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The Fukushima Accident and Public Perceptions about Nuclear Power around the Globe – a Challenge & Response Model.

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The Fukushima Accident and Public Perceptions about Nuclear Power around the Globe – a Challenge & Response Model.

In this paper we examine the impact of the Fukushima accident (March 2011) on public perceptions of nuclear power on a global scale. It is widely recognized that any future of nuclear power critically depends on public acceptance to sustain massive public subsidies. We will contrast conceptually and empirically two models of the 'Fukushima effect', an event & effect (EE) model (Kim, Kim & Kim, 2013) and our own challenge & response (CR) model. Firstly, we replicate Kim et al. (2013) who modelled retrospective opinion changes after March 2011 across 42 countries on a set of 'objective' predictors including geographical distance from Fukushima. But, instead of survey data ex-post-facto, we use historical opinion data 1996-2016 for 23+ countries. On historical data, the EE model has little explanatory power for opinion shifts, beyond the dependency on nuclear power in the energy mix. Secondly, we introduce the alternative CR model. Our hypothesis is that individual and societal responses to nuclear accidents are constrained by cultural memories. Memory, both individual and collective, is primarily adaptive and makes available schematic information to deal with novel situations. Memory creates familiarity and facilitates coping with uncertainty. The CR model introduces symbolic factors such as 'Past Responses to Nuclear Incidents', 'Nuclear Renaissance', and 'Long-term Acceptance Level' to explain the Fukushima effect of 2011.

New abstract [April 2018]

We examine the impact of the Fukushima accident (March 2011) on global public perceptions of nuclear power. We contrast conceptually and empirically two models, an event & effect (EE) model [Kim, Y., Kim, M., & Kim, W. (2013). *Effect of Fukushima nuclear disaster on global public acceptance of nuclear energy*. Energy Policy, 61, 822–828] and our own challenge & response (CR) model. We replicate Kim et al. (2013), who modelled retrospective opinion changes on a set of "objective" predictors, using historical opinion data 1996–2016 for 23+ countries. The EE model shows little explanatory power for opinion shifts beyond nuclear dependency in the energy mix. We argue that individual and societal responses to nuclear accidents are constrained by cultural memories, and introduce the alternative CR model. Memory, both individual and collective, is primarily adaptive and makes available schematic information to deal with uncertain and novel situations. The CR model explains better the responses to Fukushima with memory factors of “Past Responses to Nuclear Incidents”, of “Nuclear Renaissance” and “Long-term levels of Acceptance”. We are able to typify 23 countries according to their characteristic pattern of cultural memory and their Fukushima responses.

Keywords: Fukushima; nuclear accident; nuclear disaster; public opinion; cultural memory

Introduction

On 11 March 2011, a massive earthquake reaching a magnitude of 9.0 M_W off the East Coast of Japan triggered a Tsunami, which flooded the coast in the area of Fukushima, where a nuclear power station is located. The flooding caused a failure of the backup electricity supply needed to control the reactor. The reactor at Fukushima-Daiichi went out of control, critical and exploded. A massive evacuation of more than 150,000 people living in the vicinity ensued, and an evacuation of Tokyo was only avoided because of a fortunate turn in wind conditions. The clean-up of the aftermath at the Fukushima nuclear plant continues to the present day.

In this paper, we re-assess the Fukushima effect on a global scale. When we say ‘effect’ we more likely mean ‘response’. Rather than a mechanical cause & effect model, we consider a *challenge & response (CR) model* for how different societies perceive, interpret and infer action imperatives from an ‘event’ that occurred at some geographical distance. How does a society draw conclusions from a nuclear accident that happened elsewhere? Researchers have asked this question three times already in the history of civil nuclear power: after Three Miles Island (TMI; 1979), after Chernobyl (1986) and again after Fukushima (2011). The response to an accident that happened at home is one problem; a totally different affair is what has happened elsewhere. Our focus will be the remote responses to the nuclear accident in Japan (we therefore exclude Japan from our analyses). The meaning of Fukushima 3/11 for Japan is still in the making (Funabashi & Kitazawa, 2012) and might take some time as in the case of Chernobyl (Alexievich, 1997).

Clearly, the societal response to a nuclear accident has many dimensions, involving operational, judicial, policy, and public opinion responses. The technical understanding of what went wrong has lessons for future operations (Nöggerath et al., 2011), for judicial apportioning of blame and liability; for the review of current nuclear power policy (Elliot, 2013) and for public attention in mass media and conversations about what had happened and what the ‘future’ might be. Public perceptions involve changing assessments of risks and support for nuclear power. Our present paper will focus on public opinion in global comparison.

Nuclear protagonists around the world have recognized that there is no future for nuclear in the civil energy mix without public acceptance to sustain massive public subsidies, which are inevitable to absorb the large up-front investments, to insure the operational safety risks however small, to avoid nuclear proliferation, and to guarantee the cleanup at the end of the reactor life cycle. The

International Atomic Energy Agency (IAEA) commits member states to report regularly on the processes of building public acceptance under section 2.3.6 of the Country Nuclear Power Profile. Although, compared to the details reported on policy and technical operations, this section is often short and thin in content (see http://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2016/pages/index.htm).

At the high point of nuclear enthusiasm, the Stockholm International Peace Research Institute (SIPRI; 1974) reported on the 'Nuclear Age' and intimated how '*few people have a clear idea of how extensive the spread of nuclear technology around the world has already become and how rapidly it will continue'*. SIPRI predicted a ten-fold increase in energy production by the year 2000 (SIPRI, 1974, p. 30); but things did not develop as planned for the then 19 nuclear energy producing countries and a further 20 countries with nuclear aspirations. By 2017, the global nuclear complex had less than doubled producing a fraction of predicted energy. 30 countries, many recruited from former USSR and Yugoslavia, are operating a declining park of 450 plants, 55 new ones are under construction out of which 35 are behind schedule (*Economist, 30 Jan 2017*). Nine countries are in the 'Nuclear Club' and also command the bomb (Norris & Kristanson, 2013). The present study will consider public opinion data from over 30 countries, many of which oscillate between entering and closing the Nuclear Age, and in order to reach this decision are anxiously monitoring public opinion, most of it for private eyes only.

The impact of nuclear accidents on public opinion

Previous research on the impact of nuclear accidents focused on public support for nuclear power, emphasizing three issues: a) did the accident mark a trend shift in opinion formation; b) was there a rebound effect, and c) who most likely changed opinion and behavior in response to events.

Three Mile Island, USA (TMI, 28 March 1979)

TMI did not usher in a new nuclear opinion in the USA; it rather reinforced a trend change since the mid-1970s, which corrected consistently high levels of support during the 1960s to reach an anti-nuclear majority in the 1980s (Rosa & Dunlop, 1994). Weart (1988) finds that negative US media coverage of the 'atom' overtook positive ones by the late 1960s. Hohenemser, Kasperson, & Kates (1977) had diagnosed mounting distrust and divergence between environmentalists and the public; safety monitoring did not keep track with the expansion of the nuclear park. Kepplinger (1988) finds news shifting after 1969 in Germany; by 1972 nuclear news was dominantly skeptical. Jasper (1988) shows how responses to accidents depended on the issue cycle: TMI strengthened the anti-nuclear case in the US, while France and Sweden saw favorable opinions surge. Accidents are ambiguously coded signals and, amplified by media reportage, opinions are contingent on the local issue cycle and symbolic representations. Positions on nuclear power depend less on factual knowledge, but on what people imagine and value about the future.

Chernobyl, former USSR, now Ukraine (26 April 1986)

Verplanken (1989) reviews evidence from pre-post Chernobyl 1986 studies. He reports stronger effects on attitudes among residents living in fall-out affected areas, among pregnant women and farmers in Sweden. In Britain, anti-nuclear positions strengthened, while across Europe, responses followed existing attitudes on nuclear waste. While opposition strengthened, uncertainty regarding health hazards persisted and only a minority reported changing food choices. Across Europe, a consistent picture shows opposition increasing after Chernobyl, but rebounding to the long-term trend below pre-Chernobyl levels. These changes co-varied with the fall-out radiation dose. Risk perceptions of nuclear power increased the dread element, while the severity decreased. Supporters were more ambivalent and less stable in their positions as opponents. Verplanken's three-wave study in the Netherlands showed that the catastrophic image of risks, and its association with nuclear bombs, became predominant after Chernobyl; most people came to stigmatize nuclear technology as fundamentally unsafe. Many studies reported declining confidence in governments' handling of nuclear technology (Van der Plight, 1992, p. 126). It was later found that visual commemoration of events was significant. While visualization was light for controversies of the 1990s, such as BSE (Bovine Spongiform Encephalopathy otherwise also known as 'mad cow disease'), road traffic, excessive alcohol consumption, and chemical waste, Chernobyl was a visually rich story in Sweden, Norway, UK, France and Spain. Chernobyl took on a new meaning, lifting the physical events accountable in terms of scientific risk, to one by divine force striking a sinful humanity (Boholm, 1998). The latter is best illustrated by the Noble Prize of Literature 2015; Sveltana Alexievich reflects in her 'Chernobyl Prayer': '*Chernobyl is a mystery that we have yet to unravel. An undecipherable sign. A mystery perhaps for the 21st century; a challenge for it …challenges more fiendish and all-embracing, although still hidden from view; yet after Chernobyl, something has cracked open'* (Alexievich, 1997, p25)

Fukushima Daiichi, Japan (11 March 2011)

With Russia, Spain, and Latvia as exceptions, the Fukushima accident lead to a universal loss of support for nuclear energy with implications for energy policies. The Germans and Swiss phasing out nuclear energy and the French reducing the number of plants, came in direct response to the Japanese events. Hindsmarsh & Priestley (2016), with a set of in-depth country analyses, show how policy responses vary from weak to strong strategic adjustments. The case studies point to social media as a new vehicle of knowledge dissemination, and highlight the discursive practices and national storytelling conditioning policy responses to Fukushima. In Finland, a traditional 'nuclear exceptionalism' allowed to sustain a clear distinction between them and us, the Japanese and Finnish technology. Similarly, in post-Soviet regimes, a purely technical discourse dominated the assessment and policy responses. Bernardi et al. (2018) show that far from a direct cause-effect, policy changes across Europe post-Fukushima require a pattern of factors, which make the situation 'ripe for change'. On public opinion, studies focus on prominent countries such as Italy (Prati & Zani, 2012), Switzerland (Siegrist & Visschers, 2012; Siegrist et al., 2014), Japan (Kato et al, 2013), and Germany (Arlt & Wolling, 2016), used qualitative data and survey-based designs to characterise the specific national trajectories. A comparison of such historical trajectories is offered by a EURATOM project (HoNEST, 2017).

The Fukushima disaster: comparing two different models to explain the global response

We consider and compare conceptually and empirically two models that claim to explain the global variation of responses to the events in Japan of March 2011. On the one hand we analyse and replicate Kim et al.'s (2013) formulation of an event & effect (EE) model, which takes into account only physical factors of reactions across the world. Our own challenge & response (CR) model considers in addition traces of cultural memory as the determinant of local responses to the global event. We will test both models on our own data.

The EE model of reacting to nuclear accidents

Few studies compare the Fukushima effect across many countries. Kim et al. (2013) provides the broadest coverage. Using a WIN-Gallup Global Snap Poll administered within one month after the accident, 24556 responses from 42 countries are modelled post-Fukushima. The study concludes that energy mix, physical distance to Fukushima, and degree of media censorship explain some variation in self-reported opinion change. Yamamura (2012) also uses the WIN-Gallup data to gauge the aggregate relationship between risk of a nuclear accident and other risk experiences, and finds that perceived risk correlates positively with prior experience of technological, not natural, disasters.

