Effect of the Fukushima nuclear accident on the risk perception of residents near a nuclear power plant in China

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We assessed the influence of the Fukushima nuclear accident (FNA) on the Chinese public's attitude and acceptance of nuclear power plants in China. Two surveys (before and after the FNA) were administered to separate subsamples of residents near the Tianwan nuclear power plant in Lianyungang, China. A structural equation model was constructed to describe the public acceptance of nuclear power and four risk perception factors: knowledge, perceived risk, benefit, and trust. Regression analysis was conducted to estimate the relationship between acceptance of nuclear power and the risk perception factors while controlling for demographic variables. Meanwhile, we assessed the median public acceptable frequencies for three levels of nuclear events. The FNA had a significant impact on risk perception of the Chinese public, especially on the factor of perceived risk, which increased from limited risk to great risk. Public acceptance of nuclear power decreased significantly after the FNA. The most sensitive groups include females, those not in public service, those with lower income, and those living close to the Tianwan nuclear power plant. Fifty percent of the survey respondents considered it acceptable to have a nuclear anomaly no more than once in 50 y. For nuclear incidents and serious incidents, the frequencies are once in 100 y and 150 y, respectively. The change in risk perception and acceptance may be attributed to the FNA. Decreased acceptance of nuclear power after the FNA among the Chinese public creates additional obstacles to further development of nuclear power in China and require effective communication strategies.

public perception | nuclear risk | spatial distribution

On March 11, 2011, an earthquake of 9.0 Moment magnitude scale (M_w) off the coast of Japan and the subsequent tsunami triggered the Fukushima Daiichi nuclear disaster. This was the largest nuclear disaster since the Chernobyl event of 1986 in Ukraine and only the second disaster (along with Chernobyl) to measure level 7 on the International Nuclear Event Scale (INES) (1). The Fukushima nuclear accident (FNA) forced residents within 20 km of the reactors to evacuate immediately; the estimated full evacuation involved close to 6.3 million people, and the economic loss was estimated to be around 5.7 trillion yen (or US $700 billion) by the Japanese Nuclear Fuel Cycle Technology Committee (2). The FNA has slowed the rapid expansion of the nuclear industry in China dramatically (3). The Chinese government suspended all applications to construct new nuclear power projects after the FNA. Although approved projects are still under construction, the crisis induced the Chinese government to strengthen the security management of nuclear facilities (4).

Various studies (5–9) show that public concern over the safety of nuclear power in Europe was stimulated by the Three Mile Island accident in 1979 and further increased by the Chernobyl accident in 1986. For example, Sjoberg and coworkers (5) found a strong negative relationship between attitudes regarding the acceptability of nuclear power and perceived nuclear risk. Hüppe and Janke (6) and Mardberg et al. (7) found that women and younger people showed more emotional concern than men and older adults about the nuclear accident in Chernobyl. Bromet et al. (8) reported that evacuee adolescents who were from the 30-km zone surrounding Chernobyl and raised in Kiev after the Chernobyl accident held more negative risk perceptions toward nuclear power than their classmates who were not from Chernobyl. These negative risk perceptions were modestly associated with mental health problems, e.g., major depression and generalized anxiety disorder. The accident caused changes in public perception of nuclear power plants beyond Europe (10–13). In comparing two surveys before and after the Chernobyl disaster, McDaniels (13) found that Americans' perceived dread and knowledge of nuclear power increased, whereas their perceived severity of risk decreased. Additionally, Goldsteen and Schorr (12) found that the Three Mile Island accident had long-term effects on American residents' perceptions of their physical and mental health, trust of public officials, and attitudes toward nuclear power generation. However, few studies have analyzed how nuclear risk acceptance is affected by risk perception variables (9) (i.e., acceptance, knowledge, perceived risk, benefit, trust) while controlling for demographic variables (i.e., sex, age, education, employment, income, residential location) after a catastrophic nuclear accident such as the FNA.

Because the Chernobyl and Three Mile Island disasters took place before the rapid expansion of nuclear power in China and occurred thousands of miles away, researchers have not studied the risk perception of the Chinese population on nuclear power

Significance

Because of its severity and proximity, the Fukushima nuclear accident exposed the Chinese public to the potential risks associated with nuclear power. Our analysis of surveys taken before and immediately after the event shows that this disaster has dramatically changed the risks of nuclear power perceived by the public and has significantly decreased public acceptance. Our study identified females, those who are not in public service, lower-income workers, and residents close to existing nuclear facilities as potentially the most affected. Effective communication strategies to facilitate public judgments about new nuclear plants should recognize these sensitive subgroups.

