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ABSTRACT

Based on prefecture-level panel data from Japan for 2010 and 2012, this paper investigates how the 2011 Fukushima nuclear accident influenced the body mass index (BMI) of students aged between 5 and 17 years old. A differences-in-differences approach was used to show that (1) students' BMIs reduced across Japan from 2010 to 2012 and (2) compared with other prefectures there was an increase in the BMIs of primary school students aged 5–11 years old in Fukushima as a result of the Fukushima accident. These findings suggest that restrictions placed on outdoor exercise as a result of the nuclear accident in Fukushima prevented primary school children from burning calories consumed; in other areas a reduction in the use of air-conditioning increased the burning of calories.

JEL classification: I18; H12

Keywords: Fukushima, Nuclear accident; Body mass index

1. Introduction

On March 11, 2011, a devastating natural disaster that combined both earthquake and tsunami struck Japan. As a consequence, the Fukushima Daiichi nuclear plants located on the Fukushima coast (northeast Japan) were crippled. A level 7 nuclear disaster rating was assigned to the Fukushima nuclear accident, a level reached only once before with the Chernobyl disaster. As a result, Fukushima's residents had to directly confront the danger of nuclear leakage. Furthermore, the accident at Fukushima caused Japanese people to doubt the safety of other nuclear plants in Japan.

Prior to the Fukushima nuclear accident, there had been two other infamous incidents: the Three Mile Island accident, which occurred in the United States in 1979 and the 1986 Chernobyl incident in the Ukraine. These accidents are regarded as the most devastating nuclear disasters in history. Data regarding the long-term effect of the Chernobyl disaster have been complied, and researchers have investigated its long-term influence on the stricken areas. The Chernobyl accident was found to decrease people's happiness levels (Danzer and Weisshaar, 2009) and to reduce the performance of the labor market in the Ukraine (Lehmann and Wadsworth, 2008). The effects of the accident have also been observed in other European countries. For instance, German people were found more inclined to worry about the environment after the Chernobyl disaster (Berger, 2010). In Sweden, students born in regions exposed to higher levels of Chernobyl radiation fallout had poorer performance in secondary school (Almond et al., 2009).[1]

The Great East Japan Earthquake and the Fukushima nuclear accident are thought to have had a substantial impact on socio-economic conditions and lifestyles in Japan (Ando and Kimura, 2012; Hayashi, 2012). Japanese life relies heavily on air-conditioning; however, this has led to a growing number of elementary school students becoming obese during the summer (Kobayashi and Kobayashi, 2006)[2] Such weight gains occur because the heavy use of air-conditioning, in lowering the temperature of a room, makes it more comfortable to stay inside and results in a reduction in the burning of calories consumed during the summer. However, the Fukushima accident resulted in the suspension of other

[1] Other major disasters have also been found to influence the outcomes of elections and policies in the United States (Eisensee and Strömberg, 2007; Kahn, 2007).
[2] The degree of urbanization has been found to have differing effects on the BMIs of teenagers across ages (Yamamura, 2012).

power plants in Japan until the safety of the power plants was confirmed. This increased the likelihood of an electricity shortage. To avoid shortages, the government requested in 2011 that businesses and households reduce their summer peak-time power use by 15 percent to offset any shortages caused by the damaged and suspended nuclear power plants (Japan Times, 2012 p. 7).

The possibility of electricity shortages is now high across Japan during the summer months as air-conditioning use increases the demand for electricity. Inevitably, people are urged to reduce their use of air-conditioning, and as a result they are now less likely to depend on air-conditioning and will maintain their rooms at higher temperatures than before the accident. High temperature causes people to use calorie. Accordingly, this could result in a decrease in children's BMI. In contrast, according to media reports in Japan, the nuclear accident also led to "a lack of physical exercise and stress stemming from prolonged living in shelters and restrictions on playing outside" (Daily Yomiuri, 2012). As a consequence, "an alarming trend toward obesity has been found among children in the Fukushima prefecture, which has the highest rate of obese children in every age group between 5 and 9 years old" (Daily Yomiuri, 2012). Thus, the nuclear accident produced two possible polar effects on children's BMIs. It is not known whether the accident increased or decreased BMIs. The disaster can be regarded as a natural experiment—it has provided an opportunity to ask many empirical questions regarding the disaster's various outcomes. It is thus worthwhile to empirically examine how the Fukushima nuclear accident has influenced the BMI of children. For this purpose, based on prefecture-level data before and after the 2011 nuclear accident, this paper uses a differences-in-differences approach to determine the influence of the nuclear accident on the BMI of children in Japan.

