.8	1.3
	Min	1.6	0.4	0.1	0.8	0.9	0.9	0.7	10.6	0.4	0.0	10.6	3.7	6.0	0.0	1.1	0.1	1.5	5.3	2.2	0.0	5.2	0.5	0.1	1.0	0.8
	Max	3.2	2.3	0.5	10.2	1.5	1.4	1.7	16.0	5.9	0.1	16.0	22.9	31.6	0.0	2.6	0.1	1.8	25.0	2.5	0.5	11.8	2.9	0.4	8.3	1.8
Gas	Mean	18.1	27.9	1.6	21.0	14.6	3.8	12.0	16.9	33.7	0.0	53.0	18.9	48.3	91.3	59.1	1.3	2.7	26.5	7.2	2.8	27.5	0.8	1.4	45.8	41.1
	Min	15.3	22.1	1.2	17.9	13.0	3.3	9.4	13.1	29.0	0.0	43.6	0.1	35.8	88.1	56.8	0.2	1.5	16.6	5.6	2.0	13.4	0.3	1.1	40.6	35.8
	Max	21.1	33.5	2.1	24.6	16.4	4.2	14.0	22.0	38.1	0.0	62.3	37.5	56.0	93.9	62.8	3.9	3.6	33.4	8.6	3.6	38.8	2.3	1.7	49.7	46.3
Nuclear	Mean	0.0	55.0	30.9	0.0	29.5	78.2	24.6	0.0	38.5	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	56.0	37.2	20.9	44.4	41.8	0.0	18.9
	Min	0.0	51.1	24.7	0.0	26.5	75.9	17.8	0.0	32.3	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	53.1	34.8	18.1	38.2	39.9	0.0	13.6
	Max	0.0	58.5	33.3	0.0	33.0	79.4	28.3	0.0	43.3	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	58.1	39.1	26.1	51.1	44.8	0.0	22.8
Hydro	Mean	58.9	0.4	2.7	0.1	16.7	10.2	3.3	7.8	0.6	76.8	2.7	0.0	13.9	3.3	0.1	97.7	1.5	21.1	15.0	24.3	10.2	44.0	53.0	23.3	1.2
	Min	54.2	0.2	1.7	0.0	11.4	8.1	3.0	4.1	0.5	70.1	2.1	0.0	10.6	2.3	0.1	94.7	1.1	10.2	11.2	21.4	6.2	39.5	49.8	16.8	0.8

	Max	66.3	0.5	3.3	0.1	22.1	11.2	4.0	13.0	0.6	83.4	3.7	0.1	17.1	4.8	0.1	99.3	1.9	33.8	19.1	28.7	15.9	48.2	54.6	30.6	1.6
Sol/Win	Mean	2.4	1.0	0.5	17.6	0.3	0.9	6.2	3.3	0.5	23.1	6.8	0.2	4.1	2.1	3.0	0.5	0.5	8.9	0.2	0.1	10.4	1.3	0.1	0.6	1.6
	Min	0.3	0.1	0.0	12.1	0.1	0.1	2.8	1.2	0.0	16.5	1.6	0.0	2.5	0.9	1.2	0.1	0.0	1.0	0.1	0.0	3.9	0.4	0.0	0.1	0.3
	Max	3.5	4.4	2.9	28.0	0.7	2.7	11.3	7.4	1.7	29.9	16.0	0.8	9.2	3.2	4.7	1.0	1.7	18.5	0.2	0.4	17.8	4.0	0.2	2.4	4.4
Biofuel	Mean	6.0	4.1	1.5	10.1	13.0	1.0	4.2	0.4	4.0	0.0	0.7	0.0	2.5	3.2	5.9	0.3	2.1	4.6	1.3	1.1	1.3	6.4	3.4	0.1	2.9
	Min	2.9	1.9	0.6	6.4	11.3	0.8	2.2	0.2	0.2	0.0	0.3	0.0	1.3	2.2	4.0	0.2	0.5	3.6	0.1	0.7	1.1	3.0	2.9	0.1	2.1
	Max	10.2	6.8	3.1	14.0	14.4	1.3	7.2	0.6	6.8	0.0	1.2	0.1	4.5	5.9	7.8	0.4	4.9	6.3	2.7	1.8	1.8	9.0	3.9	0.2	4.1

Table A4: Detailed Estimation Results for Aggregate Supply Structure

	A	B
Female	0.0697***	0.0718***
	(0.00701)	(0.00851)
Age	-0.0335***	-0.0339***
	(0.00193)	(0.00204)
Age-squared	0.000332***	0.000329***
	(0.0000193)	(0.0000198)
Household Size	-0.00147	0.000893
	(0.00300)	(0.00391)
Married	0.196***	0.229***
	(0.0133)	(0.0159)
Divorced	-0.0581***	-0.0441**
	(0.0165)	(0.0193)
Separated	-0.215***	-0.198***
	(0.0266)	(0.0315)
Widowed	-0.0630***	-0.0479**
	(0.0157)	(0.0201)
In Education	0.104***	0.132***
	(0.0177)	(0.0212)
Voluntary Unempl.	-0.347***	-0.369***
	(0.0350)	(0.0372)
Sick	-0.504***	-0.506***
	(0.0261)	(0.0301)
Retired	0.0162	0.0129
	(0.0158)	(0.0182)
Social/Military Serv.	0.101	0.157
	(0.0978)	(0.111)
Housework	-0.00776	-0.0104
	(0.0138)	(0.0166)
Other Empl.	-0.0763***	-0.0771**
	(0.0293)	(0.0345)
Involuntary Unempl.	-0.476***	-0.443***
	(0.0292)	(0.0330)
Household Income	0.0625***	0.0731***
	(0.00295)	(0.00316)
Austria	-0.666***	-0.847***
	(0.122)	(0.156)
Belgium	-0.693**	-0.643
	(0.319)	(0.426)
Switzerland	-0.230	-0.195
	(0.189)	(0.232)
Czech Republic	-1.236***	-1.237**