Kim et al. (2013) find that a country's distance from Fukushima tends to increase negative reactions; apparently distance brings a decay function of information which amplifies fears of nuclear energy (ibidem, 2013, p. 826), assuming that closeness means complete and accurate information and less fear. On the other hand, nuclear energy production exerts mixed influences. With high density of nuclear reactors, public acceptance decreases more sharply. Longer operating time of nuclear parks also exacerbates negative shifts. Conversely, a larger nuclear energy share buffers changes in acceptance post-Fukushima. Lastly, where media environment is highly censored, opinion also become more negative than elsewhere. In sum, Kim et al. (2013) adhere to an implicit *event & effect (EE) model*, whereby opinions react to the 'physics' of an incident, contingent only on 'objective' factors. Furthermore, in the WIN-Gallup survey, with fieldwork end of March through early April 2011, respondents self-reported opinion change ex-post factum; it is more than plausible that hindsight is biasing this data.[1] We will show later that the WIN-Gallup hindsight effects are more severe compared to historical data from successive surveys; people over-estimate their shift of opinion, when asked post factum.

The CR model of responding to nuclear accidents

The EE model has limited power to explain the variability of public opinion to nuclear power after Fukushima, as we will show below. This is however not the only drawback. The EE model also seem highly unrealistic; it over-generalizes the special case of physical contact with the accident. Most opinions are formed at a distance from events and on the basis of symbolic 'images' (Boulding, 1956), meaningful discourse of sense making (Taylor, 2016) and social representations in national 'echo chambers' of communication and supported by stereotypes of 'us and them'[2] (Bauer & Gaskell, 2008; Farr & Moscovici, 1984). Public debates cultivate over years the symbolic resources to make sense of nuclear power. Humans respond to an accident outside the immediate danger zone based on 'schemata', not signals. Behavioural reactions to alarm signals, or to physical impact of pushing or pulling according to Newton's Third Law of 'actio = reactio', are unlikely to occur at a distance. Most responses therefore occur at a psychological distance from the materiality of noise, water, combustion and radioactivity of Fukushima.

Our alterative CR model postulates the response formation to nuclear incidents with a dual regulation: firstly, there is interpretive flexibility of the 'challenge', and secondly, there is flexibility in the 'response set'. The event triggers a response, but the particulars are correlated to the 'response set', which embodies a symbolic representation of nuclear power. Thus, the response to a nuclear accident is the characteristic of a historically grown mindset and collective mentality. The responses to Fukushima are conditioned by cultural memory; the challenge itself is a function of cultural memory, and the responses are constrained by cultural memory. The image of nuclear power (Weart, 1988) has a memory function, preparing for future responses.[3]

Notions of 'cultural memory' suggest functional analogies between individual and collective remembering. In this light, memory mixes contents on three dimensions: sensory (sensory memory), conceptual (symbolic order), and affective (episodes of pride, anger, happiness etc.). Memory is not only recall of facts on a decay function, but reconstruction involving imagination for a purpose. The primary function of remembering is to retain schematic information for reuse in the environment in which we operate: *'**schemas** are especially important in guiding memory retrieval, promoting memory for schema-relevant information, and allowing us to develop accurate expectations of events that are likely to unfold in familiar settings on the basis of past experience in those settings'* (Schacter, 1999, p. 197). To prepare us for future action is thus the primary function of memory.

But we also worry about dysfunctions, secondary effects of otherwise adaptive remembering: **omission** from loss and transience, absent-minded insufficient encoding, and blockages leave us temporarily or permanently unable to retrieve; in **commission** we misattribute time, place, and persons, and we succumb to social influence and schematic bias. And **persistence** leaves us ruminating and unable to forget. Here critical historical reflection comes to its task to correct these contents when they become dysfunctional.

Bar-Tal (2000) identifies four functions of the social commemoration of events: **epistemic, national and social identity, preservation of unity, and action guidance**. Shared images and beliefs are trans-actively shared: when needed, people know who knows what and how. A repertoire of beliefs is not accidental, but solves problems of social integration. Images and representation facilitate coping with complex situations; different contexts sustain different repertoires. Assmann (1992 and 2008) highlights the difference between history and memory; cultural memory is relative to time and place, has a reference group, and is to be assessed less on 'accuracy' than on maintaining a tribal sense of community. Cultural memory enables resistance to interference, produces and maintains non-simultaneity, and enlarges the present time. The indicators **of cultural memory are ritual repetition, architecture, and representations** in scriptural and pictorial media. By contrast, historical reflexivity is the methods by which we check the memory for facts or mythical stories. Historians and their critical methods are called to task on convenient ‘stories’, which only hold the community together and nothing else. However, to explain responses to Fukushima, the question of ‘accuracy’ of memory is secondary; prior is its function to cultivate acceptance or resistance. Thus, memory is a relatively persistent structure of current activity: who are we, what are we doing and how are we doing it? We can expect that traces of cultural memory of nuclear power will explain better the responses to Fukushima than a physical cause & effect model. We postulate that cultural memory characterizes the ‘nuclear life world’ of nations and includes at least the following indicators:

The **Chernobyl effect** is the past response to the accident of 1986, equally measured as negative shift in acceptance before and after the event. Past behavior can predict future behavior through ‘habit formation’ and ritual commemoration of events. Everyday life is littered with past episodes and rehearses them by playfully asking for flashbulb memories ‘… and what did YOU do on that day?’ So we might ask: are earlier responses to TMI and to Chernobyl correlated with responses to Fukushima?

Nuclear renaissance: we define as the slope of acceptance from 1996 to 2010. The IAEA (1994) called for a ‘nuclear renaissance’ and started to reframe nuclear power as ‘green technology’ and, adding little to Green House gases, a solution to global warming. The very idea of a ‘re-naissance’ involves the harking back to an earlier ‘golden period’ when nuclear expansion was uncontested. This adds ‘sustainable technology’ to those traditional discursive frames of nuclear power which included progress, energy autarky, public accountability, cost-effectiveness, technology as runaway train to jump-on or being left behind, or a devil’s bargain as Mephistopheles had struck (Gamson & Modigiani, 1989). The period 1987 to 2010 was a time of quiet normality for the global nuclear park. And the challenges of global warming offered nuclear a different light. Stigmatized by earlier accidents at TMI and Chernobyl, since the mid-1990s nuclear seemed presentable again in the light of climate change and energy mix scenarios. This discussion took place in countries already operating or aspiring to nuclear energy. We can thus easily recognize the ‘renaissance’ (1996-2010) which renews expectations of a shining nuclear future. We must ask: to what extend did public opinion endorse a ‘nuclear renaissance’ 1996-2010, and how did this affect the Fukushima responses?

Level of acceptance refers to the long-term level measured as central tendency of the available historical data between 1996 and 2010. This level reflects the climate of discourse. In most countries acceptance fluctuates over time, but it does so at a certain level, which shows that the country is overall favoring or rejecting nuclear power. Low levels of acceptance points to a dominantly critical discourse, high level of acceptance would suggest a predominantly supporting public discourse in commemorating nuclear power, and a mid-level of acceptance traces a history of divided opinions and possibly vivid nuclear debates. The history of civil nuclear power reaches back to the 1950s, but it rolled out only in the 1970s when also measures of public opinion become available. This is the time when the discursive frame ‘Atom = Progress’ lost its credibility and resonance (see Weart, 1988; Gamson & Modigliani, 1989; Bauer, 2015). Ever since, public opinion reflects this debate with levels of acceptance and volatility. Thus, again we must ask: how does the prior climate of discourse condition the Fukushima response?[4]

The curated historical database

We have at our disposal a global database of nuclear opinion covering the years 1977 to 2016. This database was curated by the lead author over the past 25 years and contains an unequal number of polls per year across a range of 60 countries. The numbers range from 1 to 46 polls in any one year; the overall saturation of the database is 18% (see Appendix, Figure A3). The database is of course incomplete, as probably the most comprehensive nuclear opinion data-series are not even in the public domain. The nuclear issue has a historical legacy of secrecy and incomplete public data, as Rose & Sweeting (2016, 114) have observed for data on nuclear incidents.

Our database reflects diligent academic vigilance to national and international polls of nuclear power issues that were publicly reported. Data has been curated over years and compiled in a database to track public controversies; nuclear power is an important example, and the database served as a continuous teaching resource at the London School of Economics. It was also the basis of a book chapter on the history of public perception of nuclear power (Bauer, 2015). The sources include international agencies such as Eurobarometer, Gallup, Harris International, IPSOS-Mori, and IAEA, and national agencies such as *OBSERVA* in Italy, *Bisconti* and PEW in the US, *Morgan Polls* in Australia, and *Angus Reid* in Canada. Many polls were sponsored by news media such as *ASAHI* in Japan or BBC in the UK and CBS and *Washington Post* in the US, and *Sanomat* and Confederation of Industry in Finland. Percentage of responses mainly to three basic questions, with variations in wording, entered the database, retaining single annual scores:

- *Do you favor or oppose nuclear energy* (generally gives the most favorable results, e.g. Harris, Gallup, Eurobarometer; considered to operationalize NIABY attitudes, ‘not in anybody’s back yard’)
- *Do you favor or oppose nuclear power plants in your area* (gives least favorable results; seen as an operationalization of NIMBY, ‘not in my back yard’)
- *Do you favor or oppose the expansion of nuclear energy* / *new build of nuclear power plants* (produces less favorable responses than the previous question; e.g. CBS, PEW, Eurobarometer; operationalizing expansion or status quo)

Where several polls were reported, the ‘most favorable’ to nuclear power was retained. If there is a bias in our database, it is overestimating support for nuclear power. For purposes of analysis, we created the ’acceptance’ score on the following definition:

$$\text{Acceptance} = \%\text{Favor} / [\%\text{Favor} + \%\text{Oppose}] \quad \text{(ignoring DK-responses)}$$

The score’s range is 0-1, with M = 0.451 and SD = 0.084; where 0 signifies near complete opposition, 1 means near complete acceptance of nuclear power in the country. A score = 0.5 indicates a balance of opinion, ignoring DKs. A score < 0.5 indicates more opposition, a score > 0.5 more favorable views. We are excluding DK-responses because our focus is the balance of opinion at each data point. DK-responses vary considerably and depend on the style of interviewing and the mode of data collection; ratios are on average around 15%. The analysis of DK-response could be an index of ‘ambivalence’ in the micro-dynamics of opinion formation. Over longer observation periods, excluding DKs is ‘good practice’ and provides reliable indicators for opinion balances on biotechnology (Gaskell et al., 1999) or for general optimism toward new technology (Gaskell et al., 2011). This curated historical data allows us to revisit Kim et al. (2013) with actually expressed opinions before and after the Fukushima accident.

Replicating the EE model and previous regression results

Firstly, we replicate Kim et al. (2013) in a cross-sectional OLS regression setup. The dependent variable is the difference in acceptance before and after Fukushima. For example, in Lithuania, acceptance before Fukushima amounted to a net positive acceptance of 19 points, while this changed to negative acceptance of -80 points after the accident. Consequently, the shift after Fukushima becomes -99 points.[5] Table 1 presents our reanalysis. Our four models match those of Kim et al. (2013, p. 826), and the included 'objective' predictors are based on their description.[6] While the original models includes data from 42 countries, our analysis draws on aggregated data from 28 countries. 20 countries are in both studies, while eight countries are not in the original sample.[7] Most importantly, unlike Kim et al. (2013), we exclude Japan from our sample, as shifts in opinion here constitute a response to a 'traumatic national disaster', not comparable to responses elsewhere.

Model 1 presents the basic regression model. Generally, the model lends support for only some of the observations proposed by Kim et al. (2013). Their prominent explanation is the physical distance of a country's capital from Fukushima (Kim et al., 2013, p. 823). As they explain, remoteness of a country either amplifies fears due to lack of relevant information (*the distance effect)*, or it mitigates reactions by lowering the probability of radiation exposure (*the proximity effect)*.