2. Data and methods

2.1. Data

The Ministry of Education, Culture, Sports, Science and Technology conducts an annual school health survey across Japan. This survey collects data regarding the height and weight of all students aged 5–17 years old. A Japanese prefecture is the equivalent to a state in the United States or a province in Canada. There are 47 prefectures in Japan and the ministry releases the average heights and weights in each prefecture. Height and weight data are further categorized for male and female students. However, data from Fukushima, Iwate, and Miyagi prefectures were not collected in 2011 because the Great East Japan Earthquake directly hit these areas. Thus, data from 2010 and 2012 are used in this analysis.[3] The structure of the data is shown in Table 1. That is, in 2010 and 2012, data showing average height and weight values were obtained for 47 prefectures over a range of 13 school years (for students aged 5–17 years old) and are available for male and female students. Using these data, average BMI values can be calculated. For example, in Fukushima Prefecture, the average BMI for boys aged 5 years old in 2010 can be calculated using these data. A total of 2,244 observations were used in this study.

Table 2 shows that in the Fukushima Prefecture, the difference in BMI between 2010 and 2012 takes the positive sign for students aged between 5 and 11 years old, and the negative sign for those aged over 12 years (with the exception of students aged 17 years old). In contrast, the average value for the difference in BMI for other prefectures takes the negative sign for children aged 5–17 years old. Therefore, with the exception of students in the Fukushima Prefecture, overall the Fukushima accident slightly reduced the BMI of Japanese children. This is congruent to the conjecture that the use of air conditioning was reduced to avoid an electricity shortage, and this resulted in a greater burning of calories and decreased students' BMIs.

In Japan, primary school students include children aged 5–11 years old, junior high school students include those aged 12–14 years old, and high school students are generally aged 15–17 years old. Table 3 implies that there is a remarkable difference in changes in BMIs from primary school students to junior high school (and also high school) students in the Fukushima Prefecture. Further, it is inferred from the results in Table 3 that the BMIs of Fukushima primary school children increased because of the nuclear accident although the BMIs of students in other prefectures reduced.

2.2. Econometric Framework

The basic statistics of the variables used in the estimation are presented in Table 3. Following the description above, the estimated function takes the

[3] Data regarding children's heights and weights used in this paper are available from the website of the Ministry of Education, Culture, Sports, Science and Technology: http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001044483&cycode=0 (accessed on Jan 8, 2012).

following form:

$$BMI_{itga} = \alpha_0 + \alpha_1 Fukushima\ dummy_{tga} * 2012\ year\ dummy_{iga} + \alpha_2 Iwate\ dummy_{tga} * 2012\ year\ dummy_{iga} + \alpha_3 Miyagi\ dummy_{tga} * 2012\ year\ dummy_{iga} + \alpha_4 Fukushima\ dummy_{tga} + \alpha_5 Iwate\ dummy_{tga} + \alpha_6 MIyagi\ dummy_{tga} * 2012\ year\ dummy_{iga} + \alpha_7 2012\ year\ dummy_{iga} + Y'_{iga} B_{iga} + u_{itga},$$

where BMI_{itga} represents the dependent variable in prefecture *i*, year *t*, gender group *g*, and age group *a*. The vectors of the control variables including age dummies, male dummy, unemployment rate,[4] per capita income, population, number of school are denoted by Y_{iga}. The regression parameters are denoted by α[5], and B is the vector of the regression parameters for the control variables. The error term is denoted by *u*.