	(0.374)	(0.507)
Germany	-1.071***	-1.096***
	(0.273)	(0.369)
Denmark	-0.351	-0.340
	(0.246)	(0.323)
Spain	-0.783***	-0.913**
	(0.288)	(0.392)
Finland	-0.405*	-0.244
	(0.233)	(0.317)
France	-0.991***	-0.897*
	(0.354)	(0.472)
United Kingdom	-1.094***	-1.160***
	(0.297)	(0.397)
Greece	-1.582***	-1.699***
	(0.326)	(0.438)
Hungary	-1.543***	-1.549***
	(0.395)	(0.553)
Ireland	-0.968***	-1.079***
	(0.260)	(0.338)
Israel	-1.234***	-1.309***
	(0.378)	(0.496)
Iceland	-1.213***	-1.413***
	(0.266)	(0.352)
Italy	-0.889**	-1.202**
	(0.388)	(0.484)
Luxembourg	-1.013***	-1.014***
	(0.287)	(0.375)
Netherlands	-0.363**	-0.501**
	(0.153)	(0.195)
Norway	-1.344***	-1.395**
	(0.420)	(0.573)
Poland	-1.784***	-2.005***
	(0.316)	(0.425)
Portugal	-0.247	-0.204
	(0.203)	(0.265)
Sweden	-0.899***	-0.902**
	(0.297)	(0.408)
Slovenia	-1.063***	-1.047**
	(0.360)	(0.515)
Slovak Republic	-1.577***	-1.609***
	(0.424)	(0.575)
2003	0.0567	0.0884*
	(0.0368)	(0.0485)
2004	0.0403	0.0306
	(0.0308)	(0.0345)
2005	0.0746	0.0580
	(0.0456)	(0.0585)
2006	0.0539	0.0395

	(0.0473)	(0.0569)
2007	0.0677	0.0276
	(0.0590)	(0.0753)
2008	0.123**	0.109
	(0.0603)	(0.0762)
2009	0.0885	0.0980
	(0.0584)	(0.0656)
2010	0.220***	0.216***
	(0.0542)	(0.0689)
2011	0.164**	0.145
	(0.0655)	(0.0895)
GDPPC	-0.00302	0.000250
	(0.0126)	(0.0161)
Inflation Rate	-0.0106*	-0.00450
	(0.00613)	(0.00670)
Unemployment Rate	-0.0168***	-0.0144**
	(0.00601)	(0.00607)
Fossil	0.00719**	0.00956**
	(0.00335)	(0.00392)
Renewable	0.00118	0.00408
	(0.00400)	(0.00508)
Observations	139517	139517
Pseudo R2	0.0488	0.1157

Table A5: 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 €.

Fukushima and the Preference for Nuclear Power in Europe: Evidence from Subjective Well-Being Data*

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Abstract: The sustainable supply of energy is high on the agenda of many European countries. One of the pertinent issues, the future role of nuclear power, has gained increasing attention after the nuclear disaster at Fukushima, Japan. As a contribution to preference elicitation, we test whether the relationship between subjective well-being (SWB) of European citizens and the supply of nuclear power has changed after the Fukushima nuclear accident of March 11, 2011. Survey data for about 124,000 individuals in 23 European countries reveal that while European citizens' SWB was statistically unrelated to the share of nuclear power before the Fukushima disaster, it was negatively related to the nuclear share after the disaster. Taking the relationship between SWB and the nuclear share as an indicator of preference, this suggests the existence of an induced preference change.

Keywords: nuclear power; Fukushima; preference change; subjective well-being

JEL classification: Q54; Q42; I31

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*Appendix to chapter 7.

1. Introduction

The sustainable supply of energy is high on the agenda of many European countries. A controversial issue in this context is the future role of nuclear power. While some countries, such as Germany, have long been skeptical towards nuclear energy, France has recently extended the lifetime of its nuclear power plants, and the UK is planning to build new ones.

With respect to sustainability and the environment, nuclear power may appear attractive since it is largely free from greenhouse gases and air pollution, but it poses unresolved problems of nuclear waste disposal and the latent threat of nuclear disaster. The latter issue has recently gained renewed attention in the aftermath of the nuclear accident at Fukushima, Japan. This disaster may have altered European citizens' perceptions of nuclear safety, that is, of subjective accident probabilities as well as expectations as to the damage potential of an accident. Moreover, increased concern over nuclear safety may have affected people's subjective well-being, and this effect, if any, can be expected to be larger the greater is the contribution of nuclear power to a country's power supply.

A number of studies have found that the disaster at Fukushima-Daiichi on March 11, 2011, caused mental distress not only among people directly affected (Ohtake and Yamada 2013, Rehdanz et al. 2013) but, due to media coverage, in people thousands of miles away from the place of the event. Goebel et al. (2013) for instance found an increase in environmental concern in Germany after the Fukushima disaster. Similarly, an increase in German people's concern about the environment was found after the Chernobyl nuclear accident in 1986 (Berger 2010).

In contrast to studying disaster-related well-being *per se*, the present paper is concerned with the question of whether a disaster abroad – the Fukushima nuclear accident – may have changed the *relationship* between subjective well-being (SWB) and the structure of electricity supply. Using data for about 124,000 individuals in 23 European countries we test whether a relationship exists between SWB and the contribution of nuclear power to power supply in these countries and whether this relationship is different before and after the Fukushima disaster. Taking SWB as a measure of experienced utility (Kahneman et al. 1997) we interpret a change in the SWB-nuclear relationship as a change in people's implicit preference for nuclear power, as will be explained in the next section.