[Table 1 near here]

The results of Model 1-4 show little support for these effects. Focusing on Model 1, the coefficient of distance (ln) is 55.58, meaning that a 1% increase in distance to the Fukushima plant translates into a 0.55 more positive opinion after Fukushima. This tendency mimics Kim et al. (2013, p. 826): the reaction is more negative the farther away a country is located. However, the effect is not statistically significant ($p < 0.137$) and only becomes significant if we include Japan, but also drops to 8.39. Whether geographical distance has a discernible effect on the response to the Fukushima accident thus seems highly dependent on the inclusion of one country, which by design is located closest to the disaster. This bodes for a very cautious use of such explanatory factors.

Model 1 does however reveal more interesting results. Nuclear energy dependence is relevant, but also reveals a rather mixed story. Operating a nuclear power reactor should reduce the negative impact of Fukushima by 62 points ($p < 0.008$). This is largely in congruence with Kim et al. (2013), although their coefficient was not significant. Our results do however point towards very diverse effects of nuclear dependence. Merely having nuclear reactors mitigates the negative effect, while nuclear density, i.e. the number of reactors per square kilometres, or the energy mix have contradicting and insignificant effects. Total operating experience, measured in number of years since a first nuclear power plant was connected to the grid, mitigates the Fukushima effect. As Kim et al. (2013, p. 827), one can speculate that a tradition of nuclear energy bring familiarity and reduce fear; however a long history could be seen as entrenched risk and exacerbate negative responses to disaster. Lastly, 1 pct. change in cumulative operating time (ln) leads to a negative shift in acceptance of 0.1594 ($p < 0.004$), meaning that a 100% different operating experience would yield a negative shift in acceptance of 15.9. This only constitutes 0.7 of a standard deviation of the Fukushima effect, and is therefore not very substantial. Lastly, the Freedom House Freedom of the Press index also mitigates the negative effect of Fukushima. In the index, 0 indicates ‘most free’ and 100 ‘least free’. In our country sample, Finland and Sweden obtain the scores of 10, while Russia scores 80, as having the most controlled media. A change in press freedom equivalent of a standard deviation should therefore lead to less negative shift in acceptance, by an average of 12.6 points. With Model 2-4, we do not detect any interaction between the distance and operating experience, press freedom or earthquake frequency. Contrary to Kim et al. (2013), our analysis does not show that the distance from Fukushima influences differently the shifts in nuclear acceptance at specific levels of operating experience, press freedom, or earthquake proneness.

In our second analysis, we utilise the historical time-series of our database. The analyses so far investigate determinants of the shift in acceptance after Fukushima, but say little about the impact of the incident on national acceptance levels. Table 2 presents panel data models using the database's acceptance score. Model 5 and 6 capture the effect of the Fukushima accident for a sample of 23 countries with public opinion data between 1999 and 2012.[8] Model 5 documents random effects for the variables employed in the previous analyses, but also a dummy 'After Fukushima accident', 0 if the observation is pre-2011 and 1 if post-2011. Controlled for all the variables, Fukushima had a significant effect of lowering acceptance by an average of 0.09, or roughly 10%.

[Table 2 near here]

This estimate is corroborated by the fixed effects regression (Model 6), which only considers the average *within* country shifts in acceptance. The effect of the Fukushima dummy is slightly stronger when considering only within country changes, but equally brings a 10% reduction. Compared to the average volatility across the 23 countries over the years this is a sizeable effect. Between 2008 and 2010, the average move in acceptance was positive 0.005 (0.526-0.521), and from 2009 to 2010 we saw a mean negative change of -0.003 (0.523-0.526).

Independently, across and within-country time-varying evidence seems to corroborate that Fukushima was significant for public sentiment, generally decreasing acceptance levels. The controls included in the models show some significant effect. Surprisingly, acceptance declines with distance, a 50% increase in distance translates into 27.5% drop in acceptance. This is however only a main effect. Model 7 shows the interaction of the pre/post-2011 dummy and distance; remoteness mattered to acceptance before Fukushima ($\beta = -0.613$, $p < 0.029$), however the interaction term shows no effect post-disaster ($\beta = 0.342$, $p < 0.164$).

In sum, the Fukushima incident has brought a discernable negative shift of public acceptance of nuclear energy across a wide array of countries. This has however been a response with large variation; the event does therefore not explain itself the shift. So far, no robust residual factors that structure the responses have emerged. An EE model does not explain why acceptance in some countries fell drastically while in others the reactions to Fukushima are more modest.

Response variation to Fukushima as matter of cultural memory

Figure 1 below summarizes the movement of global nuclear opinion between 1977 and 2016 from our database. Over 40 years, nuclear opinion experiences a bumper ride. The overall picture of moving averages suggests three phases: a) declining acceptance from the 1970s to the late 1980s, b) recovering support into the new Millennium as a 'nuclear renaissance', and c) again declining support after 2011. Globally, the linear long-term trend is negative and sides with 'nuclear scepticism'. What we call the TMI, Chernobyl and Fukushima effects are indicated by the three down-ward pointing bars in Figure 1 on the right hand scale. The year on year median pre-post shift in acceptance across all countries with data was -0.109 for TMI (n=11), -0.333, for Chernobyl (n=17) and -0.165 for Fukushima (n=32). This shows the total dampening effect on the World's acceptance of nuclear power was largest for Chernobyl, followed by Fukushima and TMI.

[Figure 1 near here]

Aggregate responses to TMI and Chernobyl are weakly correlated (r = 0.08, n=11); the correlation of Chernobyl and Fukushima is stronger, r = 0.84 (n=11, without Japan) as shown in Figure 2.

There is no correlation between TMI and Fukushima (n= 10). The graphs also shows that the Fukushima effect responds positively to nuclear renaissance (r=0.21, n=31) and negatively to level of acceptance in the country (r= -0.29, n=31). This means, when considering only bi-serial correlations, we can say that cultural memory of a 'renaissance' and the 'level of acceptance' seems related to the shifts in public opinion after Fukushima. While the memory of TMI has faded, the Chernobyl effect is evident: the stronger the response to the Chernobyl accident, the stronger it is to Fukushima. Also, the impact of the renaissance is in evidence: the stronger the slope of increasing support, the weaker the Fukushima effect; the stronger the expectations of a nuclear revival, the lower the disappointment over Fukushima. Finally, the overall level of acceptance is also directly related: the higher the level of acceptance, the stronger the Fukushima effect. Countries with a more accepting culture for nuclear power respond more negatively to Fukushima.

[Figure 2 near here]

Figure 2 also gives the volatility of acceptance and the nuclear renaissance across 39 countries (see also A2 in appendix). A nuclear renaissance is in evidence, but in degrees. Where countries such as United Kingdom or Sweden have seen a continuous surge in acceptance after 1996, Belgium, France or Germany only saw increased acceptance late in the period. Others shows a stable public opinion landscape, as in Denmark or Finland. Overall, the volatility of opinion increases with the median level of public acceptance, not so the slopes of a 'nuclear renaissance'. Countries with a more favorable climate of opinion over the past 30 years were also experiencing more volatility (r = 0.27; n=38) but were not more likely to endorse a nuclear renaissance (r = 0.05; n=38). For the former, a curvilinear trend indicates that medium levels of acceptance might be most volatile.

To test the effect of cultural memory suggested by our CR model, we consider two sets of countries in Model 1 (M1) and Model 2 (M2); we compare the impact of memory, by holding other influences constant. We have data for three memory types, Chernobyl, renaissance, and level of acceptance , in 11 countries (M2, excluding Japan), and we have data on renaissance and level of acceptance in 23 countries (M1). We have bi-serial data on these indicators for up to 38 countries. Table 3 shows the correlations between these variables in bi-serial format, and partial and semi-partial (part) format. We add as controls economic power, nuclear energy production, and a dummy for membership of the Club of Nuclear States. As mentioned before, overall the stronger the Chernobyl effect, the stronger is the Fukushima response (r=0.84). The stronger the renaissance, the smaller is the negative Fukushima shift (r=0.18), while a favorable climate of opinion increases the response (r= -0.15), so does a larger GDP (r= -0.74) and experience with nuclear power (r= -0.47); however belonging to the exclusive club with the nuclear defense posture buffers the Fukushima response (r= 0.08). These correlations depend however on the set of countries considered. For restricted groups of countries (M1, M2), the renaissance becomes a more significant predictor of responses and with inverted direction. For the select group of countries, the stronger the renaissance, the stronger is the Fukushima response as if built up expectations make for stronger disappointment (r= -.73 M1; r=-0.52 M2); this holds if we control for all the other influences. Without the memory of Chernobyl, renaissance clearly influences the Fukushima response; otherwise Chernobyl is the stronger constraint. Considering partial correlations (in Table 3, in bold) controlling other factors, renaissance is the strongest determinant in M2 countries (r=-0.72), while others fade out. Among M2, both Chernobyl (0.84) and renaissance (-.50) remain important, and so does nuclear experience (-0.39), Club membership (0.31) and GDP (.20) in that order. The level of acceptance is however not significant (0.12).

[Table 3 near here]

In summary, the CR model shows that beyond GDP and Club membership, which mitigate the Fukushima effect, and the nuclear power experience of a country, which accentuates it, cultural memory adds significant explanatory power, showing that the legacy of Chernobyl and the nuclear renaissance 1996-2010 directly affect the responses to Fukushima. The stronger the renaissance, the stronger the disappointment with nuclear power.

Grouping the response variation post-Fukushima

To further investigate these effects we conduct a hierarchical cluster analysis of countries in order to group them according to the cultural memory dimension. We identify three clusters of countries based on renaissance (i. e. the linear trend of nuclear acceptance levels from 1999 to 2010) and the Chernobyl effect. The analysis covers only a small portion of countries with time-series opinion polls data for both nuclear disasters (N = 11 and N =23). Noting that the small number of cases may lead outlying countries to exert great influence on the cluster solution, we utilize a weighted average linkage, hierarchical cluster analysis. Groups of countries are combined by comparing the distance between the weighted averages of two groups (Hair et al, 2010). Furthermore, because of disparate in ranges[9], we standardize the factors as z-scores, though this remains debated[10] (Miligan & Cooper, 1988; Hair et al. 2010). Without standardizing, one variable could dominate the solution. The dendrograms in the appendix (Figure A2) summarize the agglomerative clustering of countries with Euclidean distances. In order to decide on a feasible cluster solution, we examined the Duda/Hart pseudo T^2. The three-cluster solution resulted in the lowest value for both sets of countries indicating that this grouping is the most distinct.

Response variation post-Fukushima in M1 (23 countries)

Examining the three clusters for set M1 reveals patterns with respect to countries' history of nuclear acceptance and their response to Fukushima. Table 4 presents the within-cluster means for nuclear renaissance, acceptance level, and Fukushima effect. Cluster 1 covers only Greece, which has a very low historic level of acceptance. Greece also experienced a moderate renaissance, and saw the smallest shift post-Fukushima. Conversely, the countries in cluster 2 had the largest negative response to Fukushima (42%). Compared to cluster 1, the four countries in cluster 2 have traditionally been much more accepting of nuclear energy (M=0.666), the highest of all clusters, and had no nuclear renaissance 1996-2010. Figure 3 plots the M1 countries on the two clustering components, and clearly shows that cluster 2 unites the two countries with a negative renaissance. Lithuania and Romania have not been rebuilding expectations for a bright nuclear future before Fukushima. It thus seems that countries with traditional high level of acceptance and a declining trend 1996-2010 experienced the most severe responses to Fukushima.

The third cluster of M1 countries is the largest. As shown in Table 4 and Figure 3, these countries have generally had moderate historic levels of acceptance (M= 0.459). As Greece, these countries have seen a surge after 1996 with a slope of 0.009, but as depicted in Figure 5, this varies a great deal. Poland has seen acceptance decline proportional to the trend in Hungary, while Switzerland lived through a remarkable renaissance. It is therefore not surprising that the Fukushima effect is situated between that of cluster 1 and 2, with a 18.5 point drop.