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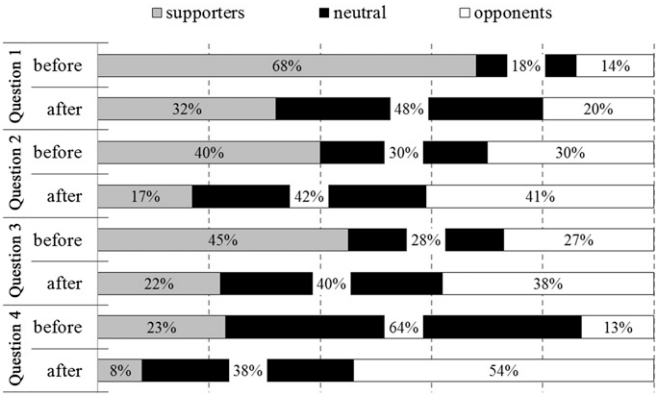

Fig. 1. Ratios of opponents and supporters to questions 1–4 in the survey. Responses to these questions range from values 1–5, where 1 means "do not agree at all," 2 means "do not agree," 3 means "neutral," 4 means "agree," and 5 means "totally agree." We defined supporters as those choosing values 4 or 5, opponents as those choosing 1 or 2, and neutral responders as those choosing 3. Question 1 is "Nuclear power should be used in our country." Question 2 is "We should quickly increase the number of nuclear power stations in China." Question 3 is "If there is a vote for promotion of nuclear power, I will strongly vote for it." Question 4 is "I strongly welcome construction of a nuclear power station in my dwelling city, such as Lianyungang."

extensively, except that Xie et al. (14) briefly discussed the attitudes of the Chinese citizens toward nuclear power across 28 kinds of risks. In recent years before the FNA, China implemented the largest program of nuclear power construction in the world. The FNA caused great concerns among the Chinese public regarding the safety of domestic nuclear power plants. However, previous research done elsewhere may not be applicable, as the Chinese public differs significantly from the European and American public in education level, access to information, economic status, and attitude toward the government.

In the current analysis, we use data from two surveys, conducted before (August 25–30, 2008) and immediately after the FNA (March 30 to April 7, 2011), to examine how individual-level differences in risk acceptance vary with the risk perception factors of knowledge, perceived risk, benefit, and trust. We attempt to answer three questions: (*i*) What changes have occurred in the Chinese public's risk perception regarding nuclear power after the FNA? (*ii*) Which groups of people are the most sensitive to a severe nuclear accident such as FNA? (*iii*) What is the current public acceptance related to the frequencies of three different levels of nuclear events?

Results

We conducted surveys before and after the FNA in independent samples of the population living in the city of Lianyungang of Jiangsu Province in China. The adjacent Tianwan Nuclear Power Plant (TNPP) is the closest Chinese nuclear plant to Fukushima. Our two surveys covered a total of 850 randomly sampled residents in Lianyungang, and 668 valid questionnaires were returned (300 samples before the FNA and 368 samples after the FNA). The questionnaire before the FNA has two sections: (*i*) socioeconomic and demographic variables and (*ii*) 27 risk perception questions, which were evaluated on a five-point Likert scale. A third section was added to the survey after the FNA. This additional section includes a series of questions about public acceptance related to the frequencies of three different levels of nuclear events. A structural equation model (SEM), geographic information systems (GIS) analysis, and regression analysis were used to analyze the data.

As seen in Table S1, the survey respondents were similar to the city's population in terms of sex, occupation, and monthly income. The respondents were slightly younger and more educated than the rest of the city, a pattern also found by Sjöberg (15) and Bronfman and Cifuentes (16). This might be attributed to the fact that older, uneducated people are more likely to have difficulty understanding survey questions and cannot complete a questionnaire easily. Approximately 31% and 27% of the survey respondents before and after the FNA live in the three urban districts (Xinpu, Lianyun, and Haizhou), which is a slightly higher proportion than the city average. Overall, the sampling biases indicated by these differences likely are small.