We find that European citizens' SWB was statistically unrelated to the contribution of nuclear power before the Fukushima disaster but negatively and significantly related to nuclear power after the disaster. This change in the SWB-nuclear relationship is robust to several specifications. Quantitatively, a 1-standard-deviation increase in the supply share of nuclear power is associated with a drop in SWB comparable to the drop associated with major personal life events. The change in the SWB-nuclear relationship applies to women and men, to all age groups and to environmentalists and non-environmentalists, but was stronger in the former than the latter.

We note that the percentage contribution to a country's power supply is a crude approximation to (perceived) exposure to nuclear risk. Arguably, the latter might be better represented by distance to nuclear power stations. Rehdanz et al (2013) have pursued such an approach for the case of Japan. They found no change in the relationship between SWB and the distance to the nearest nuclear power plant after the Fukushima disaster, which, they argue, reflects the fact that nuclear plants were shut down after the event. Goebel et al. (2013) used German data and found that changes in SWB after Fukushima did not differ between respondents within and outside a radius of 5 kilometers from the nearest nuclear power plant, whereas changes in environmental concern did differ according to distance. To the best of our knowledge, similar studies on a European scale have not been undertaken, presumably because information on the location of respondents in European-wide surveys is relatively crude.

The paper is organized as follows. Section 2 explains our general approach and conceptual framework. Section 3 presents the empirical framework and section 4 the empirical results. Section 5 concludes.

2. General Approach and Conceptual Framework

2.1 Experienced Preference

Previous literature has used data on SWB as a novel tool for measuring people's preferences for non-market goods. Examples with respect to environmental preferences include Welsch (2002, 2006), Rehdanz and Madison (2005) van Praag and Barsma (2005), Luechinger (2009), Ferreira and Moro (2010), Levinson (2012), Welsch and Biermann (2014).

The SWB approach to preference elicitation involves using these data as a proxy for experienced utility (Kahneman et al. 1997) and to employ them as the dependent variable in a preference function over non-market goods. In contrast to stated preference methods, this approach – dubbed by Welsch and Ferreira (2014) the experienced preference approach – does not rely on what people say about their preference, but solely on the statistical association between SWB and the non-market good in question. While the experienced preference approach requires to make the non-standard assumption of ordinal interpersonal comparability of utility (Ferrer-i-Carbonell and Frijters 2004), it avoids problems of strategic or socially desired response inherent in stated preference methods (Welsch and Ferreira 2014).

2.1 Conceptual Model and Hypotheses

The non-market good considered in this paper is perceived nuclear safety, denoted by *S*. The preference for *S* is captured by a strictly increasing utility function *U*(*S,A*), where *A* denotes attributes of nuclear power other than safety (e.g. cost, pollution).

Perceived nuclear safety is assumed to be inversely related to subjective accident probability, *p*, and to the subjective expected damage associated with an accident, *D*; hence *S* = *f*(*p*,*D*) with negative partial derivatives. Moreover, the subjective probability of a nuclear accident in a country is assumed to be increasing in the contribution of nuclear power to overall power supply, *N*, that is, *p* = *p*(*N*) with *p*(0) = 0.[57]

We thus have *S* = *f*(*p*(*N*),*D*) =: *g*(*N*) as the (downward-sloping) relationship between perceived nuclear safety and nuclear power supply and *U* = *U*(*S*,*A*) = *U*(*g*(*N),A*) =: *V*(*N*) as a reduced-form utility function. The latter represents the preference for nuclear power in terms of perceived safety and other attributes. Its slope is undetermined *a priori.*

We hypothesize that the Fukushima nuclear accident may have changed the functions *g*(*N*) and, hence, *V*(*N*) by changing European citizens' assessment of accident probabilities associated with a given level of *N* (that is, *p*) and/or their assessment of the damage potential of an accident (that is, *D*). In addition, the accident may have changed *V*(*N*) by changing the utility weights people place on nuclear safety relative to other attributes and it may have raised people's awareness of the role of nuclear power (*N*) in their countries.

3. Empirical Framework

3.1 Econometric Strategy

Our aim is to test whether the reduced-form utility function *U* = *V*(*N*) is different before and after the Fukushima nuclear accident. To do so, we use SWB data elicited in surveys as a proxy for *U* and specify *V*(*N*) as follows:

$$SWB_{ict} = \alpha * nuke_{ct} + \beta * post_{ict} + \gamma * post_{ict} * nuke_{ct} + \delta \cdot controls_{ict} + country_c + time_t + \varepsilon_{ict}$$

where *nuke* is the percentage of nuclear power in the electricity mix, *post* is a dummy variable taking the value 1 if *SWB* was elicited after the Fukushima accident (March 11, 2011) and 0 otherwise, *controls* is a vector of control variables, *country* and *time* are fixed effects, ε is the error term, and *i*, *c* and *t* denote

[57] The latter assumption neglects the possibility of nuclear risk from power plants abroad.

individuals, countries and time periods, respectively. The vector of controls comprises person-specific (micro) variables (sex, age, marital status, household size, employment status, household income) and macro variables (GDP per capita, inflation rate, unemployment rate). The *country* dummies account for unobserved time-invariant country characteristics that affect well-being whereas the *time* dummies account for unobserved time-specific well-being factors that are common to all countries.

With respect to the time dimension it should be noted that the variable *nuke* is measured on an annual basis (as are the macro controls) whereas the person-specific variables, in particular *SWB*, are identified by calendar date. For the *time* fixed effects we use several alternative specifications capturing the quarter, year and season in which *SWB* was measured. Controlling for season serves to account for seasonal mood patterns (Rosenthal 2006) that may interfere with the Fukushima event.