[Figure 3 near here]

Response variation post-Fukushima in M2 (11 countries)

In the second analysis, we group countries according to both nuclear renaissance and prior Chernobyl effect. Again, the analysis yields three clusters as depicted in Figure 3. The clustering of the 11 countries on cultural memory into three groups corresponds well to the Fukushima response.

Cluster 1, with only Italy, exhibits the largest Chernobyl effect, but also had a strong renaissance 1996-2010. The Italian response to Fukushima was the most negative.

For Cluster 2, a common denominator is the moderate prior response to Chernobyl, on average roughly -32 points, which is 25 points less than in Italy. The countries in cluster 2 also experienced a nuclear renaissance, but less steep than Italy. The trend was 0.00062, while Italy's was 0.0181. This central trend does however cover a broad range of nuclear renaissances. Cluster 2 comprises countries with moderate renaissance, Germany and France, and also USA, which experienced no renaissance or even a decline or negative slope. Figure 3 plots the (non-standardized) values of the two cluster components for each country. The scatterplot also reveals that the countries in cluster 2 have had very different responses to Chernobyl, from 16 points in Denmark to 38 points in Germany.

Looking across this group of countries, they also had less severe responses to Fukushima. In Italy, Chernobyl and Fukushima response were consistent, Fukushima being slightly less negative (6 points). The same dynamic is evident in cluster 2. On average, these countries saw a drop in acceptance levels of 21.75 points, which is 11 points less than for Chernobyl. A more moderate response to Chernobyl, combined with a moderate nuclear renaissance, corresponds with a less drastic response to Fukushima.

[Table 4 near here]

This point is also interesting for cluster 3, comprising Belgium, Finland, Ireland, Greece, Netherlands, and the UK. These countries responded strongly to Chernobyl, on average -14.67 points. Also, these countries had very diverse nuclear renaissances. While Finland, Ireland and Greece saw a slight renaissance, the Netherlands and UK have seen the larger surges in nuclear acceptance 1996-2010. It thus seems that a modest nuclear renaissance cushions less abrupt responses to Fukushima. Examining the Fukushima response in these countries support this notion further. Within this group of 11 countries, Finland also had the smallest Fukushima effect with a negative shift of 7 points. Likewise, Ireland experienced a drop in acceptance of 8.5 points, the third smallest drop behind Belgium's 8 points.

Our analysis thus suggests four cultural dispositions to respond to Fukushima. Firstly, Greece and Italy as isolated cases respond negatively from a low and a high prior level of acceptance. Secondly, Former Eastern European nuclear operators with no renaissance and high levels of prior acceptance show sharp negative responses to Fukushima (Bulgaria, Hungary, Lithuania, Romania). Thirdly, Denmark, France, Germany, and USA with little nuclear renaissance but a strong legacy of Chernobyl. And finally the largest group of nuclear operators, where little nuclear renaissance and moderate prior nuclear enthusiasm correspond with only moderate negative shifts after Fukushima (UK, Netherlands, Switzerland, Finland, etc.).

In conclusion, our analysis on a CR model points to recognizable patterns in country responses to the Fukushima accident.

Conclusions

In this paper we set out to explain the global variation of public opinion responses to the events in Fukushima 2011; we do this in a context where it is widely recognized that public consent is pivotal for any nuclear future. Historically, the global responses are consistent with the severity of nuclear events; public opinion responded most strongly to Chernobyl 1986, followed by Fukushima 2011 and TMI 1979. Overall, public opinion responds in proportion to the events. The Fukushima incident has brought another discernable negative shift in public acceptance of nuclear energy across a wide array of countries. This has however been a response with large variation; the event does therefore not explain itself the shift; this response is locally contingent.

To examine this variation we replicated an earlier study which, based on an implicit event-effect (EE) model, assumed that only ‘objective’ factors condition local reactions. We argue that an EE model unrealistically assumes that physical collision contact is the key factor of opinion formation. We showed that the EE model explains very little variance when using historical opinion data rather than retrospective accounts of opinion change. The model does not explain why acceptance in some countries fell drastically while in others the responses to Fukushima are more modest.

We offer an alternative, the challenge & Response (CR) model, which postulates cultural memory as the symbolic mediator of responses at a distance from the events. We show, that the prior responses to Chernobyl, the ‘nuclear renaissance’ 1996-2010, and the long-term level of acceptance, jointly and independently, explain better the formation of the Fukushima effect across a wide array of countries.

Our CR model shows that beyond GDP and Club membership, which mitigate, and the total nuclear experience of a country, which accentuates the Fukushima effect, cultural memory adds the more important explanatory power. The legacy of Chernobyl and a nuclear renaissance 1996-2010 directly affected opinion responses to Fukushima. The more negatively countries responded to Chernobyl in 1986, so they did to Fukushima 2011, and the stronger the nuclear renaissance, the more disappointment with nuclear power after Fukushima. The long-term climate of opinion does not matter so much; the above dynamics occur in different discursive situations.

Our analysis also grouped countries according to their patterns of cultural memory and their Fukushima response. We were able to characterize four patterns of responses to Fukushima contingent on cultural memory of nuclear power. Firstly, prior reactions to past nuclear accidents structure the present response. All countries have experienced drops in the proportion of citizens who hold positive views of nuclear energy, but in countries where prior reactions to Chernobyl

1986 were less severe, the reactions to Fukushima was also more moderate. Secondly, the renaissance of nuclear positivity provides additional explanatory context. Country differences aside, it seems that a stronger renaissance of nuclear expectations 1996-2010 corresponds with a more drastic response to Fukushima. Conversely, where the level of acceptance eroded over the long period, further negative shifts after 2011 were less severe. Overall, it thus seems that a long-term level of acceptance with divided opinions and a modest nuclear renaissance cushioned the responses to the events in Japan in 2011.

The limitations of our approach are several: the global picture which we are able to paint is neither complete nor unequivocal. The impact of prior disaster responses, the long-term climate of discourse, and the role of a 'nuclear renaissance' in structuring responses to nuclear disaster need further investigation. This calls for comparative case studies between and within our clusters with more detail on the public debates. Secondly, our database of public opinion is incomplete and not saturated over the period. We hope that in the not too distant future, national agencies and nuclear industries in different countries, such as EDF in France, or Japan's Prime Minister Office, will make available their long-series of nuclear opinion data held in private for further public research. This would allow to progressively saturate the historical database and allow researchers to test or reformulate the CR models. Thirdly, our CR model to nuclear accidents also asks for historical mass media maps to index the public discourse. We were unable to collate such data for the range of the present comparative analysis. However, such longitudinal mass media indicators might be within reach if we consider the novel techniques of on-line data scraping, automatic text classification and sentiment analysis which are enabled by the progressive digitization of news archives. It would clearly be desirable to compile a more complete historical corpus of public opinion data in conjunction with maps of mass media coverage and sentiments reaching back to the 1970s, when it all began. Nuclear power has much to show about the dynamics of techno-scientific developments and their perceptions in public opinion.

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Appendix

Table A1 provides an overview of the variables used in the cross-sectional and panel analyses and in the cluster analysis.

Table A1. Coding of variables for regression analyses.

Variables	Description	Measurement	Source
• Acceptance	Balance of opinion per survey	%Favor / %Favor+%Reject	Own database
• Fukushima effect	Shift in balance of opinion	Post-Pre acceptance (2011	Own database
• Renaissance	Recovering acceptance	Slope of acceptance, 1996-2010	Own database
• Acceptance level	Average acceptance 1996-2010	Mean acceptance 1996-2010	Own database
• Chernobyl effect	Shift in balance of opinion	Post-Pre acceptance (1986)	Own database
• Club Member	Nuclear bomb status	1= Nuclear capability 0 = no capability	Bulletin of the Atomic Scientist annual report 2016
• Distance from Fukushima (logarithmic transformation)	Natural logarithm of the distance between the Fukushima power plant to a country's capital	Kilometers	Free Map Tools
• Nuclear power reactors	Whether or not nuclear power reactors are operated in a country.	0 = No reactors 1 = At least 1 reactor	IAEA
• Number of reactors per 100.000 sq. km.	Number of reactors in operation (yearly) (IAEA) per 100.000 sq. km. of national land surface area (World Bank)	Number	IAEA and World Bank
• Proportion of nuclear power	Proportion of energy deriving from nuclear reactors (yearly).	Percent	IAEA
• Total operating experience(logarithmic transformation)	Number of years since first national reactors was connected to national electricity grid.	0, 1, 2, …, Y.	IAEA
• Freedom of the Press		0-100 with 0 being most free press and 100 least free.	Quality of Government Dataset
• Significant earthquakes	Cumulative number of earthquakes rated significant by the USGS in 2011. For panel models, the number of significant earthquakes occurring that year.	Number	U.S. Geological Surveys
• Nuclear accidents	Number of nuclear accidents identified by The Guardian[A] based on IAEA data since 1952.	Number	IAEA
• GDP per cap. (logarithmic	Natural logarithm of per capita GDP in current	Number	Quality of Government Dataset

transformation)	prices (US dollars) in individual years.	

Note: [A] : https://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank#data

The variables used in the replication of Kim et al. (2013) have been coded following their descriptions (see section 3.3. and Table 1 in Kim et al., 2013: 824).

Distance from Fukushima: The distance from a county's capital to the Fukushima Daiichi Power Plant as the crow flies measured using Free Map Tools (2017). We take the natural logarithm to the distance to ensure linearity and mimic the decision taken by Kim et al. (2013: 825).

Nuclear power reactors, Number of reactors, Proportion of nuclear power, Total operating experience: Data pertaining to the prevalence of nuclear power in a country is coded from the International Atomic Energy Agency's (IAEA) PRIS database on nuclear power reactors (IAEA, 2017). We coded whether a country operated a functioning nuclear power reactor connected to the electricity grid in a given year (Yes = 1, No = 0), the number of such reactors in operation divided by 100.000 sq. km. of national land surface area of the country (World Bank, 2017), the yearly percentage of energy deriving from nuclear reactors, and the natural logarithm of years since the first reactor was connected to the electricity grid.

Freedom of the press and GDP per capita: Freedom of the press scores build on the Freedom House Freedom of the Press score taken from the Quality of Government Dataset (Teorell et al., 2017). The variable refers to the QoG variables *fhp_score4* (1996-2001) and *fhp_score5* (2001-2012). GDP per capita is measured as the natural logarithm om GDP per capita for each country, and corresponds to the QoG variable *wdi_gdpcapcur*.

Significant earthquakes: The cumulative number of earthquakes within a country deemed to be "significant" by The U.S. Geological Surveys (USGS). In the corss-sectional analysis, the reference year is 2011, while the panel analysis includes data from each year from 1999-2012. The number of earthquakes were recorded from the USGS list of significant earthquakes. The definition of a significant earthquake rests on three types of significance:

- Magnitude significance: $Magnitude \times 100 \times (\frac{Magnitude}{6.5})$
- Pager significance: Green = 0, Yellow = 500, Orange = 1000, Red = 2000
- "Did you feel it" (DYFI) significance: $\min(number\ of\ responses, 1000) \times \frac{\max(Community\ Decimal\ Intensity)}{10}$

These are combined to form the overall significance: $\max(Magnitude\ significance, Pager\ significance) + DYFI\ significance$ where a significance above 600 is deemed significant.

Table A2. Overview of countries included in regression analyses.

