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(分担)研究報告書

放射線汚染に対する母親の精神的ストレスが子どもの出生時体重と出生後の健康アウトカムに与える影響について
－東日本大震災における福島原子力発電所事故の事例から－

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研究要旨

We study the effects of exposure to radiation fear in utero on health at birth and five years later, using universal birth records linked to Censuses in Japan. We are the first to assess maternal stress due to a risk factor that is intangible and uncertain─radiation exposure. We leverage the Fukushima nuclear power plant accident in 2011 and create a quasi-experimental setting by focusing on children whose expected birthdates were within a 280-day window to the accident. We find radiation fear in utero causes a 30-gram decrease in birth weight, with a 19% and 38% increase in the risks of low birth weight and preterm delivery, respectively. The effects are more pronounced if expectant mothers are less educated or have toddlers, and if expectant fathers work in agriculture, indicating that the ability to collect information is important for stress alleviation and that food contamination is the main source of radiation fear. The findings have immediate implications for offspring health loss owing to maternal stress from intangible risk factors, such as infectious viruses. This study has two major contributions. To our knowledge, this is the first study to show population-representative casual evident on the impact of maternal stress from radiation fear on birth outcomes. The findings have immediate implications for understanding the effects of fear caused by intangible risk factors like infectious virus. Furthermore, this is the first study to link universal birth records to the Censuses and further to large-scale surveys in Japan, laying the groundwork to build relevant datasets for future research.

A. 研究目的

This study exploits the effects of exposure to radiation fear in utero on health at birth and five years later. We leverage the accident of Fukushima nuclear power plant (NPP) in 2011 in Japan to show the intergenerational health consequences of maternal stress from radiation fear. In terms of identification, NPP accidents outperforms the stressors documented in the literature. Unlike self-reported stressors (e.g., family ruptures, assault, and job loss) that are typically related with selection issues, NPP accidents occur exogenously like nature disasters and terrorist attacks (Douglas et al., 2009). Meanwhile, NPP accidents differ from those exogenous events in terms of the essence of the induced stress. Natural disasters and terrorist attacks frequently cause tangible and measurable damages, while the NNP accidents' legacy—radiation exposure—is intangible, uncertain, and with ambiguous loss. Accordingly, stress induced by natural disasters and terrorist attacks tends to be concentrated among people directly affected, whereas NPP accidents instill fear in a far wider range of people, including those who are not immediately affected (Huizink et al., 2007). This allows us to better isolate the impact of stress during pregnancy, as opposed to the literature, where the impact of maternal stress may be bundled with the impact of other repercussions related to the stressful events.

We overcome the issue of small sample by leveraging a population data from Japan's universe birth records linked to contemporary Censuses. To better distinguish the impact of radiation fear from the possible impacts of tsunami-related stress or radiation exposure, we omit data from municipalities that were devastated by the tsunami or received an annual radiation dose more than 1 millisievert. To create a quasi-experimental setting, we focus on the health of children at birth and five years later whose expected birthdate was within a 280-day window to the Fukushima accident. We confirm with various tests that the accident occurred at random to the expectant mothers in this narrow bandwidth. We use a prenatal vs postnatal model to compare children exposed to radiation fear in utero and after birth, accompanied by a difference-in-difference model to examine if the prenatal-postnatal difference varies by fear level. We further investigate the trimester-specific impact of prenatal radiation fear, as well as its various heterogeneous impacts and potential mechanisms. We also check the robustness of the results.

B. 研究方法

The dataset used in this study is constructed by linking three administrative records in Japan: the universe birth records, as well as the 2015 and 2010 Censuses. The birth records track the outcomes of all newborns in Japan, and the censuses complement the newborns' parent and household characteristics. We begin with extracting households from the 2015 Census where a child was born between the June 2010 and December 2011 (hereinafter, the newborns). The extracted households are then identified in the 2010 Census using information on household residency in 2010, birth year and month of the newborns' parents, and birth year, month, and gender of the newborns' older siblings if the newborns are not the household's first child. Finally, using information on household residency in 2010, the newborns' birth year, month, and gender, and their parents' birth year and month, the identified households are linked to the universe birth records. The linked dataset consists of 684,548 newborns.