In the specification above the coefficient on *nuke* measures the relationship between nuclear power generation and SWB before the Fukushima accident whereas the coefficient on *post***nuke* measures if and how that relationship has changed after the accident. Likewise, it measures if and how a change in SWB at the time of the accident varies with nuclear power. The coefficient on *post* measures a change in SWB in countries without nuclear power. Consistent with the conceptual model in subsection 2.1, these countries serve as the control group where nuclear risk is assumed to be absent. A change in their SWB at the time of the event (nonzero coefficient on *post*) may have any reason and cannot necessarily be attributed to the Fukushima disaster. Rather than the coefficient on *post*, the crucial parameter in our analysis is the coefficient on *post*nuke*. It represents our hypothesis that at the time of the event the relationship between life satisfaction and nuclear power changed or, equivalently, that life satisfaction changed *differently* in countries with different nuclear shares (difference-in-differences). Specifically, we expect the coefficient on *post*nuke* to be negative.[58]

To test for heterogeneity, we replace *post* with *post***Z* and *post*nuke* with *post*nuke***Z* in some of our regressions, where *Z* indicates sex, age, and environmental attitude.

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[58] Our approach assumes that people have some knowledge of the importance of nuclear power in their countries. In particular, the Fukushima event may have directed their attention to this issue. A change in the relationship between life satisfaction and nuclear power after the accident, if any, may thus partly reflect people's increased awareness of the role of nuclear power. To account for the circumstance that knowledge may be imprecise, we run an additional regression with broad categories of nuclear percentages.

Based on the results by Ai and Norton (2003) and Ferrer-i-Carbonell and Frijters (2004) we estimate the equation above and variants thereof by least squares. We report robust standard errors adjusted for clustering at the county-year level. Our results do not change qualitatively if we cluster our standard errors at the country-quarter level.

3.2 Data

Data on the dependent variable as well as on the person-specific controls and the environmental attitude are taken from the first five rounds of the European Social Survey (ESS); see www.europeansocialsurvey.org. Our data set covers the years 2002-2011 and the following countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the UK. Due to missing observations on power supply the final sample for econometric analysis includes 123,675 data points.

The variable used to capture 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?" Response options range from 0 = 'extremely dissatisfied' to 10 = 'extremely satisfied', and we use the answers on the 11-point scale as our dependent variable. As to explanatory variables, we use the degree to which respondents describe themselves as someone who "strongly believes that people should care for nature" and that "looking after the environment is important" to construct an indicator of environmental attitude. Specifically, we use the 6-point scale of agreement with this statement to create a dummy variable *environmentalist* which takes the value 1 if a respondent belongs to the two highest categories of agreement (about half of the respondents) and 0 otherwise. A dummy variable *non-environmentalist* (= 1 – *environmentalist*) captures the rest of the respondents.

Data on the percentage share of nuclear power in electricity generation were taken from the International Energy Agency, see www.iea.org. Data on GDP per capita and the rates of inflation and unemployment were taken from the OECD online data base (www.oecd.org).

The list of variables and the summary statistics are presented in Tables A1 and A2 in the Appendix. Table A3 reports summary statistics of the main variables before and after Fukushima. There is no statistically significant post/pre difference in those variables, and in particular in life satisfaction and the nuclear share. One exception is the unemployment rate, which is significantly higher in the post-Fukushima period. Table A4 reports correlation coefficients of the main variables. Consistent with the higher unemployment rate post-Fukushima, we find a significant positive correlation between unemployment and the dummy variable for the post-Fukushima period (0.364) as well as between unemployment and the post-Fukushima variable interacted with the nuclear percentage (0.299). The difference between these two correlation coefficients suggests that there was better post-Fukushima macroeconomic performance (lower unemployment) in countries with more nuclear power. The post-Fukushima dummy and its interaction with the nuclear share are highly correlated. To account for those properties of the data we will run a series of robustness checks on our econometric results.

It is important to note that the variation in nuclear power shares necessary for identification comes not only from cross-country differences but also from inter-temporal variability. While nuclear power is constantly absent in about half of the countries (Austria, Denmark, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Norway, Poland, Portugal and Turkey), the maximum average (across years) share amounts to 78.2 percent (France). Over time, the nuclear share varies, for instance, between 25 and 33 percent in the Czech Republic, 18 and 28 percent in Germany, 18 and 26 percent in Spain, 38 and 51 percent in Sweden, and 14 and 23 percent in the UK. Overall, we expect that the inter-country and inter-temporal variation of supply shares provides a strong enough source of identification of the relationship between nuclear power and well-being.

4. Results

4.1 Main Results

Table 1 reports the estimation results for the variables of interest.[59] Model A captures time fixed effects by quarter dummies (II/2002 to IV/2011), which are supposed to reflect seasonal mood patterns, among others. In this model, the coefficient on the nuclear share (*nuke*) is insignificant before the Fukushima disaster. The post-Fukushima dummy (*post*) is positive and statistically significant, whereas the *nuke***post* interaction is negative and significant, as hypothesized. This means that while SWB was unrelated to nuclear power before the Fukushima accident, there is a significantly negative relationship after the disaster. The magnitude of the interaction term suggests that post-Fukushima a 1-percentage point

[59] We report the complete results for model A in Table A5 in the Appendix. Results for the control variables are similar in all specifications and consistent with the bulk of previous findings in the SWB literature (see Dolan et al. (2008): Women and married persons are more satisfied and unemployed persons are less satisfied than their counterparts, satisfaction is u-shaped in age and increasing in income.

increase in the nuclear share is associated with a drop in SWB by 0.0127 points on the 11-point well-being scale. An increase in the nuclear share by one standard deviation (22.57 percent) is associated with a decrease in SWB by about 0.287 points. This is more than half of the difference in SWB between being divorced and being married (see Table A5), which is among the biggest factors of SWB (Dolan et al. 2008).[60]

In order to check the robustness of these results and learn more about their meaning we ran a series of additional regressions (models B – J).