	Included in Kim et al. (2013)	Not included in Kim et al. (2013)
Included in cross-sectional regressions [N=28]	Austria, Belgium, Bulgaria, Canada, Czech Republic, Finland, France, Greece, Iceland, India, Italy, Netherlands, Poland, Romania, Russia, Spain, Switzerland, Turkey, USA.	Australia, Denmark, Germany, Ireland, Latvia, Lithuania, Sweden, United Kingdom.
Included in various panel regressions [23 <= N <=39] Total k = 260 surveys	Austria, Belgium, Bulgaria, Canada, Czech Republic, Finland, France, Greece, Iceland, India, Italy, Netherlands, Poland, Romania, Russia, Spain, Switzerland, Turkey, USA.	Australia, Belarus, Denmark, Estonia, Hungary, Germany, Ireland, Latvia, Lithuania, Luxemburg, Malta, Norway, Portugal, Slovakia, Slovenia, South Korea, Sweden, Taiwan, United Kingdom,
Not included [N=23]	Bangladesh, Bosnia and Herzegovina, Brazil, Cameroon, China, Colombia, Egypt, Georgia, Hong Kong, **Japan**, Iraq, Kenya, Macedonia , Malaysia, Morocco, Nigeria, Pakistan, Saudi Arabia ,Serbia, South Africa, Tunisia, Vietnam,	

Note: We excluded Japan from our cross-sectional and regression analyses, as a nuclear accident in the country of origin constitutes a very different 'Challenge & Response' from that of other countries at a distance. Underlined are countries which are members of the 'Club' commanding nuclear weapon systems.

Figure A1. The nuclear renaissance 1996-2010, best documented countries [n=23; not Japan].

[Figure A1 here]

Figure A2. Dendrograms for cluster solutions of M1 (n=23) and M2 (n=11).

[Figure A2(a) & A2(b) here]

Note: Hierarchical clustering with weighted-average linkage and z-standardised variables. The three-cluster solution yields a Duda/Hart pseudo T^2 of 6.45 (M1, n=23) and of 2.78 (M2, n=11).

Figure A3. The number of countries in the historical data for each year, 1977-2016.

[Figure A3 here]

Note: The database contains unequal number of polls per year across a range of 60 countries. The numbers range from 1 to 46 polls in any one year. It seems that opinion have become more frequent and more global after 2000 with the advent of the 'nuclear renaissance'. The data collection is obviously serendipitous and not systematic across all 60 countries; existing data might not be unknown to us, thus there are missing values. The database contains 426 historical data points from 60 countries between 1977 and 2016 which is a saturation of 18% (2340 possible data points = 60 countries x 39 years). The defined acceptance score has M = 0.451; Median = 0.479; SD = 0.084, and a range of 0.053-0.886 (source: Bauer nuclear opinion database; the data used here is available to interested researchers on request).

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Tables

Table 1. Determinants of Fukushima impact on nuclear opinion balance. Cross-section

	Model 1	Model 2	Model 3	Model 4
Distance from Fukushima	55.58	-43.64	71.59	69.72
(logarithmic transformation)	(35.54)	(97.80)	(95.04)	(59.99)
Nuclear power reactors	61.86**	63.84**	60.23*	58.35*
	(20.68)	(21.30)	(25.53)	(26.00)
Number of reactors per	444.8	477.4	437.4	598.3
100.00 sq. km.	(319.2)	(327.2)	(331.9	(606.7)
Proportion of nuclear power	-0.094	-0.090	-0.076	-0.059
	(0.214)	(0.225)	(0.257)	(0.245)
Total operating experience	-15.94**	-279.6	-15.87**	-15.87**
(logarithmic transformation)	(4.832)	(243.3)	(5.096)	(5.088)
Freedom of the Press	0.834**	0.895**	5.770	0.578
	(0.237)	(0.253)	(26.49)	(0.830)
Significant earthquakes	0.095	0.100	0.093	9.742
	(0.058)	(0.063)	(0.065)	(27.73)
Nuclear accidents	-7.343	-8.298	-7.252	-6.725
	(4.831)	(5.263)	(5.172)	(5.483)
GDP per cap.	2.467	2.699	2.098	-0.044
(logarithmic transformation)	(5.328)	(5.642)	(6.032)	(9.717)
Distance from Fukushima ×		29.03		
Total operating experience		(29.03)		
Distance from Fukushima ×			-0.550	
Freedom of the press			(2.960)	
Distance from Fukushima ×				-1.041
Significant earthquakes				(2.992)
Constant	-557.1	337.4	-699.1	-655.8
	(299.8)	(877.1)	(821.9)	(454.8)
N	28	28	28	28
Adj. R^2	0.429	0.430	0.396	0.400

Note: β-coefficients from OLS-regression with robust standard errors in parentheses. Dependent variable ‘Fukushima effect’ is the difference in mean nuclear opinion balance (proponents – opponents) from 2008-2010 and 2011, and ranges from -100 to 100. **: $p < 0.01$, *: $p < 0.05$.

Table 2. Fukushima impact on nuclear acceptance. Panel models

	Model 5	Model 6	Model 7
After Fukushima accident	-0.091***	-0.102***	-3.208
	(0.025)	(0.025)	(2.240)
Distance from Fukushima	-0.549*		-0.613*
(logarithmic transformation)	(0.271)		(0.281)
Nuclear power reactors	0.059		0.060
	(0.074)		(0.076)
Number of reactors per 100.00 sq.	-575.0	-555.5	-550.1
km.	(463.9)	(1328)	(474.1)
Proportion of nuclear power	0.002*	0.004**	0.002
	(0.001)	(0.001)	(0.001)
Total operating experience	0.002	0.010*	0 .002
	(0.002)	(0.005)	(0.002)
Freedom of the Press	0.003	0.000	0.003
	(0.003)	(0.004)	(0 .003)
Significant earthquakes	-0.003	-0.005	-0.003
	(0.003)	(0.003)	(0.003)
Nuclear accidents	0.025	0.029	0.027
	(0.021)	(0.031)	(0 .021)
GDP per cap.	-0.051†	-0.086†	-0.050†
(logarithmic transformation)	(0.030)	(0.046)	(0.030)
After Fukushima accident ×			0.342
Distance from Fukushima			(0.246)
N (country-years)	159	159	159
N (countries)	23	23	23
Country fixed effects	No	Yes	No
Rho	0.455	0.455	0.474

Note: β-coefficients from random and fixed effects OLS-regression with cluster robust standard errors in parentheses. Dependent variable is an acceptance index scaled 0-1, where 0 equals 0-percentage acceptance, 0.5 equals equal opposing and accepting views, and 1 implies full acceptance. ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, †: $p < 0.1$.

Table 3. Bi-serial and partial correlations for cultural memory indicators

Fukushima effect [neg. shift]	Correlation			Partial correlation		Semi-Partial correlation	
Cultural memory	Bi-serial	M1	M2	M1	M2	M1	M2
Chernobyl effect 1986	.837**		.813***		.843***		.718***
Renaissance 1996-2010	.175**	-.728***	-.519***	-.718***	-.503***	-.699***	-.266***
Acceptance level 1996-2010	-.147**	-.038	-.070	.068	.118	.046	.054
Path dependency [controls]							
GDP ln	-.074*	-.093	.069**	-.006	.200**	-.004	.093**
5-yr total nuclear power	-.467**	-.212	-.360***	-.122	-.387**	-.083	-.192***
Member Bomb Club [1=bomb]	.084*	-.170	-.121***	-.122	.310***	.055	.149***
Countries N	11-38	23	11	23	11	23	11

Note: countries n=11 including Chernobyl effect; n=23 without Chernobyl effect and not including Japan; *** = p<0.001; ** = p<0.01, * = p<0.05

Table 4. Clusters of Fukushima Responses for 23 countries and 11 countries

	23 countries		
	Cluster 1	Cluster 2	Cluster 3
Clustering components			
Nuclear renaissance	0.0073	-0.0243	0.0093
Mean acceptance level	0.1389	0.6660	0 .4590
Fukushima effect	-11.50	-42	-18.51
Countries in cluster	Greece	Bulgaria, Hungary, Lithuania, Romania	Australia, Belgium, Canada, Czech Republic, Denmark, Finland, <u>France</u>, Germany, Ireland, Italy, Latvia, Netherlands, Poland, Spain, Sweden, Switzerland, <u>USA</u>, <u>United Kingdom</u>
	11 countries		
	Cluster 1	*Cluster 2*	*Cluster 3*
Clustering components			
Nuclear renaissance	0.0073	-0.0243	0.0093
Mean acceptance level	0.1389	0.6660	0 .4590
Fukushima effect	-11.50	-42	-18.51
Countries in cluster	Greece	Bulgaria, Hungary, Lithuania, Romania	Australia, Belgium, Canada, Czech Republic, Denmark, Finland, <u>France</u>, Germany, Ireland, Italy, Latvia, Netherlands, Poland, Spain, Sweden, Switzerland, <u>USA,</u> <u>United Kingdom</u>

Note: Within-cluster mean scores across clustering components and Fukushima nuclear disaster effect. Country groupings based on hierarchical weighted average cluster analysis. Underlined are countries which are member of the 'Club' commanding nuclear weapons systems.

Figure 1. The Chernobyl and Fukushima effect on nuclear acceptance, 1977-2016.

Figure 2. Bi-variate correlations of responses to TMI (1979), Chernobyl (1986) and Fukushima (2011); and volatility and nuclear renaissance compared to long-term levels of acceptance.

Figure 3. Clusters and long-term Level of Acceptance, Chernobyl Effect and Nuclear Renaissance for (M1) 23 countries and (M2) 11 countries.

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[1] Questions about attitudes first asked respondents whether they strongly favored, somewhat favored, somewhat opposed, or strongly opposed the use of nuclear energy for electricity at the time of the poll, and secondly, what their view was before the earthquake in Japan.

[2] One of the first and natural social-psychological responses to an aversive incident is the 'us versus them' demarcation: 'this could not happen here; our machines are different, our operators are reliable …..'. A revised risk assessment of local operations is only a secondary step.

[3] Spencer Weart (1988) refers to 'collective representation' when discussing US historical images of the atom. We prefer the more flexible notion of 'social representation' to allow for social comparison.

[4] The CR model would suggests that we consider the media coverage of Fukushima, in intensity, framing and valence as a fourth indicator of cultural memory, but we were unable to compile comparable data across very different studies; and too few countries are covered. Media attention marks ritual rehearsal. Printed words and visuals keep past events alive. Retelling of stories is known to be simplifying and assimilating to locally conventions similar to 'Chinese whispers' (Bartlett, 1932). Answers to the question, did media coverage condition the Fukushima effect, will have to come from future research; our CR model offers the framework.

[5] Consequently, our dependent variable is theoretically bounded, and can only take on values between -100 and 100. This is essentially a breach of the Gauss-Markov assumptions underlying ordinary least squares. OLS is only the best linear estimator under the assumption of linearity in the parameters and a continuous, unbounded dependent variable (Berry, 1993: 12). However, the attitude change variable is fairly normally distributed and only a single case, Lithuania, is near the theoretical bounds. 95 pct. of countries experience attitude changes from -42 points to +18 points. Furthermore, an examination of augmented partial residuals for each independent variable do not reveal any major breaches of the linearity assumptions. Based on these considerations, OLS yields the most intuitive results, without exhibiting overt breaches on key modelling assumptions.

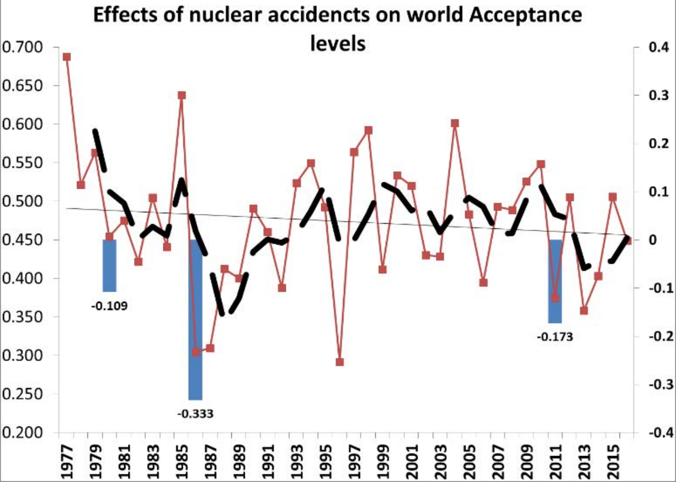
[6] See Table A and accompanying text in the appendix for a full overview of the sources and scaling of variables.