As previously stated, the earthquake-caused tsunami accounted for the majority of the fatalities and devastation. According to research on the relationship between natural disasters and birth outcomes, we anticipate that maternal stress caused by the tsunami may also result in poor birth outcomes (Currie & Rossin-Slater, 2013; Torche, 2011). To minimize this confounder, we identify and exclude data from municipalities damaged by the tsunami based on a report from the Geological Society of Japan (Akira, 2011).

Another issue is the confounding health impact of the radiation exposure. Despite the fact that little health impact of radioactivity is found following the accident, we are concerned about the potential physical insults in utero due to radioactivity. To minimize this confounder, we identify and exclude data from prefectures where the annual accumulation of radiation dose between March 2011 and April 2012 was 1 millisievert or above, using data on monthly radioactive fallout from Japan Nuclear Regulation Authority. It is noteworthy that we use the maximum levels of radiation doses of cesium-137 and cesium-134 recorded within a month to represent the monthly levels and accumulate them to annual level.

After excluding expectant mothers residing in tsunami-damaged municipalities or in municipalities with annual radiation doses of 1 millisievert or more, the linked dataset remains 566,170 mother-newborn pairs. This dataset is referred to as the primary dataset for estimations. We quantify birth outcomes using birth weight (gram), an indicator of low birth weight (LBW: <2500g), and an indicator of preterm delivery (preterm: <37 weeks).

We also trace the health of the newborns at two and five years old. To this end, we identify the newborns in the 2013 and 2016 Comprehensive Survey of Living Conditions (CSLC). The CSLC is a nationally representative triannual survey that is sampled from the most recent Census up to the survey year. Thus, we can link the 2013 CSLC to the 2010 Census and the 2016 CSLC to the 2015 Census, respectively, and then link both back to the primary dataset. We are able to track down 2,662 newborns at the age of two and 3,092 newborns at the age of five. The linkage process is documented in Appendices B.II and B.III. In CSLC, parents of children under the age of six years old are asked to report whether their children have any symptoms of health problems (e.g., fever) and whether they visit hospitals on a regular basis to be treated for diagnoses (e.g., asthma). We use an indicator of having any symptoms and an indicator of regular hospital visits to assess the health of the newborns at two and five years old. Expectant mothers residing near the Fukushima NPP may be more concerned about unintended radiation exposure than those living further away. To measure the variation in fear levels, we divide municipalities into three areas depending on their distance from the Fukushima NPP, as illustrated in Figure 1. During pregnancy, expectant mothers residing in municipalities within 250 kilometers of the Fukushima NPP are classified as having high intense radiation fear (high-fear), those in municipalities between 250 and 400 kilometers from the NPP as having moderate fear (moderate-fear), and those in municipalities more than 400 kilometers from the NPP as having low fear (low-fear). The classifications of high-fear and low-fear areas are consistent with previous research, which finds that residents in north-east Japan (high-fear area) were the most concerned about radiation exposure, while residents in Osaka (low-fear area) were less concerned (Tateno & Yokoyama, 2013). Although the moderate-fear classification may be considered as exploratory, it allows us to capture possible "dose-response" effects of radiation fear.