Instead of quarter dummies, model B uses year dummies and a dummy variable taking the value 1 in April-December and 0 otherwise, whereas model C uses year dummies only. The results are qualitatively the same as in model A: no significant relationship between SWB and nuclear power before Fukushima, a significantly negative relationship after Fukushima, and an increase in SWB post-Fukushima in countries without nuclear power. In addition, the coefficient size of the *post*nuke* interaction term is almost unaffected. The main difference to model A is that the interaction term is only marginally significant in model C. The latter highlights the importance of controlling for seasonality (as in models A and B) since otherwise a seasonal increase of mood in spring leads to imprecision in the estimate of the Fukushima effect.[61]

Acknowledging that there could be many factors that differ between the 2002-to-Fukushima sub-period and the sub-period thereafter, we checked the implications of the estimation period by restricting it to 2010-2011 (model D in Table 1). This restriction of the time frame reduces the number of observations from 123,675 to 21,865 but leads to a more balanced distribution of pre-Fukushima and post-Fukushima observations. The results are the same as in model A in terms of signs and significance. The magnitudes of both the post-Fukushima dummy and its interaction with the nuclear share are smaller by two thirds in comparison with model A.

One major factor in which the sub-period 2002 to Fukushima differs from the post-Fukushima sub-period is macroeconomic performance. In particular, the mean unemployment rate post-Fukushima was

[60] It should be noted that the quarter fixed effects in model A capture those life satisfaction dynamics of European citizens which cannot be attributed to observed factors. To learn more about those dynamics, we re-estimated the model including an explicit time trend and found it to be significant and positive (0.042). This exercise did, of course, not affect any of the other estimation results except for the quarter fixed effects.

[61] In model B, the *April-December* dummy is marginally significantly positive.

significantly greater than in the pre-Fukushima period (see Table A3). To investigate the role of macroeconomic conditions, model E omits the macroeconomic variables (while retaining the initial time frame, 2002-2011). In comparison with model A, the coefficient on *post* is now smaller (but still positive and significant), because it incorporates the poorer economic performance in the post-Fukushima period. The coefficient on *post*nuke* is now smaller in magnitude, though remaining significantly negative. The latter reflects the circumstance that the drop (post/pre) in economic performance was less pronounced in countries with more nuclear energy (as indicated by the correlations shown in seen in Table A4). The differences of the results in models E and A are thus intuitive and support our confidence in model A.

As mentioned in the data section, the post-Fukushima dummy and its interaction with the nuclear share display a considerable degree of correlation. Therefore, models F to H study the roles of these two variables in more detail. Model F omits both of these variables; it finds that the nuclear share continues to be insignificant. When only the interaction term *post*nuke* is omitted (model G), the *post* dummy is insignificant (as is the nuclear share). Insignificance of the *post* dummy suggests (consistent with the descriptive statistics reported in Table A3) that there is no post/pre difference in European citizens' life satisfaction unless we differentiate respondents according to the nuclear share in their countries (as in model A). When, instead, we omit *post* while retaining *post*nuke* (model H), we find the latter to be significantly negative, though of smaller magnitude than in model A: Given the strong correlation between *post* and *post*nuke*, omitting the former would introduce omitted variable bias into the estimate of the latter. The strong correlation *per se* does, however, not constitute a problem if the model is specified appropriately (model A).

An alternative explanation for the results reported so far is the circumstance that the set of countries for which data are available for the post-Fukushima period differs from the pre-Fukushima period. To check for this possibility, we re-estimated model A on the set of countries for which data are available for both sub-periods. This reduces the number of observations to 34,352. As reported in column I of Table 1, the qualitative findings from model A are unaffected by this modification: The nuclear share is insignificant, the *post* dummy is positive and significant whereas the *post*nuke* variable enters negatively and significantly.

A final alternative explanation of our results is that they could be a consequence of functional form. To check for this possibility we applied a semi-parametric technique based on different categories of nuclear power percentage. Specifically, we created a dummy variable *nukehigh* that takes the value 1 if the nuclear percentage is above the median (23.1 percent) and 0 otherwise. We note that this approach attenuates the problem that people may have only a vague knowledge of the percentage of nuclear power in their country.

Formally, this approach represents a standard difference-in-differences design in which countries with a nuclear share below and above the median are specified as the control and treatment group, respectively.[62] The interaction of *nukehigh* with *post* then captures the treatment effect, i.e., the difference between the treatment and the control group (as specified) of the change in life satisfaction: $(LS^{post} - LS^{pre})^{treatment} - (LS^{post} - LS^{pre})^{control}$. We expect the treatment effect to be negative: In countries with a high nuclear share, life satisfaction changed more negatively or less positively than in countries with a low nuclear share.

The results from this model are reported in column J of Table 1. The coefficient on *nukehigh* is the difference before Fukushima between the treatment and the control group (as specified). It is significantly positive (0.588): Before Fukushima, life satisfaction was higher in countries with a nuclear share above the median.[63] The coefficient on *post* is the difference in the control group between life satisfaction after and before Fukushima. It is significantly positive (0.411): In countries with a low nuclear share, life satisfaction was higher after than before Fukushima. The coefficient on the interaction term *nukehigh*post* is the difference between the treatment and the control group of the change in life satisfaction. It is significantly negative (-0.606): In countries with a high nuclear share, life satisfaction changed less positively than in countries with a low nuclear share; in fact, after Fukushima life satisfaction in countries with a high nuclear share *dropped* (by 0.411-0.606 points). Put alternatively, the coefficient on the interaction term is the change in the difference between the treatment and the control group: While before Fukushima life satisfaction was higher in *nukehigh* countries (by 0.588 points), that difference dropped (by 0.606 points) after Fukushima. Either way, specifying countries with a nuclear share below and above the median as the control and treatment group, respectively, we obtain a negative effect of the Fukushima accident on European citizens' life satisfaction.

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[62] We emphasize that this model is a difference-in-differences model in a purely formal sense. This set-up should not be construed as implying that countries with a nuclear share below the median are not exposed to nuclear risk.