Comparison of Risk Perception Before and After the FNA. Differences in responses to our 27 risk perception questions (Table S2) before and after the FNA were analyzed by *t* tests and are shown in Table S3. We further analyzed responses to the first four questions, which were designed to evaluate public acceptance of nuclear accidents (Table S2). To compare risk acceptance before and after the FNA, the scales are defined as follows: acceptance responses 4–5 are supporters, 1–2 are opponents, and 3 is neutral. Fig. 1 shows that the percentage of opponents increased modestly (6%–11%) whereas the percentage of supporters decreased more sharply (23%–36%), as seen in questions 1–3. This implies that previous supporters tended to sway toward more neutral opinions after the FNA; this shift was more common than the shift from neutral opinions to opposition. However, when asked whether they support construction of a nuclear power plant in their city, the percentage of opponents increased sharply (41%), as seen in question 4.

The risk acceptance and four risk perception factors (knowledge, perceived risk, benefit, and trust) constructed from the 27 survey questions using the SEM also were tested for their variation between the two surveys (Table 1). The most significant difference is seen with the perceived risk factor ($M_{BF} = 2.82$, $M_{AF} = 4.62$, $t = 24.00$, $P < 0.001$), indicating that the public perception of social and personal risk of nuclear power accidents changed from moderate ($M_{BF} = 2.82$) to serious ($M_{AF} = 4.62$) after the FNA. The perceived benefits of nuclear power decreased significantly ($M_{BF} = 3.27$, $M_{AF} = 2.50$, $t = -10.00$, $P < 0.001$), and the reduction is significantly associated with the increase in the perceived risk, which confirms previous findings on the risk–benefit correlation (17, 18). In addition, public trust in government declined significantly ($M_{BF} = 3.15$, $M_{AF} = 2.81$, $t = -4.63$, $P < 0.001$), and knowledge about nuclear power improved after the FNA ($M_{BF} = 2.52$, $M_{AF} = 2.85$, $t = 4.69$, $P < 0.001$). The public acceptance of nuclear power decreased significantly ($M_{BF} = 3.34$, $M_{AF} = 2.65$, $t = -8.68$, $P < 0.001$). It should be noted that the knowledge scale in this study aims at evaluating attention to and awareness of the risks associated with nuclear power, rather than factual knowledge.

Influence of the Four Perception Factors and Demographic Variables on Risk Acceptance Before and After the FNA. According to Karpowicz-Lazreg and Mullet (19), differences in public perceptions of societal risks exist across ethnicity, sex, and education levels. In the current study, we analyze how risk acceptance varies by demographic characteristics (see definitions in Table 2). In addition, we compare how the four perception factors (knowledge, perceived

Table 1. Comparison of risk perception of FNA

	Before FNA ($n = 300$)		After FNA ($n = 368$)		
Perception factors	Mean	SD	Mean	SD	*t*-statistic
Knowledge	2.52	0.91	2.85	0.88	4.69**
Risk	2.82	1.18	4.62	0.58	24.00**
Benefit	3.27	0.99	2.50	1.01	−10.00**
Trust	3.15	0.92	2.81	0.98	−4.63**
Acceptance	3.34	1.02	2.65	1.03	−8.68**

Significance: $^{**}P \leq 0.01$.

risk, benefit, trust) affect risk acceptance before and after the FNA (Table 2).

Before the FNA ($n = 300$), people who had more knowledge about nuclear power saw themselves as benefiting more from the nuclear plant and had more trust in the government, lower perceived risk, and a greater acceptance of the plant. There was no significant difference in risk acceptance between females and males, between people younger and older than 35, among people at different income levels, or among those in different occupations. Respondents with a high school education had a lower acceptance rate than those with more or less education. People who lived near a nuclear plant had a significantly higher acceptance rate than those who lived a moderate distance away, whereas those far away had an intermediate acceptance rate (not significantly different from either group).

After the FNA ($n = 368$), the influence of knowledge and trust on acceptance remained similar to that seen before the FNA, whereas the positive impact of benefit on risk acceptance declined significantly and the negative impact of perceived risk increased. After the FNA, risk acceptance of women, people making less than 2,000 yuan per month, people older than 35, and those not in public service fell more significantly than in their comparison groups. Acceptance of people with a college education or above fell more significantly than for those without a high school education, whereas the difference in acceptance between people with and without a high school education remained similar. Acceptance of people close to a nuclear plant fell more significantly than for those farther away.