As discussed in the introduction, attempts to save electricity by reducing the use of air-conditioning during the summer are likely to have been made across Japan, while reactions to actual nuclear leakage are likely to have occurred in Fukushima. Based on data from 2010 and 2012, to scrutinize the effect of the Great East Japan Earthquake on the BMI of students, I compared changes in BMIs for 2010 and 2012 in Fukushima, Iwate, and Miyagi with changes in BMIs in other prefectures over the same period. That is, I employed a differences-in-differences approach to examine the impact of the 2011 disaster on children's BMIs using data from 2010 and 2012. In this paper, the treatment groups include Fukushima, Iwate, and Miyagi prefectures because the Great East Japan earthquake directly hit these prefectures; the control group is other prefectures. The Fukushima accident had a greater direct influence on human behavior in Fukushima Prefecture compared with Iwate and Miyagi prefectures, despite all three being hit by both the earthquake and tsunami. This paper aims to distinguish the effect of the nuclear accident from that of the natural disasters. It is for this reason that the disaster-stricken prefectures are divided into three: Fukushima, Iwate, and Miyagi. The interaction term between the prefecture dummies and the 2012 year dummy is

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4 Data regarding unemployment rates are available on the website of the Ministry of Internal Affairs and Communications – Statistics Bureau, Director-General for Policy Planning & Statistical Research and Training Institute: http://www.stat.go.jp/data/roudou/pref/index.htm (accessed on Jan 8, 2012).

5 Data regarding population, number of schools, and per capita income are available on the website of the Ministry of Internal Affairs and Communications – Statistics Bureau, Director-General for Policy Planning & Statistical Research and Training Institute: http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001036889&cycode=0 (accessed on Jan 8, 2012).

the key variable to examine the effect of the nuclear accident and the Great East Japan Earthquake. If the coefficient of the cross terms has a positive sign, then the 2011 disaster caused students' BMIs to increase. More precisely, *Fukushima dummy* $_{tga}$ **2012 year dummy* $_{iga}$ captures the effect of the Fukushima accident, while *Iwate dummy* $_{tga}$ **2012 year dummy* $_{iga}$ and *Miyagi dummy* $_{tga}$ **2012 year dummy* capture that of the natural disaster (e.g., the earthquake and tsunami).

3. Estimation results and their interpretation

Before discussing the results of the differences-in-differences approach, I will explain how BMIs in Fukushima, Iwate, and Miyagi prefectures differed from other prefectures. To this end, Table 4 presents the estimation results using aggregated data from 2010 and 2012, where *Fukushima dummy, Iwate dummy,* and *Miyagi dummy* are included and the interaction terms between them and the *2012 year dummy* are excluded. Further, I can also determine how the average BMI in these prefectures differs from that in other prefectures before the Great East Japan Earthquake by conducting an estimation based on 2010 data. In addition, I also conducted the same estimation using 2012 data. Table 5 shows these estimation results. Table 6 shows the results where the interaction terms are included. In Tables 4 and 6, column (1) shows the results based on data for children aged 5–17 years old. Column (2) presents the results based on data for primary school students aged 5–11 years old.[6] Column (3) presents the results based on data for children aged 12–17 years old, i.e., junior high school or high school students. Table 4 reports the results of all dependent variables. Tables 5 and 6 show only the results for key variables; however, an estimation was conducted by including control variables that are equivalent to those in Table 4.

Table 4 shows that *Fukushima dummy, Iwate dummy*, and *Miyagi dummy* have positive signs and are statistically significant at the 1 percent level in all columns. Thus, it follows that children's BMIs are higher in the disaster-stricken prefectures than in other prefectures. Further, column (1) shows that the values of their coefficients lie at approximately 0.25. This implies that the children's BMIs are at very similar levels across the stricken prefectures. Further, *2012 year dummy* shows a significant negative sign in all estimations, suggesting that children's BMIs reduced overtime in Japan. The absolute value of the coefficient of

[6] Only 5-year-old children are regarded as kindergarten children.

2012 year dummy is approximately 0.03, which implies that children's BMIs experienced a 0.03-point decrease from 2010 to 2012; this is congruent with the last column of Table 2. These results are in line with the prediction that saving electricity after the Fukushima accident led to a decrease in BMIs. Concerning age dummies, the larger their coefficient, the older the children are.