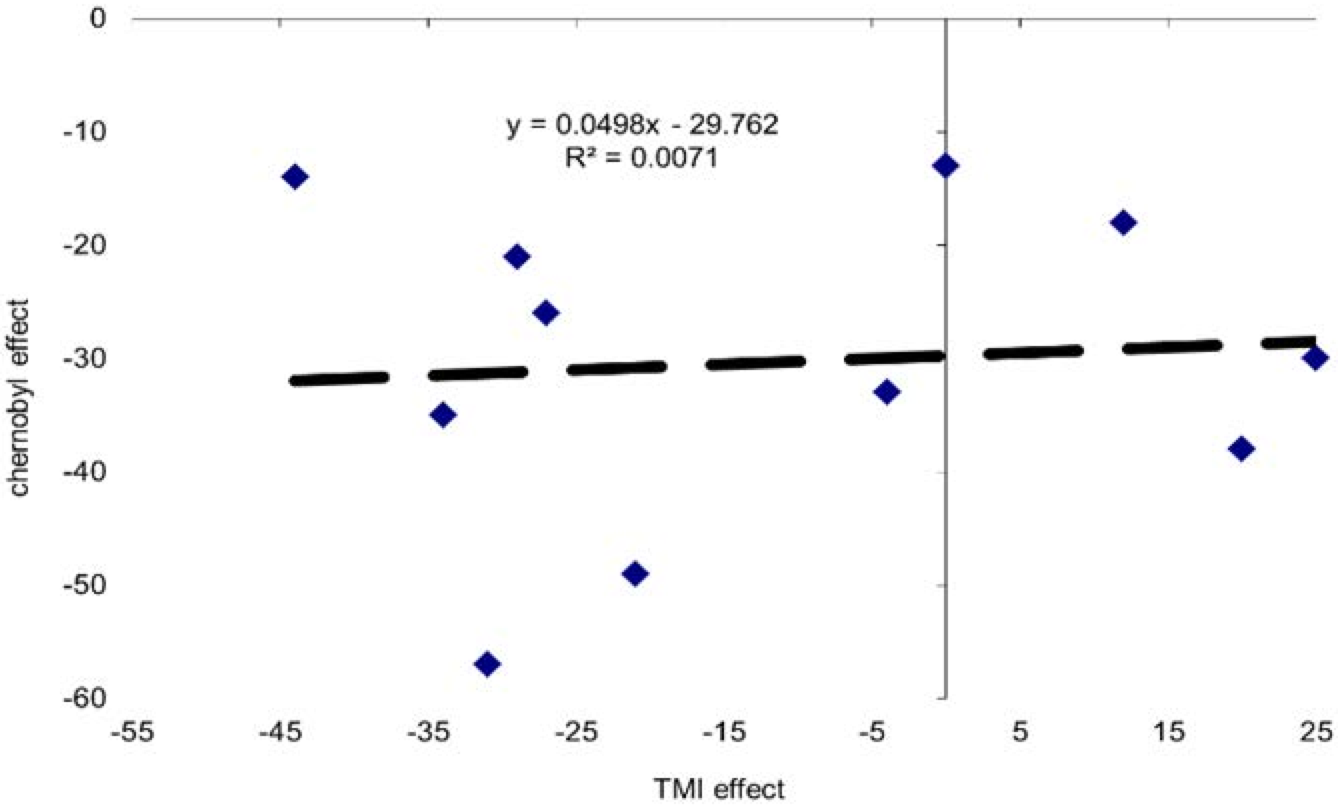
[7] See Table A2 in the appendix material for countries covered in the analyses.

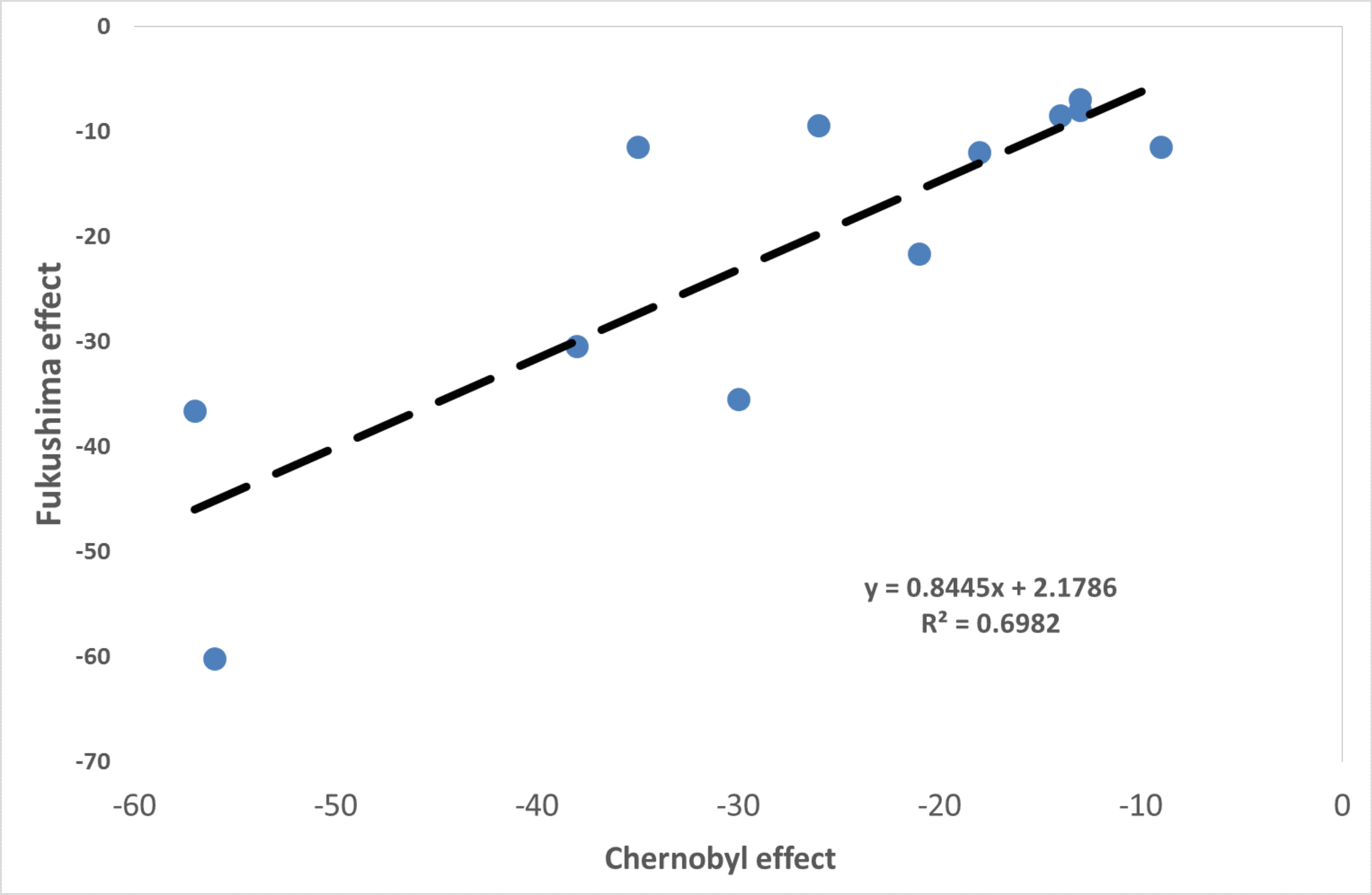
[8] See Figure A1 in the appendix for the 23 countries covered in the analyses.

[9] Our slope measure of nuclear renaissance ranges from -0.01346 to 0.02324, while the measure for the negative Chernobyl effect ranges from -57 to -9.

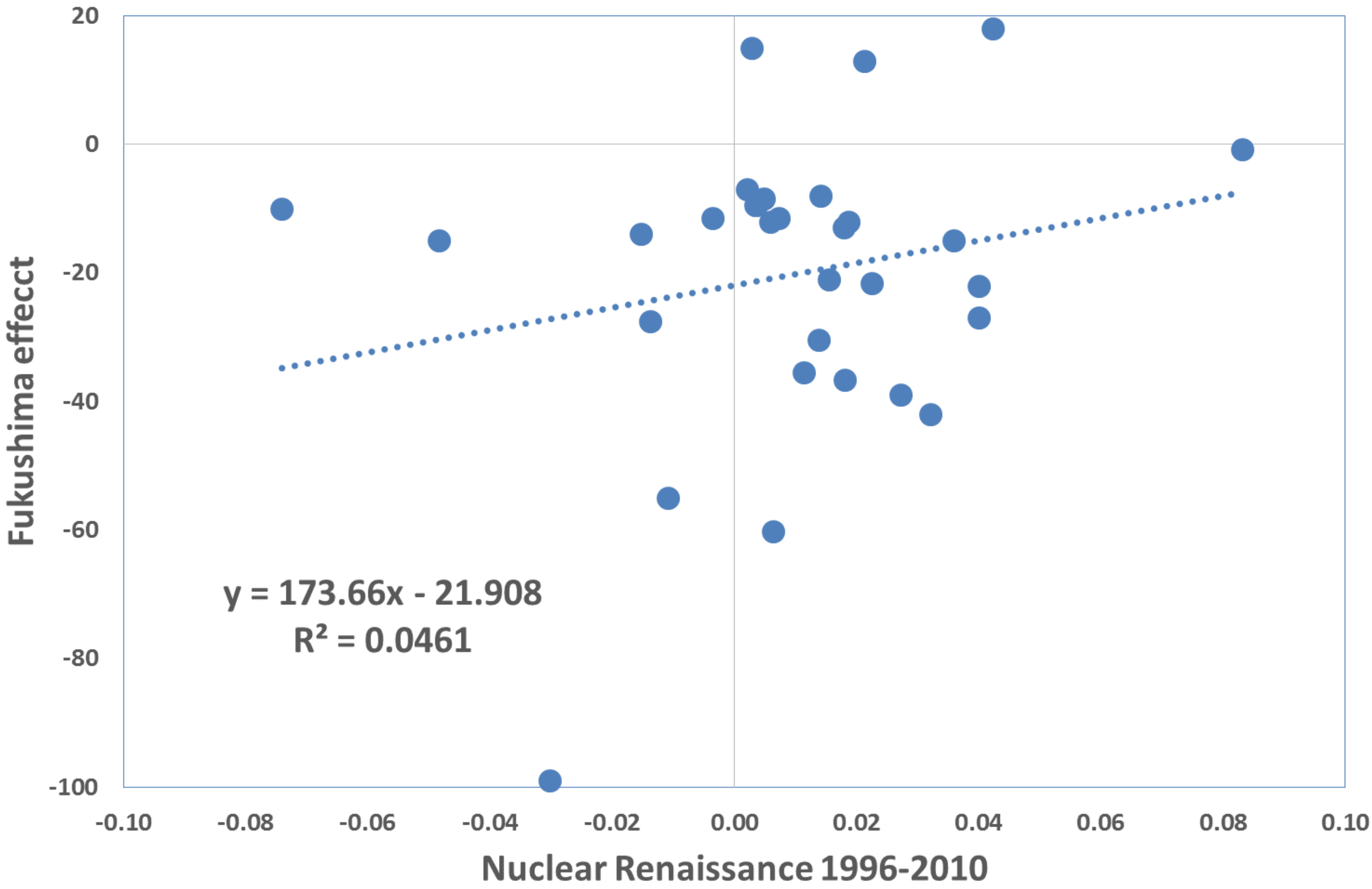
[10] The z-score is calculated by subtracting the mean value of the variable and dividing this number by the variables standard deviation. The z-standardized variable then has a mean of zero and a standard deviation of one.