The coefficient of the variable indicating the survey was conducted after the FNA is statistically significant and positive ($\gamma = 1.69$, $P < 0.001$). This implies that the decrease in risk acceptance after the FNA is smaller than would be implied by combining the changes in the four perception factors (knowledge, perceived risk, benefit, trust) with their coefficients, which are determined largely by between-subject variation within each survey. This suggests that the perception factors are more strongly correlated with between-person than intertemporal differences in acceptance.

Spatial Distribution of Risk Acceptance. The association between residential distance from the TNPP and risk acceptance is nonmonotone. Before the FNA, residents at a medium distance (20–40 km) had significantly lower risk acceptance than those living less than 20 km or more than 40 km from the plant (Fig. 2). After the accident, the acceptance of people within 20 km declined more than of those farther away. As shown by Fig. 2, the spatial distribution of risk acceptance before and after the FNA is complex, and distance to the nuclear power plant does not seem to be a primary explanation. Note that this is true even after controlling for the risk perception factors and demographic characteristics.

Familiarity, cognitive dissonance, and self-selection might be important in the higher acceptance of local residents. For example, people close to the nuclear plant may be more familiar with it and therefore more accepting of it. If one lives near the plant, it is more pleasant to believe it is safe than to worry about it. In a similar vein, previous work showed that workers are less concerned about the chemicals with which they work (20). In addition, if one is very worried about the plant, he or she may be more likely to move away.

After the FNA, all areas showed a lower level of acceptance and the geographic variation changed substantially (Fig. 2). The most dramatic changes occurred in the areas within 10 km of the nuclear power plants, where the highest acceptance (value of 5) before the FNA generally decreased sharply (value of 2–3) after the FNA. This implies that proximity to the TNPP became a key factor explaining the sensitivity of public perception to the FNA.

Table 2. Regression analysis of the risk acceptance variable as a function of risk perception factors and demographic variables

Parameter	Estimate	Variable definition
Intercept	0.62**	
FNA	1.69**	FNA = 1 for respondents surveyed after the nuclear accident; FNA = 0 for respondents surveyed before
Knowledge	0.17**	Factor "knowledge"
Risk	−0.07*	Factor "perceived risk"
Benefit	0.55**	Factor "benefit"
Trust	0.27**	Factor "trust"
Female	0.01	Female = 1 if respondents are female; 0 otherwise
Age	0.06	Age = 1 if respondents are 35 y or older; 0 otherwise
Education1	−0.11*	Education1 = 1 if respondents have high school education; 0 otherwise
Education2	0.04	Education2 = 1 if respondents have college education or above; 0 otherwise
Income	−0.08	Income = 1 if respondents have monthly income ≥2,000 yuan; 0 otherwise
Location1	−0.13	Location1 = 1 if respondents live between 20 and 40 km from the nuclear plant; 0 otherwise
Location2	−0.07	Location2 = 1 if respondents live >40 km from the nuclear plant; 0 otherwise
Occupation	0.01	Occupation = 1 if respondents are not in public service (e.g., self-employed, enterprise employees, farmers, retired, housewives, unemployed, or students); occupation = 0 if respondents are civil servants, teachers, or other state employees
FNA*Knowledge	−0.05	Interaction between FNA and factor "knowledge"
FNA*Risk	−0.27**	Interaction between FNA and factor "perceived risk"
FNA*Benefit	−0.15**	Interaction between FNA and factor "benefit"
FNA*Trust	0.03	Interaction between FNA and factor "trust"
FNA*Female	−0.18**	Interaction between FNA and "Female" variables
FNA*Age	−0.13*	Interaction between FNA and "Age" variables
FNA*Education1	−0.06	Interaction between FNA and "Education1" variables
FNA*Education2	−0.28*	Interaction between FNA and "Education2" variables
FNA*Income	0.33**	Interaction between FNA and "Income" variables
FNA*Location1	0.23**	Interaction between FNA and "Location1" variables
FNA*Location2	0.19*	Interaction between FNA and "Location2" variables
FNA*Occupation	−0.37**	Interaction between FNA and "Occupation" variables

Significance: *$P \leq 0.05$; **$P \leq 0.01$; $R^2 = 0.81$.