Looking now to Table 5, it is interesting to observe that the coefficients of *Fukushima dummy, Iwate dummy*, and *Miyagi dummy* yield significant positive signs not only in 2012 but also in 2010. From this I draw the argument that the BMIs of children in the disaster-stricken prefectures were higher than other prefectures even before the occurrence of the Great East Japan Earthquake. Compared with Tokyo and Osaka, Fukushima, Iwate, and Miyagi are considered rural areas. Hence, the above result is consistent with the finding that children's BMIs are more likely to be high in rural areas compared with urban areas (Yamamura, 2012).

For a closer examination, I now turn to Table 6. In column (1), the cross terms for the disaster-stricken prefectures and 2012 year dummy have the positive sign for *Fukushima dummy * 2012 year dummy* and *Iwate dummy * 2012 year dummy*; *Miyagi dummy * 2012 year dummy* has the negative sign. None of these, however, are statistically significant. It can be seen in column (2), based on the sample of primary school students, that only *Fukushima dummy * 2012 year dummy* is statistically significant at the 1 percent level while the other cross terms are not statistically significant. What is more, the coefficient of *Fukushima dummy * 2012 year dummy* has a positive sign. The absolute value of the coefficient of *Fukushima dummy * 2012 year dummy* is 0.28. This implies that, compared with other prefectures, children aged 5–11 years old in Fukushima experienced a 0.28-point increase in their BMIs from 2010 to 2012. In contrast, the results of column (3), based on a sample of students that graduated from primary school, suggest that none of the cross terms show statistical significance. In my interpretation, the positive effect of the accident on BMIs outweighs the negative effect of the accident for primary school students in Fukushima. However, both effects were neutralized for junior high and high school students in Fukushima, and also for Iwate and Miyagi students regardless of age. From this I derive the argument that the nuclear leakage was more severe in Fukushima Prefecture and had a greater direct effect than in any other prefectures; therefore, the positive effect of the accident on BMIs was greater than the negative effect. Further, parents and school teachers are more able to restrict students' outdoor exercise in primary school than in junior high and high school. Thus, the positive effect on primary school students was greater than on junior high and high school students. There is also another interpretation: the younger the children, the more likely they will play outdoors because junior high and high school students will be preparing for examinations and engaging in less outdoor exercise. Hence, the positive effect of the accident is smaller for older students.

The impact of the nuclear accident had a significant detrimental effect on the health of children in Fukushima through a reduction of outdoor exercise. The end result was an increase of their BMIs. In contrast, the earthquake and tsunami did not affect the level of exercise enjoyed by children living in the disaster-stricken areas.

4. Conclusion

The unforeseen Fukushima nuclear accident caused the government to suspend the operation of nuclear plants across Japan, reducing the electricity supply. This naturally reduced the consumption of electricity, especially during the summer. To this end, people were less likely to use air-conditioning and therefore kept the temperatures of their rooms higher than before the accident. This was predicted to increase the burning of calories and to reduce BMIs. Another result of the nuclear accident was nuclear leakage, especially in Fukushima Prefecture. Nuclear leakage influences human behavior because such leakage has a detrimental effect on health when people are exposed to nuclear fallout. In Fukushima, after the accident, schools and parents prevented their children from playing outside. A decrease in outdoor exercise is thought to reduce calorie use, causing an increase of a person's BMI. Hence, the impact of the accident on BMIs is expected to differ between Fukushima and other areas in Japan. By employing a differences-in-differences approach, this paper investigated the influence of the impact of the Fukushima accident on children's BMIs.

Based on prefecture-level data from 2010 and 2012, I conducted an estimation. Key findings are summarized as follows. (1) Average BMIs were reduced across Japan from 2010 to 2012. (2) Compared with other prefectures, Fukushima's primary school students aged 5–11 years old experienced an increase in their BMIs as a result of the Fukushima accident. (3) This tendency was not observed for junior high and high school students. And (4) in other natural disaster-stricken areas such as Iwate and Miyagi prefectures, children's BMIs did not increase. These findings lead me to assert that children's behavior changed as a result of the nuclear accident, rather than earthquake and tsunami. Further, there are several channels through which the nuclear accident affected BMIs, and so its impact differs according to residential area and ages of children.