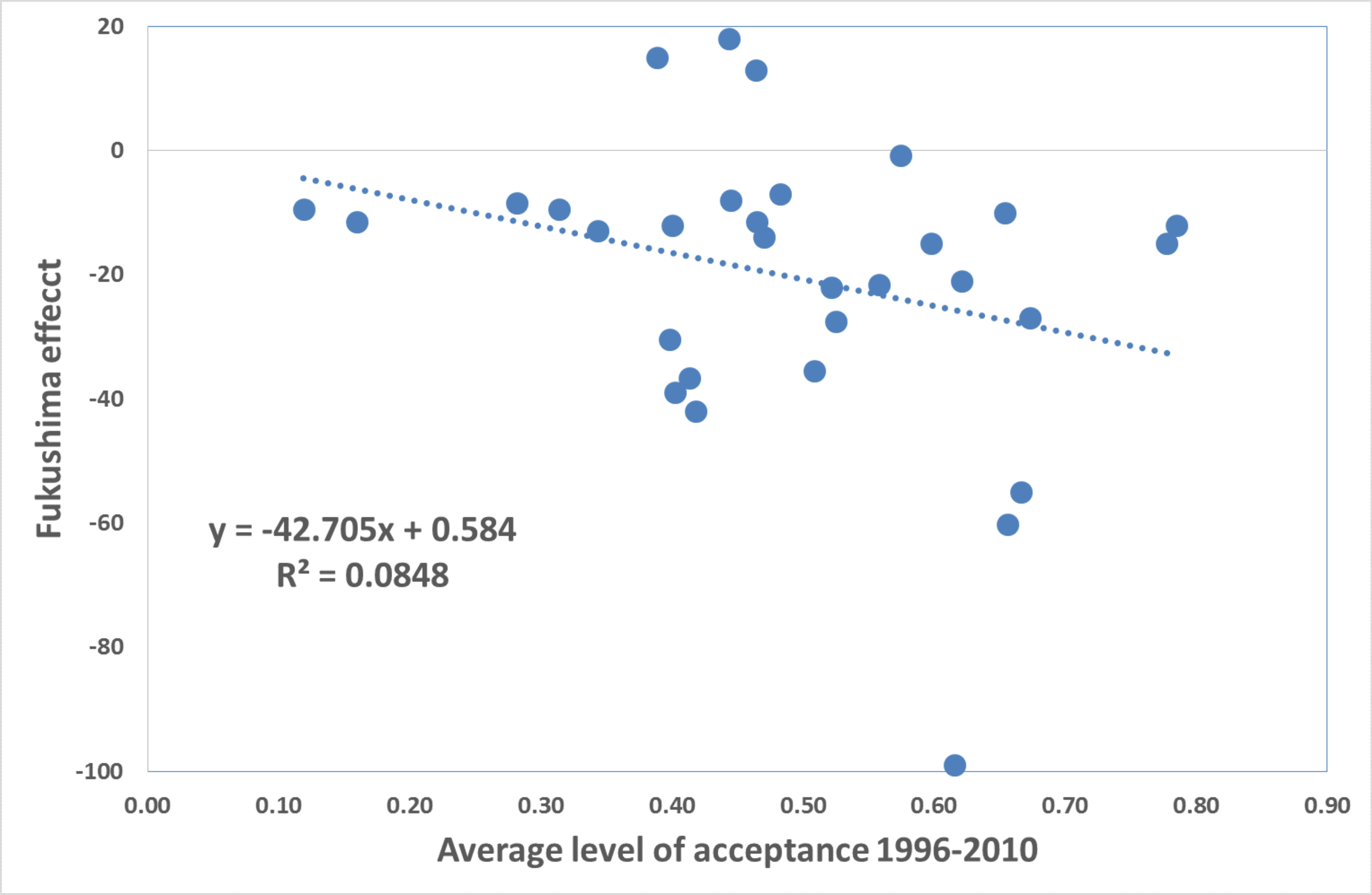

Effects of nuclear accidencts on world Acceptance levels
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.109
-0.333
-0.173
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015


y = 0.0498x - 29.762
R² = 0.0071
0
-10
-20
-30
-40
-50
-60
-55
-45
-35
-25
-15
-5
5
15
25
chernobyl effect
TMI effect

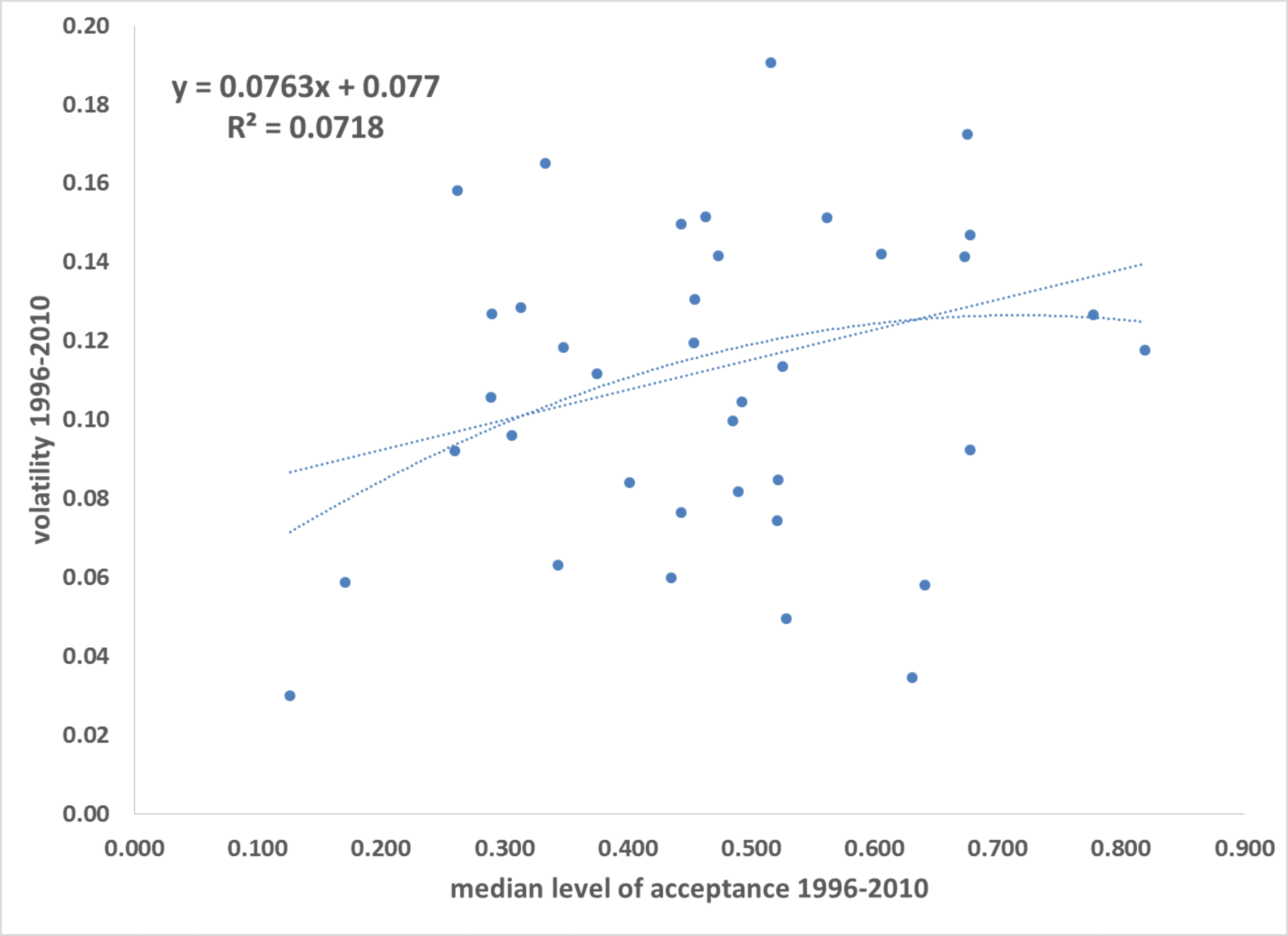


Fukushima effect
0
-10
-20
-30
-40
-50
-60
-70
-60
-50
-40
-30
-20
-10
0
Chernobyl effect
y = 0.8445x + 2.1786
R² = 0.6982

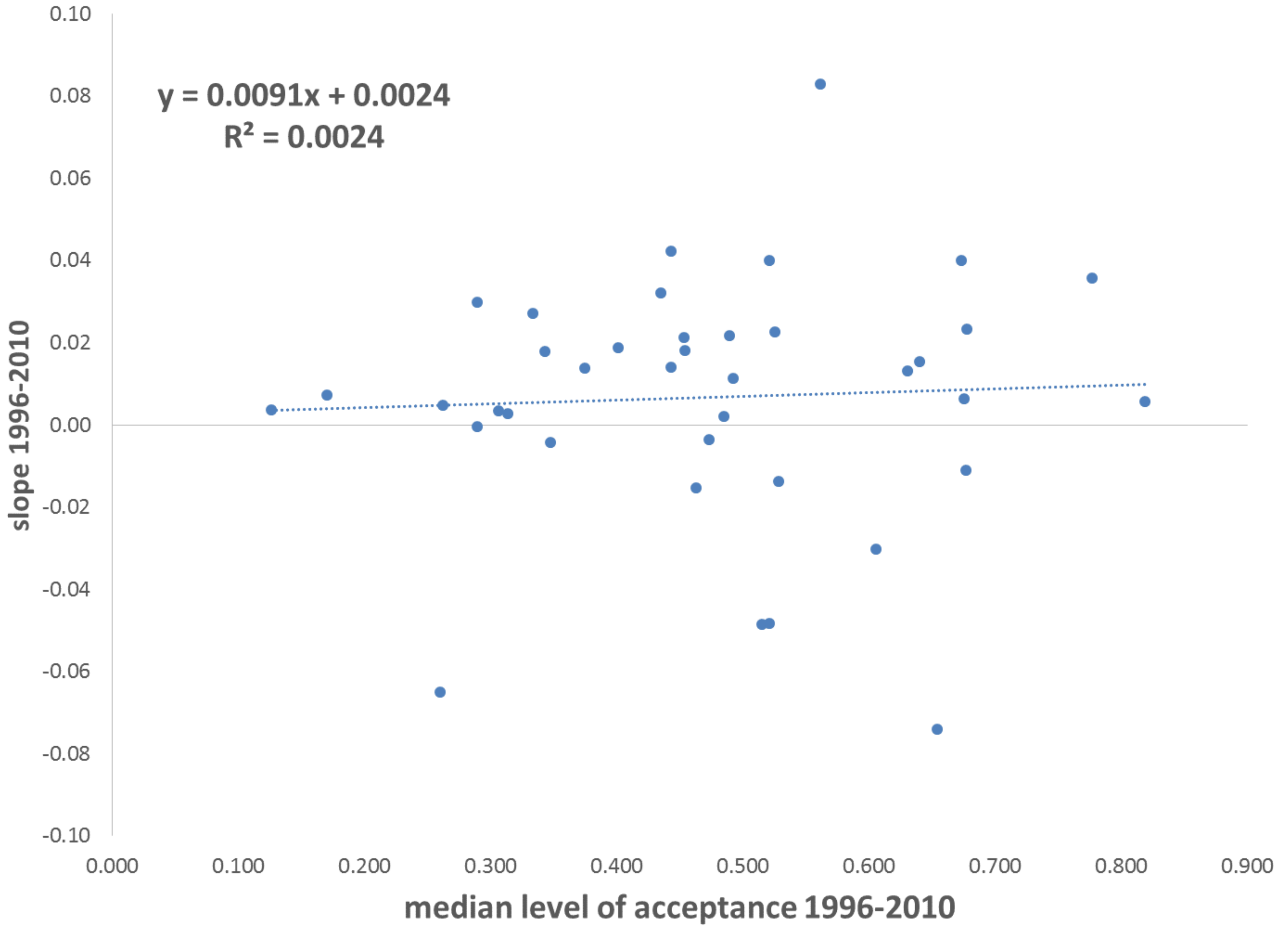

Fukushima effect
Nuclear Renaissance 1996-2010
y = 173.66x - 21.908
R² = 0.0461
20
0
-20
-40
-60
-80
-100
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
0.02
0.04
0.06
0.08
0.10