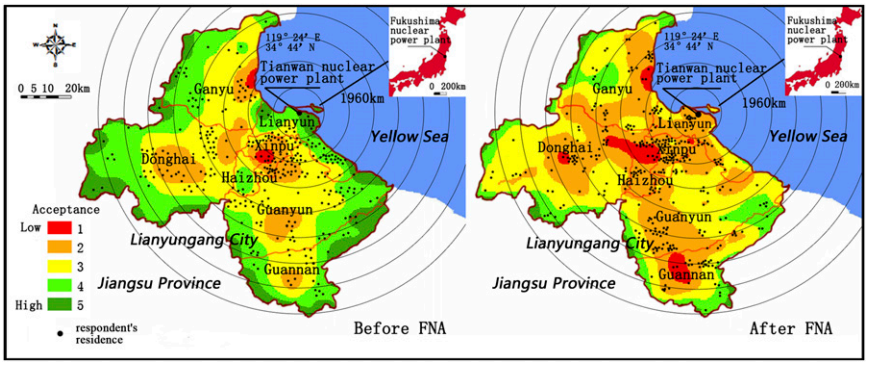

Fig. 2. Location of survey respondents' residences and risk acceptance before and after the FNA.

Median Acceptable Frequency of Nuclear Events. Fig. 3 shows the relationships between frequency of nuclear events and risk acceptance for three levels of nuclear events: anomaly, incident, and serious incident. A respondent is considered to accept the nuclear event frequency if he/she chose "fully accept," "easy to accept," or "basically accept" as responses to the relevant survey questions (Tables S4 and S5). As expected, risk acceptance decreases with an increase in the nuclear event frequency for each nuclear event level (Fig. 3). Fifty percent of the survey respondents considered it acceptable to have a level 1 nuclear event (anomaly) no more than once in 50 y. For level 2 nuclear events (incidents) and level 3 nuclear events (serious incidents), the median acceptable frequencies are 100 and 150 y, respectively.

Discussion

Before the FNA, acceptance of nuclear power appeared to be growing. A 2006 US survey found that 68% of respondents favored the use of nuclear energy (21). A 2009 research paper claimed "It is fit, it is safe, and it is back: nuclear power is a viable energy option again" (22)—an opinion supported by the press (23). By comparison, people in our 2008 pre-FNA survey had a risk acceptance of 3.34, which falls into the neutral category.

People from different nations may have different attitudes toward the same catastrophic event. For example, Renn (24) showed that the percent change in opposition to nuclear power immediately after the Chernobyl accident varied widely: increases of more than 30% in Finland, the former Yugoslavia, and Greece; more than 20% in Austria, West Germany, and Italy; 12%–18% in the United Kingdom, France, the Netherlands, Sweden, and Spain; and near zero in the United States are observed. Lindell and Perry (11) attributed this phenomenon to the possibility that the Americans surveyed believed that an accident involving a Russian reactor had no relevance to the operation of an American nuclear power plant. In Japan, Katsuya (25) found that the percentage of nuclear power supporters after the Tokai nuclear accident had barely decreased (1%–5%) whereas the percentage of opponents increased considerably (7%–23%). In our study, the maximum percent change in opposition to nuclear power immediately after the FNA— 41% as seen in question 4—was comparable to levels of opposition seen in Finland, the former Yugoslavia, and Greece after the Chernobyl disaster. Another Chinese survey conducted in July 2011 around the Haiyang nuclear power plant in Shandong province found that more than half the respondents (53%) thought the FNA would affect China (26), broadly consistent with our results. Our findings suggest there is great diversity in risk perception change among different populations, and the Chinese public as a whole has a strong reaction to nuclear accidents.