According to the literature, newborns exposed to radiation fear postnatally can serve as a proper comparison group for those exposed prenatally (Currie et al., 2020; Persson & Rossin-Slater, 2018). In our case, consider a sample of mother-newborn pairs in which the expectant mothers either experienced the Fukushima accident during pregnancy or shortly afterward:

$$S = \{i\colon \mathbf{1}[c \le \text{Accident} < e_b]_i = 1 \mid \mathbf{1}[e_b \le \text{Accident} \le e_b + 280]_i = 1\},$$

where c denotes the conception date of the newborn and e_b the *expected* date of birth. The conception date is derived by subtracting the number of gestation days from the actual birthdate. The expected birthdate is defined as 280 days (40 weeks) after the conception date ($e_b = c + 280$). Thus, $\mathbf{1}[c \le \text{Accident} < e_b]_i = 1$ indicates that the accident occurred during the expected length of pregnancy, exposing the newborn to radiation fear prenatally, whereas $\mathbf{1}[e_b \le \text{Accident} \le e_b + 280]_i = 1$ indicates that the accident occurred shortly—within 280 days—after the expected birthdate, exposing the newborn to radiation fear postnatally. It is worth noting that we utilize *expected* birthdate rather than actual birthdate because the latter is endogenous to the accident.[1] In contrast, the expected birthdate is predetermined when the accident occurred. For each $i \in \{S\}$, we estimate the following model,

$$y_{imc} = \beta_0 + \beta_1 \mathbf{1}[c \le \text{Accident} < e_b]_{imc} + \lambda_m + \lambda_c + \boldsymbol{x}_i'\boldsymbol{\tau} + \epsilon_{imc},$$

for each newborn i who was born in municipality m and conceived in month c. $\mathbf{1}[c \le \text{Accident} < e_b]_{imc}$ is an indicator that takes the value of one if the newborn was prenatally exposed to radiation fear, and zero otherwise. Thus, β_1 captures the health impact of radiation fear in utero. λ_m and λ_c are municipality and conception month fixed effects, accounting for potential geographical and seasonal variations in the outcomes, respectively (Buckles & Hungerman, 2013).[2] $\boldsymbol{x}_i$ is a vector of covariates that are predetermined to the accident, including mother's and father's ages at conception in years and education in 2010 (less than high school, vocational school, university or above).

[1] According to the literature, maternal stress may reduce gestational age and increase the likelihood of stillbirth (Torche, 2011), which may induce the issue of sample selection.

[2] We account for prefecture fixed effect in place of the municipality fixed effect when estimating the health effects at ages two and five due to small sample sizes.

Additionally, $\boldsymbol{x_i}$ includes residential characteristics in 2010 such as living in house or apartment, floor of residence (5^{th} floor or lower, 6^{th}-10^{th} floor, 11^{th} floor or higher), and length of residence (less than one year, one to five years, more than five years). These residential characteristics account for possible variations in earthquake impacts. $\boldsymbol{x_i}$ also contains neonatal characteristics such as gender and parity (first, second, and third) and a full interaction between the gender and parity. Robust standard errors are clustered on expectant mothers' municipality of residence in 2010.

C. 研究結果

C-1. 記述統計量

Table 1 depicts the basic statistics. Column (1) presents statistics for the full primary dataset, while columns (2) and (3) provide statistics for the prenatal and postnatal groups, respectively. Columns (4)-(6) present related statistics from the original administrative records and survey for children born during the same period as the newborns in the primary dataset.

Panel A shows that average birth weight in the primary dataset is 3,030 grams, with 7.6% and 4.2% of LBW and preterm delivery, respectively. Panel B reveals that 24.6% and 18.3% of the newborns have symptoms and regular outpatient visits at age two, respectively, which decreases to 18.4% and 17.0% at age five. Overall, the prenatal group has a poorer birth outcome and health at two and five years old than the postnatal group. The second part of Panel A, as well as Panels C and D, depict the characteristics of newborns, parents, and residences, with statistics that are comparable between the prenatal and postnatal groups. This is consistent with the non-significant estimates for these characteristics in Appendix Tables C1–C4. Furthermore, compared to the statistics from the original datasets in columns (4)-(6), our primary dataset has a slightly higher average birth weight and slightly lower likelihoods of LBW and preterm delivery.[3] Except for the fact that mothers and fathers in our dataset are somewhat older than all parents in the birth records, other characteristics are comparable between the primary and original dataset.