[63] Possible reasons for this finding are that nuclear power is relatively free from pollution (in comparison with electricity from fossil fuels) and relatively inexpensive (in comparison with solar and wind power), see Welsch and Biermann (2014).

Based on models A to J, we find that in countries with a higher nuclear share, life satisfaction changed less positively after Fukushima than in countries with a lower nuclear share. In the specifications with a continuous nuclear share (models A to I), life satisfaction is found to be statistically unrelated to the percentage of nuclear power before Fukushima and negatively related to the nuclear share after the accident.

4.2 Heterogeneity

While European citizens' life satisfaction was statistically unrelated to the share of nuclear power before the Fukushima disaster, it was negatively related to the nuclear share after the disaster. Models K to M in Table 2, which are counterparts to model A, differentiate this change by sex, age and environmental attitude, respectively. In all of these models, the nuclear share pre-Fukushima (which we do not differentiate) is insignificant.

Our main variable of interest, the *nuke**post* interaction, is significantly negative both for women and men (model K), the respective coefficients being almost the same. This is interesting because women generally show a higher SWB level than men (see table A5). Differentiating the *post**nuke* interaction by age (model L) shows that it is significantly negative for all age groups, being largest for people aged 48 to 62 years. In model M, the *post**nuke* interaction is significantly negative for both environmentalists and non-environmentalists. The coefficient is greater for environmentalists than for non-environmentalists.

The post-Fukushima dummy *post* is positive and significant for environmentalists and non-environmentalists, women and men, and for all age quartiles, indicating an increase in SWB post-Fukushima in countries without nuclear power for all subgroups. Interestingly, this increase is greater in environmentalists than in non-environmentalists (though the difference is not statistically significant): post-Fukushima, environmentalists became more satisfied with living in a non-nuclear country than non-environmentalists.

5. Conclusions

Due to extensive media coverage, the nuclear disaster at Fukushima-Daiichi may have affected the subjective assessment of the probability of and damages from a nuclear accident in countries far away from the place of the event. In addition, it may have changed the weight people place on nuclear safety relative to other attributes of nuclear power. This way, the disaster may have changed the relationship between SWB and the contribution of nuclear power to the energy mix.

Data for about 124,000 individuals in 23 European countries reveal that while European citizens' SWB was statistically unrelated to the supply share of nuclear power before the Fukushima disaster, it was negatively related to the nuclear share after the disaster. Post-Fukushima, a 1-standard-deviation increase in the supply share of nuclear power was associated with a drop in SWB comparable to that associated with major life events, a divorce say. The change in the SWB-nuclear relationship applies to women and men alike and to persons of all age groups. It applies to environmentalists and non-environmentalists, but was stronger in the former than the latter. Taking SWB as an indicator of experienced utility, the change in the SWB-nuclear relationship suggests the existence of a change in experienced preference for nuclear power among European citizens.

This paper focused on the supply share of nuclear power as a factor of people's perceived nuclear safety. Future research may take a spatial approach by studying whether people's location relative to nuclear facilities matters for any possible change in their preference for nuclear power.

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Table 1: The SWB-Nuclear Relationship

	A	B	C	D	E	F	G	H	I	J
Nuke	0.00379	0.00262	0.00247	0.0173	0.000318	-0.00880	-0.00890	-0.00325	-0.0209	
	(0.00692)	(0.00845)	(0.00967)	(0.0108)	(0.00841)	(0.00601)	(0.00602)	(0.00696)	(0.0230)	
Nukehigh										0.588***
										(0.143)
Post	0.481***	0.681***	0.799***	0.131***	0.325***		0.175		0.257**	0.411***)
	(0.169)	(0.224)	(0.258)	(0.0431)	(0.0920)		(0.150)		(0.123)	(0.127)
Nuke*post	-0.0127***	-0.0125**	-0.0125*	-0.00412***	-0.00674***			-0.00551***	-0.00865**	
	(0.00324)	(0.00572)	(0.00722)	(0.00101)	(0.00179)			(0.00195)	(0.00352)	
Nukehigh*post										-0.606***
										(0.115)
April-December		0.129*								
		(0.0737)								
Micro controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro controls	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	No	No	No	No	No	No	No
Estimation period	2002-11	2002-11	2002-11	2010-11	2002-11	2002-11	2002-11	2002-11	2002-11	2002-11
Observations	123675	123675	123675	21865	123675	123675	123675	123675	34352	123675
R-squared	0.202	0.201	0.201	0.195	0.201	0.201	0.201	0.201	0.116	0.201

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. The nuclear share (nuke) is measured in percent. Micro controls are sex, age, marital status, household size, employment status and household income. Macro controls are GDP per capita and the rates of unemployment and inflation. Model A: standard model (quarter fixed effects). Model B: year fixed effects and season fixed effect (April-December). Model C year fixed effects. Model D: estimation period restricted to 2010- 2011. Model E: macroeconomic variables omitted. Models F-H: variables *post* and/or *nuke*post* omitted. Model I: set of countries restricted to those with observations both in Pre- and the Post- Fukushima period (Belgium (mean nuclear share: 55.0%), Netherlands (3.8%), Slovenia (37.2%), Spain (20.9%), Switzerland (41.8%)). Model J: nuclear share collapsed into two categories; *nukehigh* is a dummy vaiable indicating that the share of nuclear power is above the sample median (23.1%).