In our study, the FNA significantly reduced risk acceptance and altered risk perception in females and respondents over the age of 35. These findings concur with previous studies. For example, Finucane et al. (27) suggested that men tend to view situations as less risky more often than women. Hüppe and Weber (28) found that older persons reported more negative attitudes regarding nuclear power plants. Furthermore, we found that respondents not in public service, those with lower income, those with a college education or above, and those closest to a nuclear plant were more sensitive groups, a pattern rarely reported in previous studies. Note that people in public service in China mainly include civil servants, who may be more supportive of the government and have a steady income and relatively high social status, making them more resilient to abrupt economic or social changes. In contrast, corporate workers or self-employed people are more vulnerable once a catastrophic accident occurs. This phenomenon has not been reported in similar research conducted elsewhere. By identifying sensitive subgroups, we help explain which groups contributed to the sharp decrease of the risk acceptance of nuclear accidents.

Limitations

A limitation of the current study is that the respondents surveyed before and after the FNA were not the same. Because the recipients of both surveys are generally representative of the city population of Lianyungang, the impact of sampling biases is expected to be small. However, surveying different samples provides the advantage that responses to the post-FNA survey were not influenced by responses to the prior survey. A second limitation is that this study is restricted to Chinese residents near a nuclear power plant. Future research is necessary to extend the study population to regions further away from any nuclear

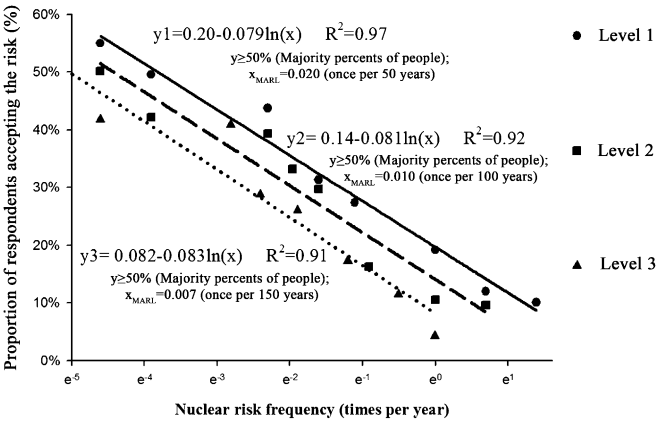

Fig. 3. Median public acceptable frequencies of nuclear events at three levels. Respondents (n = 368) are considered to accept the risk if they chose "fully accept," "easy to accept," or "basically accept" for the relevant questions in the questionnaire. $e^{-3.9}$ equals 0.02 events per year or one nuclear event in 50 y; $e^{-4.6}$ equals 0.01 events per year or one nuclear event in 100 y; $e^{-5.0}$ equals 0.067 events per year or one nuclear event in 150 y.

facilities to capture a broader spectrum of the Chinese population. Lastly, because the surveys were conducted immediately after the FNA, this study examined only the short-term effects of the FNA on public risk perception. Follow-up research is necessary to study its long-term effect.

Conclusions

First, this study analyzes changes in the Chinese public's risk perception regarding nuclear power after the FNA, using before and after surveys collected in a city near a nuclear power plant. The FNA was found to affect the risk perception of the Chinese public, especially the factor perceived risk, which increased from limited risk (2.8) to great risk (4.6) on a five-point Likert scale.

Second, the decrease in public acceptance of nuclear power differed within the population, with females, respondents over the age of 35, those not in public service, those with lower income, those with a college education or above, and residents living close to the TNPP exhibiting the greatest sensitivity to the FNA.

Third, median acceptable frequencies were calculated for three different nuclear event levels. Fifty percent of the survey respondents considered it acceptable to have a level 1 nuclear event (anomaly) no more than once in 50 y. For level 2 nuclear events (incidents) and level 3 nuclear events (serious incidents), the frequencies are once in 100 y and 150 y, respectively. These results may be useful in providing guidance for the development of risk control standards for nuclear power plant operations.

To fulfill the urgent need for electricity, the Chinese government has vigorously promoted the development of nuclear power projects in recent years. However, decreased acceptance of nuclear power after the FNA among the Chinese public creates additional obstacles to further development of nuclear power in China. To limit public controversy, the government must identify and communicate with sensitive subpopulations and direct more attention to these sensitive groups if a catastrophic nuclear accident were to happen in China. In addition, factors that concern the public merit further study and analysis. Therefore, this study might provide a useful perspective for managing the response of the Chinese public to a nuclear accident and help identify effective precautionary measures.