C-2. 回帰分析による推定結果

Table 2 depicts the effects of in utero radiation fear on average birth weight, likelihood of LBW, and likelihood of preterm delivery in Panels A, B, and C, respectively. Column (1) presents the estimates for the prenatal vs postnatal model; columns (2) and (3) illustrate respectively the estimates for the DD model by comparing the high-fear area to the moderate- and low-fear areas as a whole and separately; column (4) shows the estimates for the DD model with the continuous measure of fear.

[3] This is most likely because our primary dataset is built by linking several datasets that is conditional on the birth year and month of both the mother and father of a newborn. Put differently, the primary dataset does not include children born to single mothers. Since newborns born to single mothers may have poorer birth outcomes than those born to two-parent households, our dataset shows slightly better average birth outcomes than the overall birth records.

Panel A suggests that in utero radiation fear causes a substantial decrease in birth weight, regardless of model specifications. Specifically, newborns who were exposed in utero to radiation fear are around 30-gram lighter than those exposed within 280 days after the expected birthdate. The magnitudes remain constant after accounting for variation in fear levels. The magnitude with continuous fear indicator is larger than others because it depicts the impact on newborns born to mothers resided in areas with the shortest distance to the Fukushima NPP. Focusing on the DD model, we find that newborns in the high-fear area are 4-gram lighter than those in other areas and 6-gram lighter than those in the low-fear area. In contrast, there is no significant difference in birth weight between the moderate- and low-fear areas. The DD model with the continuous fear indicator also shows an attenuating trend in the birth weight decrease as distance from the Fukushima NPP increases, though the magnitude is insignificant. Panels B and C indicate a 1.5 and 1.6 percentage point (pp) increase in the likelihood of LBW and preterm delivery, respectively, among the newborns exposed to radiation fear in utero. The magnitudes are consistent across model specifications and correspond to a 19% and 38% increase at the sample mean, respectively. In contrast to the birth weight impact, the increases in LBW and preterm risks do not vary by fear levels.

The findings are consistent with previous research, indicating a negative impact of maternal stress on birth outcomes. The 30-gram decrease in birth weight is the lower bound of the magnitude reported in the literature when maternal stress is induced by natural disasters or terrorist attacks (Camacho, 2008; Hugo De Oliveira et al., 2021; Torche, 2011). Meanwhile, the magnitude is greater than that found when maternal stress is caused by life events such as family ruptures (Black et al., 2016; Persson & Rossin-Slater, 2018). This could be attributable to the distinct nature of these stressors. Unlike the concrete damages of natural disasters and terrorist attacks, radiation exposure is intangible and ambiguous, which may result in less acute shocks in the expectant mothers. On the other hand, fear of radiation exposure tends to have a more prolonged aftermath than stress from life events, leading to a more pronounced impact on birth outcomes. Furthermore, the large impacts of natural disasters and terrorist attacks on birth outcomes reported in the literature are likely due to the difficulty in disentangling maternal stress from other consequences of these events, whereas in our study, in utero radiation fear is carefully isolated from the confounders. Finally, the findings show that, unlike stress from natural disasters or terrorist attacks, maternal radiation fear has a nationwide impact on birth outcomes, with only moderate fear level heterogeneity.

D. 考察／E. 結論

Despite a growing body of literature measuring the intergenerational health effect of various kinds of maternal stress, little is known about the impact of maternal stress caused by risk factors that are intangible, uncertain, and with ambiguous loss. This study is groundbreaking because it provides the first population-based casual evidence on the impact of in utero radiation fear on health at birth and five years later, where widespread anxiety about radiation exposure caused by the Fukushima accident serves as an indicator for intangible risk factors.