Table 2: The SWB-Nuclear Relationship with Heterogeneity

	K	L	M
Nuke	0.00397	0.00339	0.00484
	(0.00689)	(0.00693)	(0.00672)
Post*Male	0.622***		
	(0.178)		
Post*Female	0.403**		
	(0.156)		
Nuke*Post*Male	-0.0130***		
	(0.00323)		
Nuke*Post*Female	-0.0129***		
	(0.00316)		
Post*Age [13-32]		0.477***	
		(0.175)	
Post*Age [33-47]		0.364**	
		(0.173)	
Post*Age [48-62]		0.425**	
		(0.171)	
Post*Age [>62]		0.687***	
		(0.178)	
Nuke*Post*Age [13-32]		-0.0110***	
		(0.00356)	
Nuke*Post*Age [33-47]		-0.0117***	
		(0.00328)	
Nuke*Post*Age [48-62]		-0.0138***	
		(0.00322)	
Nuke*Post*Age [>62]		-0.0129***	
		(0.00363)	
Post*Environmentalist			0.598***
			(0.157)
Post*Non-environmentalist			0.385**
			(0.154)
Nuke*Post*Environmentalist			-0.0140***
			(0.00306)
Nuke * Post*Non-environmentalist			-0.0117***
			(0.00299)
Constant	8.364***	8.162***	8.536***
	(0.861)	(0.855)	(0.852)
Observations	123675	123675	123675
R-squared	0.202	0.203	0.203

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. The nuclear share (nuke) is measured in percent. Regressions include country dummies, quarter dummies, micro controls (sex, age, marital status, household size, employment status and household income) and macro controls (GDP per capita and the rates of unemployment and inflation). Estimation period: 2002-2011.

Appendix

Table A1: List of Variables

VARIABLE	SOURCE	DESCRIPTION
Socio-demographic Indicators	ESS	
Life Satisfaction ("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		9 categories: paid work; in education; unemployed and actively looking for job; unemployed and not actively looking for job; permanently sick or disabled; retired; housework; Social/ Military Service; 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 percentage of total civilian labor force.
Nuclear share	IEA (http://iea.org/)	The share of electricity output generated by nuclear power plants relative to total electricity output (%).
Environmental attitude	ESS	Constructed from a six point scale where people are supposed to estimate whether an environmentally aware person is like them or not. We constructed a dummy taking the value 1 for people above the median and 0 otherwise.
Age Groups	ESS	The age groups are captured by dummy variables corresponding to the quartiles of age in years.

Table A2: Descriptive Statistics

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

Poland	0.0370879	0.1889775	0	1
Portugal	0.0428484	0.2025157	0	1
Slovak Republic	0.0288817	0.1674744	0	1
Slovenia	0.0296387	0.1695888	0	1
Spain	0.0404652	0.197048	0	1
Sweden	0.0382691	0.1918456	0	1
Switzerland	0.0387225	0.1929331	0	1
Turkey	0.0177682	0.1321083	0	1
United Kingdom	0.0462382	0.2100009	0	1
Time Dummies (Year)				
2002	0.1109184	0.3140317	0	1
2003	0.064622	0.2458582	0	1
2004	0.1226183	0.3279993	0	1
2005	0.0679951	0.2517381	0	1
2006	0.1350128	0.341738	0	1
2007	0.0436595	0.2043367	0	1
2008	0.1243694	0.3300031	0	1
2009	0.1099077	0.3127753	0	1
2010	0.0871234	0.2820164	0	1
2011	0.1076077	0.3098849	0	1
GDP per capita	28718.62	9439.162	11394.04	68210.83
Inflation	2.82585	2.253715	-4.479938	14.10775
Unemployment	7.771362	3.740002	2.538279	21.72335
Nuclear Share (%)	21.27605	22.56884	0	79.36616
Environmental Attitude	2.315503	1.460956	1	6

Table A3: Mean of Main Variables Before and After Fukushima

Variable	Pre	Post	Post-Pre	SD (Post-Pre)
Life satisfaction	7.140155	7.355682	0.215527	-0.469416
Nuclear share	23.91828	21.72956	-2.18872	-10.56068
GDP p.c.	30.61412	28.35398	-2.26014	-5.66796
Inflation	2.295768	3.153826	0.858058	-1.3316622
Unemployment	7.285737	19.02759	11.741853***	2.47552

*** $p < 0.01$

Table A4: Correlation Matrix for Main Variables

	Life Satisfaction	Nuclear Share	Post	Post*Nuclear Share	Unemployment	GDP p.c.	Inflation
Life Satisfaction	1						
Nuclear Share	-0.0219	1					
Post	-0.0568	-0.012	1				
Post*Nuclear Share	0.0122	0.0179	0.8872	1			
Unemployment	-0.1991	0.1052	0.3640	0.2993	1		
GDP per capita	0.2839	-0.127	-0.0305	-0.0249	-0.6578	1	
Inflation	-0.1742	-0.0153	0.0634	0.0628	0.1526	-0.3431	1