Methods

Study Site. We selected Lianyungang (a coastal city in Jiangsu province) for our surveys because of its proximity to the TNPP (Fig. 2). Established in August 2007, the TNPP is one of the six nuclear power plants in China. The TNPP has an electricity generation capacity of 1 million kilowatts. Six additional reactors currently under construction are expected to bring its total capacity to 8 million kilowatts by 2020 (29). In addition, Lianyungang is the Chinese city with a nuclear power plant closest to Fukushima (~1,960 km). Like other regions near nuclear power plants, the construction and operation of the plant have benefited local residents with employment opportunities, improved road maintenance, and overall economic growth (30, 31).

Sample Selection. The first of our two surveys was administered to Lianyungang residents between August 25 and August 30, 2008, and covered 350 adults; a total of 300 questionnaires were returned (response rate, 85.7%). The second survey was administered between March 30 and April 7, 2011 (shortly after the March 12 FNA), and reached 500 adults, with 368 questionnaires returned (response rate, 73.6%). The participants were selected by stratified random sampling. First, the city was divided into seven districts, and each district was further divided into five to seven residential communities. Households within each community were selected randomly. To ensure that the respondents had sufficient knowledge of the presence of the TNPP, we retained only respondents who had lived in Lianyungang for more than 3 y. This additional screening resulted in a lower response rate in the second survey. Survey questionnaires were distributed in person and were completed individually. No clustering procedure was used.

Questionnaire. The questionnaire for both surveys was designed based on Katsuya's (25) psychometric approach, with minor modifications to fit our context (Table S2). In addition to demographic variables (sex, age, education, employment, and residential location), our questionnaire included questions to measure opinions concerning risk acceptance of nuclear power (questions 1–4), interest in and knowledge of nuclear power (questions 5–9), perceived risk of nuclear power (questions 10–16), perception of the benefits of nuclear power (questions 17–21), and trust in government and nuclear power companies (questions 22–27). All questions were evaluated on a five-point Likert scale (1, do not agree at all; 2, do not agree; 3, neutral; 4, agree; 5, completely agree). A pilot study with 20 respondents showed that the questions were easily understood. Reverse scoring scales were used for several questions to avoid response-set (Table S2).

In the post-FNA survey, we added a series of questions about the degrees of public acceptance related to the frequencies of three different levels of nuclear events (Tables S4 and S5). According to the classification criteria of the INES, there are seven levels of nuclear events: anomaly, incident, serious incident, accident with local consequences, accident with wider consequences, serious accident, and major accident (1). We conducted a pilot study to investigate the acceptance of the first four levels: anomaly, incident, serious incident, and accident with local consequences. However, nearly all respondents believed a level 4 event (accident with local consequences) was "unacceptable." Thus, the level 4 event category was not included in the full survey. The frequencies of nuclear events in the questionnaire range from 3 mo to 200 y, which were selected using the pilot study results.

Analytical Approaches. ***Hypothesis.*** We investigated the effects of the FNA on the Chinese public's attitudes and risk perception, using data from the two surveys administered before and immediately after the accident. Risk perception factors included knowledge about and interest in nuclear power (15, 32–34), perceived social and personal risk of nuclear power accidents (5, 16, 35–39), perception of the benefit and necessity of nuclear power (17, 30, 36), and trust in the government and electric power companies (14, 25, 40). It is hypothesized that the FNA affected not only the acceptance of nuclear power, but also the other risk perception factors mentioned above.

Basic SEM construction. As described in the questionnaire design section, the survey had four questions regarding nuclear risk acceptance as well as 23 questions corresponding to four main risk perception factors: knowledge, perceived risk, benefit, and trust (Table S2). We developed a four-factor SEM, as shown in Eq. **1**, to evaluate the impact of these four risk perception factors on perceived nuclear risk acceptance (43):

$$Y_A = \sum \alpha_i \times X_i + Intercept, \quad [1]$$

where Y_A is risk acceptance; X_i is the risk perception factor variable (i.e., knowledge, perceived risk, benefit, trust); and α_i is the regression coefficient for the corresponding risk perception factor.