We link universe birth records to contemporary Censuses, constructing a unique dataset that contains not only birth outcomes but also parental and residential information. We rule out other plausible ways for the accident to affect birth outcomes by excluding children born to mothers who resided in municipalities that were damaged by the tsunami or received a subclinical radiation dose. We use two identification strategies. The first focuses on children whose expected birthdate was within a 280-day window of the accident and compares those exposed in utero to those exposed after birth. The second allows for further variation in the prenatal-postnatal outcome differences by fear level. We find that radiation fear in utero decreases birth weight and increases the risks of low birth weight and preterm delivery. The impact varies only marginally by fear level, implying that radiation fear affects expectant mothers with nearly consistent intensity regardless of distance from the accident site. We find that the negative health impact fades by the age of five, indicating a tentative physical health consequence of radiation fear, and that the impact appears to be driven by exposure from the first trimester onwards, showing an accumulative effect of the fear. We also find that food contamination is the main source of radiation fear, as evidenced by the greater impact on children born to mothers with toddlers and fathers working in agriculture. Finally, we underline the importance of information collection in the face of intangible risk factors, since children born to higher educated mothers and professional fathers are less susceptible to prenatal radiation fear.

This study is subjected to several limitations due to data constraints. We are unable to assess the mental health or cognitive functions of prenatally exposed children because the CSLC only collects relevant information for respondents over the age of six. We are also unable to trace the children for a longer period because the most current survey available is the 2016 CSLC. Future research on the longer-run and cognitive consequences of prenatal fear exposure is needed. Furthermore, we are unable to assess birth outcomes in terms of abnormal conditions or complications of labor because the information is not included in birth records. Finally, we are unable to investigate changes in prenatal medical care utilization following the accident, which is a critical pathway via which the accident can alter birth outcomes. Future research into neonatal and maternal medical records may provide a more thorough understanding of the impact on health at birth.

What conclusions can we draw from the findings? We contend that policymakers may have underestimated the welfare costs of intangible risk factors on an important population segment, i.e., newborns, as we demonstrate that the costs include not only the actual damage caused by those risks, but also the fear of them. An immediate implication is the loss of offspring health due to maternal stress from infectious virus like COVID-19. Furthermore, we highlight that timely and adequate information sharing could be the key solution for the welfare loss of intangible risks. This is especially beneficial for parents who have lesser human capital and can contribute to prevent the persistence of such disadvantage through generations

F. 健康危険情報
特に無し.

G. 研究発表
1. 論文発表
特に無し.

2. 学会発表
October/15-16/2022: "In utero exposure to radiation fear and birth outcomes: evidence from Fukushima nuclear power plant accident".日本経済学会 2022 年度秋季大会（予定・未採択）

January/6-8/2023: "In utero exposure to radiation fear and birth outcomes: evidence from Fukushima nuclear power plant accident". ASSA 2023 Annual Meeting of American Economic Association（予定・未採択）

H. 知的財産権の出願・登録状況(予定を含む)
1. 特許取得
特に無し.

2. 実用新案登録
特に無し.

3. その他
特に無し.