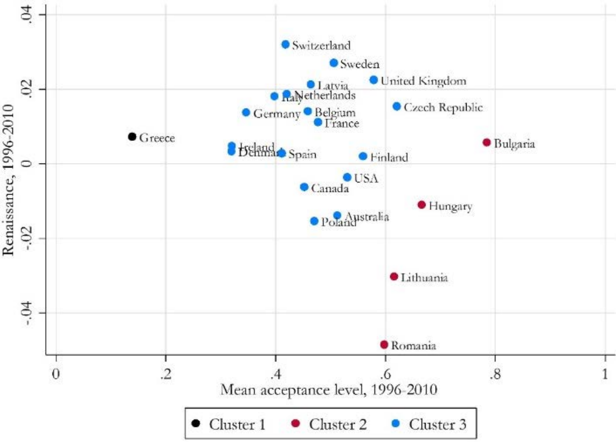


20
0
-20
-40
-60
-80
-100
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Fukushima effect
Average level of acceptance 1996-2010
y = -42.705x + 0.584
R² = 0.0848

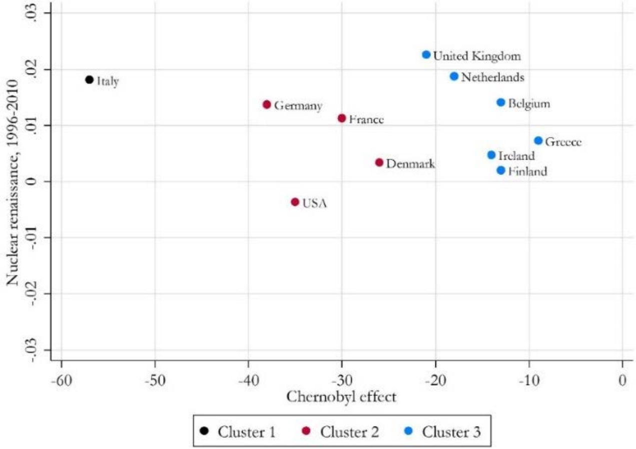


y = 0.0763x + 0.077
R² = 0.0718
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
volatility 1996-2010
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
median level of acceptance 1996-2010

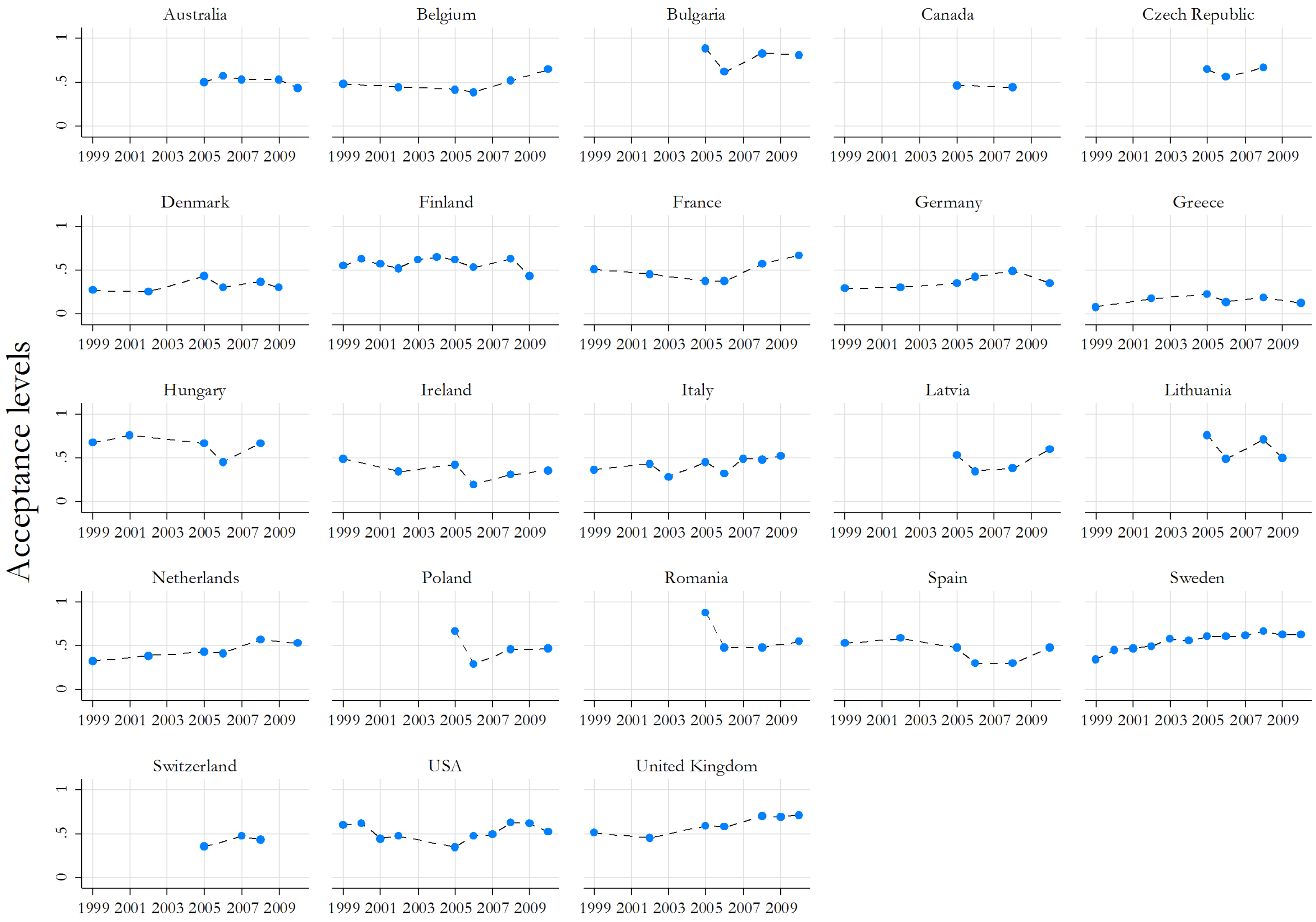

y = 0.0091x + 0.0024
R² = 0.0024
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
slope 1996-2010
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
median level of acceptance 1996-2010

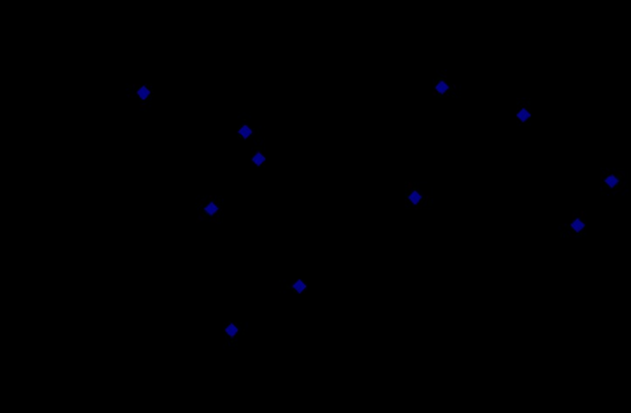


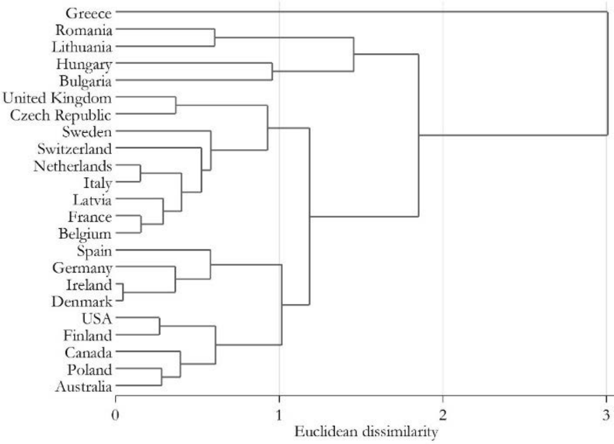
.04
.02
0
-.02
-.04
Renaissance, 1996-2010
0
.2
.4
.6
.8
1
Mean acceptance level, 1996-2010
Switzerland
Sweden
United Kingdom
Latvia
Netherlands
Italy
Czech Republic
Germany
Belgium
France
Greece
Bulgaria
Ireland
Denmark
Spain
Finland
USA
Canada
Hungary
Australia
Poland
Lithuania
Romania
Cluster 1
Cluster 2
Cluster 3

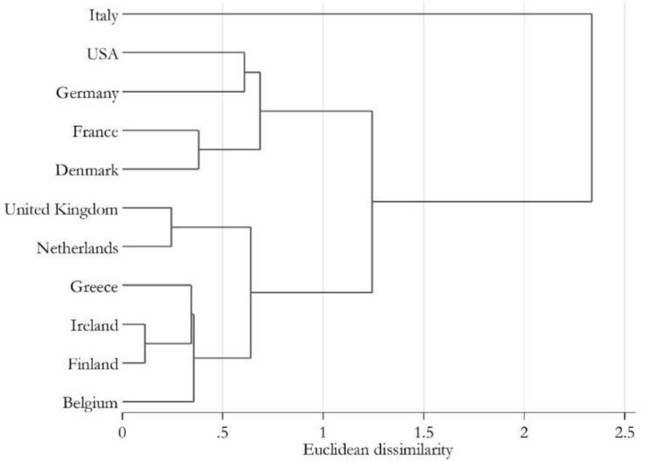


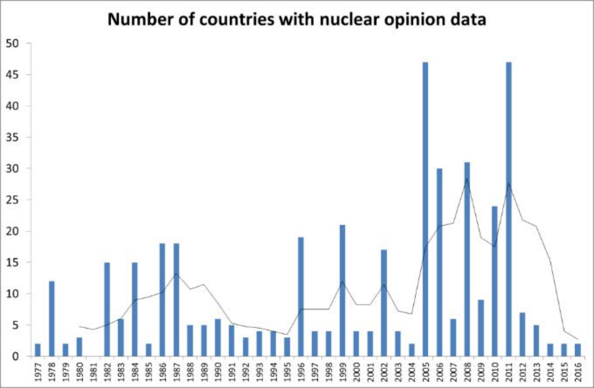
.03
.02
.01
0
-.01
-.02
-.03
Nuclear renaissance, 1996-2010
-60
-50
-40
-30
-20
-10
0
Chernobyl effect
Italy
Germany
France
Denmark
USA
United Kingdom
Netherlands
Belgium
Greece
Ireland
Finland
Cluster 1
Cluster 2
Cluster 3


Acceptance levels
Australia
Belgium
Bulgaria
Canada
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Netherlands
Poland
Romania
Spain
Sweden
Switzerland
USA
United Kingdom
0
.5
1
1999 2001 2003 2005 2007 2009




Greece
Romania
Lithuania
Hungary
Bulgaria
United Kingdom
Czech Republic
Sweden
Switzerland
Netherlands
Italy
Latvia
France
Belgium
Spain
Germany
Ireland
Denmark
USA
Finland
Canada
Poland
Australia
0
1
2
3
Euclidean dissimilarity


Italy
USA
Germany
France
Denmark
United Kingdom
Netherlands
Greece
Ireland
Finland
Belgium
0
.5
1
1.5
2
2.5
Euclidean dissimilarity



Number of countries with nuclear opinion data
50
45
40
35
30
25
20
15
10
5
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016