Table A5. Detailed Results for Model A in Table 1

	Coef.	Std. Err.	t	P-Value	[95% Conf. Interval]	
Female	.1258093	.0120655	10.43	0.000	.1019624	.1496562
Age	-.0641292	.0044915	-14.28	0.000	-.0730065	-.0552519
Age-squared	.0006412	.0000434	14.76	0.000	.0005554	.0007271
Household Size	-.0105556	.0061611	-1.71	0.089	-.0227328	.0016215
Married	.3321761	.0239239	13.88	0.000	.2848915	.3794606
Divorced	-.1644597	.0333386	-4.93	0.000	-.2303521	-.0985672
Separated	-.4715335	.0542592	-8.69	0.000	-.5787746	-.3642923
Widowed	-.1708191	.0334891	-5.10	0.000	-.2370088	-.1046293
In education	.1957656	.034804	5.62	0.000	.1269769	.2645543
Voluntary unemp.	-.8667127	.0819545	-10.58	0.000	-1.028692	-.704733
Sick	-1.174255	.0564391	-20.81	0.000	-1.285805	-1.062706
Retired	-.0287901	.0337522	-0.85	0.395	-.0954998	.0379197
Social/Military	-.0424696	.1606879	-0.26	0.792	-.3600628	.2751235
Household	-.0688948	.0275109	-2.50	0.013	-.1232689	-.0145207
Other employment	-.2642257	.059804	-4.42	0.000	-.3824259	-.1460256
Involuntary unemp.	-1.117695	.0698506	-16.00	0.000	-1.255752	-.9796379
Net Hh. Income	.1328409	.0074321	17.87	0.000	.1181516	.1475302
Austria	-.494268	.0929636	-5.32	0.000	-.6780068	-.3105292
Belgium	.1010691	.3395758	0.30	0.766	-.5700888	.7722269
Switzerland	.3584359	.284907	1.26	0.210	-.2046714	.9215431
Czech Rep.	-1.177996	.3601202	-3.27	0.001	-1.889759	-.4662333
Germany	-.6202225	.1887029	-3.29	0.001	-.9931861	-.2472589
Denmark	.4586953	.1058239	4.33	0.000	.2495387	.6678519
Spain	-.248021	.2088448	-1.19	0.237	-.6607943	.1647523
Finland	.3888654	.2086556	1.86	0.064	-.023534	.8012648
France	-.855457	.4875273	-1.75	0.081	-1.819035	.1081211
United Kingdom	-.5811657	.1509979	-3.85	0.000	-.8796069	-.2827246
Hungary	-2.065425	.4396634	-4.70	0.000	-2.934402	-1.196448
Ireland	-.2497387	.1385913	-1.80	0.074	-.5236588	.0241814
Iceland			Reference			
Luxembourg	.4128343	.7209286	0.57	0.568	-1.012052	1.83772
Netherlands	-.2752106	.0988122	-2.79	0.006	-.4705088	-.0799124
Norway	.0834874	.2908767	0.29	0.775	-.4914186	.6583934
Poland	-1.299954	.4031895	-3.22	0.002	-2.096841	-.5030658
Portugal	-2.38947	.3113968	-7.67	0.000	-3.004933	-1.774007
Sweden	.3588633	.288858	1.24	0.216	-.2120528	.9297794
Slovenia	-.7616983	.3279981	-2.32	0.022	-1.409973	-.1134233
Slovak Rep.	-1.085924	.4662269	-2.33	0.021	-2.007403	-.1644458
Turkey	-2.12949	.4904767	-4.34	0.000	-3.098898	-1.160083
Q2_02	-.7595747	.2366541	-3.21	0.002	-1.227312	-.2918373
Q3_02	.4430054	.2360365	1.88	0.063	-.0235112	.909522

Q4_02	.4424436	.2331423	1.90	0.060	-.0183528	.90324
Q1_03	.5265114	.2475122	2.13	0.035	.0373135	1.015709
Q2_03	.2268557	.2460863	0.92	0.358	-.2595239	.7132354
Q3_03	.8638502	.2527667	3.42	0.001	.364267	1.363433
Q4_03	.5136812	.3375261	1.52	0.130	-.1534256	1.180788
Q3_04	.5464664	.2461246	2.22	0.028	.060011	1.032922
Q4_04	.5292374	.242633	2.18	0.031	.0496831	1.008792
Q1_05	.5344606	.2535803	2.11	0.037	.0332694	1.035652
Q2_05	.6694147	.2550884	2.62	0.010	.1652428	1.173587
Q3_05	1.134847	.2531971	4.48	0.000	.634413	1.635281
Q4_05	.9988774	.2841685	3.52	0.001	.4372298	1.560525
Q1_06	.8764281	.7699091	1.14	0.257	-.645266	2.398122
Q2_06	.9586345	.267363	3.59	0.000	.4302023	1.487067
Q3_06	.4725763	.2504355	1.89	0.061	-.0223993	.9675518
Q4_06	.5874481	.2495535	2.35	0.020	.0942156	1.080681
Q1_07	.5545794	.2541285	2.18	0.031	.0523046	1.056854
Q2_07	.6198042	.2782448	2.23	0.027	.0698646	1.169744
Q3_07	.7666984	.2685839	2.85	0.005	.2358533	1.297544
Q4_07	.5747753	.2644634	2.17	0.031	.0520742	1.097477
Q3_08	.7349816	.2462834	2.98	0.003	.2482123	1.221751
Q4_08	.6481327	.2509125	2.58	0.011	.1522142	1.144051
Q1_09	.5508214	.2619362	2.10	0.037	.0331151	1.068528
Q2_09	.8031555	.2679566	3.00	0.003	.2735502	1.332761
Q3_09	.8355337	.3295369	2.54	0.012	.1842173	1.48685
Q4_09	.7873978	.3044951	2.59	0.011	.1855755	1.38922
Q1_10	2.803852	.4407416	6.36	0.000	1.932744	3.67496
Q3_10	.9119801	.2473829	3.69	0.000	.4230378	1.400923
Q4_10	.8781479	.2485291	3.53	0.001	.3869402	1.369356
Q1_11	.7151478	.2574353	2.78	0.006	.2063374	1.223958
Q2_11	1.117582	.2882809	3.88	0.000	.5478062	1.687357
Q3_11	.8958804	.2880277	3.11	0.002	.3266052	1.465156
Q4_11	1.636168	.2673732	6.12	0.000	1.107716	2.164621
GDP	-.0286208	.0230205	-1.24	0.216	-.0741198	.0168783
Inflation	-.0177347	.0145538	-1.22	0.225	-.0464996	.0110303
Unemployment	-.0498553	.0107054	-4.66	0.000	-.0710141	-.0286966
Nuke	.0037889	.0069234	0.55	0.585	-.0098949	.0174726
Post	.4809473	.1694627	2.84	0.005	.1460112	.8158834
Nuke*Post	-.0127401	.0032446	-3.93	0.000	-.019153	-.0063272
Constant	8.502943	.8599911	9.89	0.000	6.803205	10.20268

Dependent variable: life satisfaction (11-point scale). Method: least squares. Cluster-robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01. The nuclear share (nuke) is measured in percent.