Table 1. Basic Statistics

	Sample for Estimation			Population Data		
	The primary dataset	**Prenatal**	**Postnatal**	**All Births**	**CSLC**	**Census 2010**
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Birth Outcomes						
Birth weight (g)	3030.118	3027.114	3034.387	3025.475		
	(407.109)	(412.846)	(398.775)	(433.817)		
LBW (<2,500g)	0.076	0.078	0.074	0.080		
Preterm (< 37 weeks)	0.042	0.045	0.037	0.042		
Parity						
First	0.469	0.458	0.481	0.489		
Second	0.389	0.390	0.388	0.377		
Third	0.142	0.152	0.131	0.134		
Male newborn	0.512	0.512	0.512	0.512		
Panel B: Health at Age Two and Five						
Any symptoms (Age Two)	0.246	0.263	0.218		0.221	
Outpatient visit (Age Two)	0.183	0.197	0.160		0.161	
Any symptoms (Age Five)	0.184	0.191	0.178		0.180	
Outpatient visit (Age Five)	0.170	0.171	0.169		0.171	
Panel C: Parent Characteristics						
Mother's age at conception	31.310	31.035	31.003	30.456		
	(4.441)	(4.361)	(4.534)	(5.032)		
Father's age at conception	33.091	33.031	32.984	32.432		
	(5.249)	(5.192)	(5.313)	(5.769)		
Mother's education						
High school	0.309	0.309	0.310			0.301
Vocational school	0.365	0.365	0.364			0.347
University and above	0.255	0.255	0.255			0.266
Father's education						
High school	0.364	0.363	0.364			0.355
Vocational school	0.145	0.146	0.145			0.140
University and above	0.418	0.418	0.419			0.420
Panel D: Residence Characteristics						
Residence						
House	0.425	0.426	0.423			0.412
Apartment	0.574	0.572	0.576			0.586
Floor of Residence						
F1-F5	0.854	0.859	0.849			0.831
F6-F10	0.091	0.090	0.091			0.099
F11+	0.055	0.051	0.060			0.070
Residence period						
Less than one year	0.228	0.230	0.226			0.229
One-five years	0.527	0.526	0.529			0.528
More than five years	0.245	0.244	0.245			0.244
N	566,170	332,331	233,839	1,887,741	19,700	984,528

Table 2. Impacts of in Utero Radiation Fear on Birth Outcomes

	Prenatal vs Postnatal		Difference-in-Difference					
	(1)		(2)		(3)		(4)	
Panel A: Birth Weight								
In-utero	-29.9703	***	-29.0241	***	-28.3828	***	-41.3734	***
	(1.5706)		(1.6656)		(1.7741)		(12.1635)	
In-utero × Fear								
High			-4.1174	*	-6.1809	**		
			(2.4296)		(2.8322)			
Moderate					-4.0566			
					(2.5904)			
In-utero × log(Distance)							1.855	
							(1.655)	
Mean	3030.118		3030.118		3030.118		3030.118	
N	548,533		548,533		548,533		548,533	
Panel B: LBW								
In-utero	0.0149	***	0.0147	***	0.0147	***	0.0166	**
	(0.0010)		(0.0011)		(0.0011)		(0.0080)	
In-utero × Fear								
High			0.0003		0.0017			
			(0.0017)		(0.0020)			
Moderate					0.0000			
					(0.0017)			
In-utero × log(Distance)							-0.0003	
							(0.0013)	
Mean	0.0762		0.0762		0.0762		0.0762	
N	548,533		548,533		548,533		548,533	
Panel C: Preterm								
In-utero	0.0160	***	0.0160	***	0.0159	***	0.0174	***
	(0.0008)		(0.0008)		(0.0009)		(0.0061)	
In-utero × Fear								
High			0.0001		0.0007			
			(0.0014)		(0.0017)			
Moderate					-0.0002			
					(0.0014)			
In-utero × log(Distance)							-0.0004	
							(0.0010)	
Mean	0.0419		0.0419		0.0419		0.0419	
N	548,533		548,533		548,533		548,533	

Notes: Each column in each panel is a separate regression. Column (1) presents estimates for equation (2), columns (2)-(3) for equation (3); column (4) for equation (4). “In-utero” corresponds to 1[c≤Accident<e_b]_imc=1. All regressions control for municipality fixed effect, conception month fixe effect, mother’s and father’s age at conception in years and education in 2010, residential characteristics in 2010, and neonatal characteristics. Robust standard errors are clustered on expectant mothers’ municipality of residence in 2010. Statistical inference: * p<0.1 ** p<0.05 *** p<0.01