The goal was to find the model that best fit the data and to obtain an understanding of where the path coefficients were invariant. A comprehensive structural model was estimated using LISREL 8.8 software (44). We used the root mean square error of approximation (RMSEA), non-normed fit index (NNFI), and comparative fit index (CFI) as fitting criteria. A large RMSEA indicates a poorly fitting model, whereas RMSEA values (0.080 and 0.058) equal to or smaller than 0.08 signify a model that fit the data well. For the NNFI (0.98 and 0.90) and CFI (0.98 and 0.91), values >0.90 indicate a close fit (Table S6).

Regression analysis. To measure the effect of the FNA on the risk perception of the Chinese public, the accident was measured as a dichotomous variable, X_F (before FNA = 0, after FNA = 1). However, questions arose on whether X_F might have a direct effect on Y_A, or an indirect effect on Y_A via risk perception factors (i.e., knowledge, perceived risk, benefit, trust) and how these relationships are influenced by the demographic characteristics as the result of complete or partial mediation (45).

To explore the characteristics of people whose attitudes were more sensitive to the nuclear accident, we categorized respondents by demographic characteristics. The median age of the city's population was 35 y. Thus, we divided age into two categories: <35 y and ≥35 y. Education was divided into three categories: junior high school or less, high school, and college or beyond. Occupation was based on job characteristic and divided into two groups: people in public service (e.g., civil servants, teachers) and people in other occupations (e.g., self-employed, enterprise employees, farmers, retired, housewives, unemployed). The survey asked respondents for their income by range (e.g., <1,000, 1,000–2,000, 2,000–4,000, 4,000–8,000, 8,000–12,000, 12,000–20,000, and 20,000–60,000 yuan). Forty-three percent had a household income between 2,000–4,000 yuan ($317–$635) per month. For comparison, the average monthly household income in Lianyungang was about 3,800 yuan (or $600/mo) in 2010. We originally classified income into three levels: <2,000 yuan, 2,000–4,000 yuan, and >4,000 yuan. Because the influence of the latter two groups on risk acceptance was similar both before and after FNA, we merged them so that income had two categories in our final analysis: <2,000 yuan and >2,000 yuan. Finally, distance (i.e.,

proximity to the TNPP) was grouped as close (≤20 km), moderate (20–40 km), and remote (>40 km).

We modified Eq. **1** to include demographic variables, the dichotomous variable X_F, as well as the interactions between X_F and other variables in the analysis:

$$Y_A = \sum(\alpha_i + \beta_i \times X_F) \times X_i + \gamma X_F + \text{Intercept}, \quad [2]$$

where Y_A is risk acceptance, X_i is the risk perception factor variable (i.e., knowledge, perceived risk, benefit, and trust) or demographic variable (i.e., sex, age, education, income, location, occupation); X_F is the dichotomous covariate indicating whether the survey was conducted before or after the FNA ($X_F = 0$ before FNA and $X_F = 1$ after FNA); and α_i, β_i, and γ are the regression coefficients for the relevant variables. All regression analyses were conducted in SAS 9.3 (SAS Institute Inc.).

GIS analysis. Hung and Wang (37) and Bickerstaff and Walker (46) found that public risk attitudes are localized in the geographical, social, and cultural context. Hence, we examined risk perceptions by grouping individual attitudes spatially. GIS was applied previously to map the "risk perception shadow" (15, 30, 37, 47, 48). In the current analysis, the residents' risk acceptance was first geocoded using their residential addresses. Then, ordinary kriging was applied to construct the contours representing population attitudes toward the risk acceptance of the nuclear power plant.

Median acceptable frequency for nuclear events. In the survey after FNA, we added a series of questions about the respondents' degrees of acceptance to different frequencies of nuclear events. These questions focus on nuclear events at INES levels 1–3 (Tables S4 and S5). Respondents were asked to rate their acceptance at six levels: fully accept, easy to accept, basically accept, hard to accept, do not accept fully, and do not accept. Based on these questions, we conducted a regression analysis to link public acceptance (i.e., respondents who chose "fully accept," "easy to accept," or "basically accept) with nuclear event frequency. In previous analyses, the consequences (e.g., the number of deaths, injured, or evacuators) of a disaster and risk frequencies usually display a logarithmic relationship (49), such as the FN curve (50) (the relationship between the frequency of certain fatalities and the number of deaths). Therefore, a log format was chosen for this part of the correlation analysis. Based on these analyses, we calculated the median acceptable frequency corresponding to the frequency of nuclear events that 50% of survey respondents said they could accept.

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