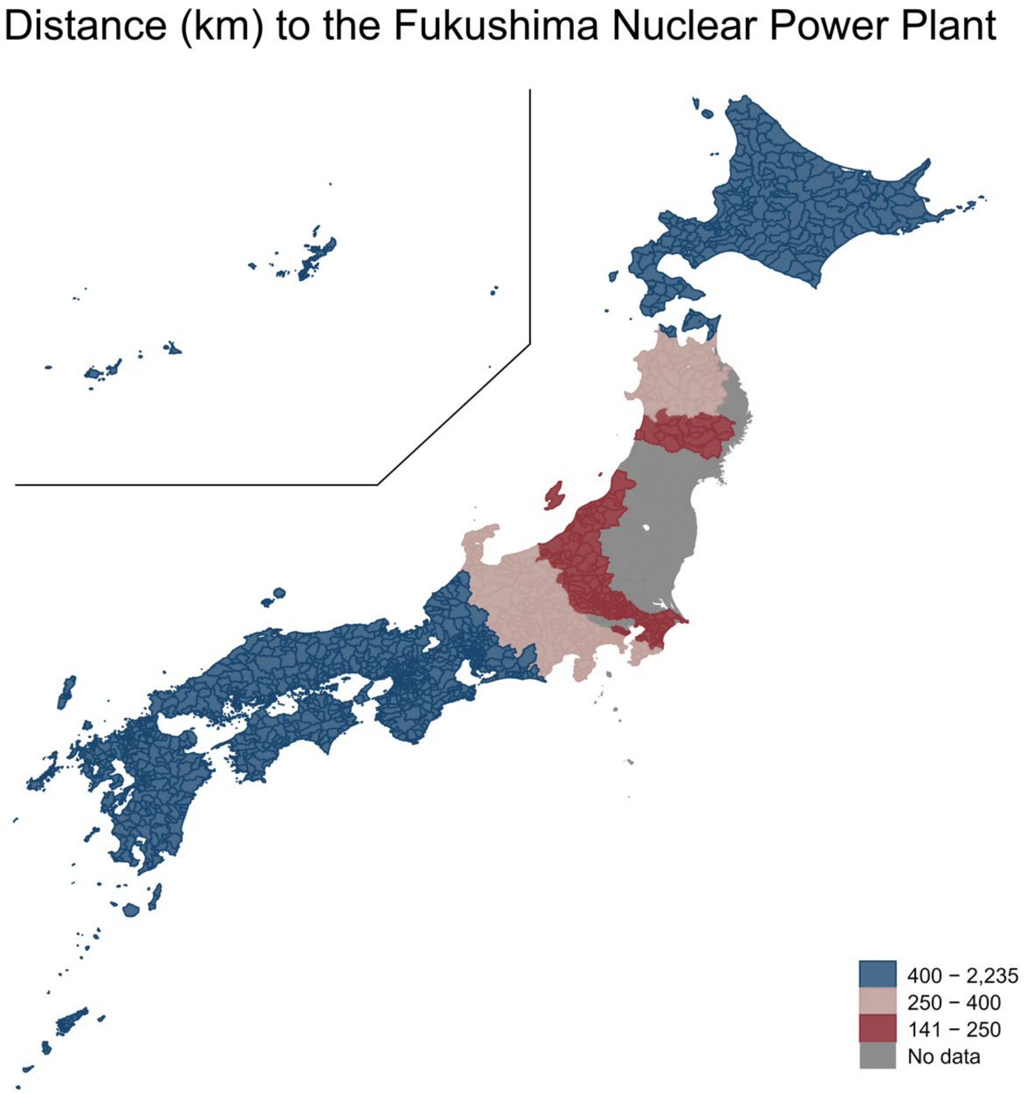

Figure 1. Data Exclusion and Areas with Different Fear Levels

Notes: The municipalities with "no data" are those for which data are excluded for estimation. These municipalities were either damaged by the tsunami or had an annual radiation dose over one millisievert. Details about these municipalities are in Appendix A. The red area corresponds to the high-fear area, with distances to Fukushima NPP ranging from 141 km to 250 km. The pink area corresponds to the moderate-fear area, with a distance range of 250 km to 400 km. With a distance greater than 400 km, the blue area corresponds to the low-fear area.