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Table 1
Data structure (showing number of data units)

Prefectures	Years (2010 and 2012)	Gender (Male and female)	Ages (5–17)	Observations
47	2	2	13	2,244

Note: prefectures * years * genders * ages = total observations

Table 2
Difference in BMI for 2010 and 2012

Age	Fukushima			Average values for other prefectures		
	2010	2012	Difference (2012–2010)	2010	2012	Difference (2012–2010)
5	15.66	15.81	0.15	15.48	15.45	–0.04
6	15.82	16.14	0.32	15.77	15.71	–0.06
7	16.22	16.33	0.11	16.00	15.99	–0.01
8	16.64	16.90	0.26	16.50	16.45	–0.05
9	17.31	17.55	0.23	17.03	17.01	–0.02
10	17.61	18.00	0.39	17.58	17.54	–0.04
11	18.63	18.87	0.24	18.22	18.18	–0.04
12	19.53	19.34	–0.19	19.08	19.03	–0.05
13	19.99	19.88	–0.11	19.56	19.53	–0.03
14	20.59	20.56	–0.03	20.25	20.19	–0.06
15	21.67	21.27	–0.40	21.00	20.96	–0.04
16	21.66	21.34	–0.32	21.27	21.25	–0.02
17	21.75	21.80	0.04	21.49	21.46	–0.03

Table 3
Basic statistics of variables used in the estimation

Variables	Definition	Mean	Standard deviation
BMI		18.3	2.11
School[a]	Number of schools in 2010 [Number of schools/population (millions)]	0.33	0.15
Income	Per capita income (million yen) in 2010	2.55	0.33
Unemployment	Unemployment rate in 2010 (%)	4.78	8.31
Population	Population (millions) in 2010	1.41	1.42

Notes: a. *School* is the number of kindergartens for 5-year-old children, of primary schools for children aged 6–11 years old, of junior high schools for children aged 12–14 years old, and of high schools for children aged 15–17 years old.

Table 4
Determinants of BMI based on full sample (OLS Model)

	(1)	(2)	(3)
	5–17 years old	5–11 years old	12–17 years old
Fukushima dummy	0.26***	0.25***	0.26***
	(7.09)	(5.57)	(5.24)
Iwate dummy	0.26***	0.28***	0.22***
	(7.95)	(8.57)	(3.87)
Miyagi dummy	0.25***	0.24***	0.25***
	(7.41)	(6.98)	(4.88)
2012 year dummy	–0.03***	–0.03***	–0.04**
	(–3.41)	(–2.81)	(–2.32)
5 years old dummy	Reference Group	Reference group	
6 years old dummy	0.30***	0.30***	
	(18.6)	(17.8)	
7 years old dummy	0.56***	0.56***	
	(34.3)	(34.2)	
8 years old dummy	1.04***	1.04***	
	(54.6)	(56.0)	
9 years old dummy	1.59***	1.59***	
	(73.4)	(77.4)	
10 years old dummy	2.13***	2.12***	
	(90.9)	(95.7)	
11 years old dummy	2.77***	2.77***	
	(127.7)	(126.1)	
12 years old dummy	3.65***		Reference group
	(164.5)		
13 years old dummy	4.13***		0.48***
	(146.3)		(17.3)
14 years old dummy	4.81***		1.16***
	(165.6)		(41.4)
15 years old dummy	5.67***		2.11***
	(213.2)		(56.3)
16 years old dummy	5.94***		2.38***
	(212.7)		(62.3)
17 years old dummy	6.16***		2.59***
	(213.2)		(63.1)
Male	0.06***	0.18***	–0.08***
	(5.86)	(16.4)	(–4.75)
School	0.48***	0.42***	0.94***
	(9.26)	(8.33)	(6.42)
Income	–0.05*	–0.04	–0.03
	(–1.72)	(–1.17)	(–0.60)
Unemployment	0.07***	0.07***	0.09***

	(8.96)	(7.83)	(5.90)
Population	–0.02***	–0.01**	–0.03***
	(–3.68)	(–2.26)	(–3.07)
Constant	15.0***	14.9****	18.4****
	(136.9)	(123.8)	(96.7)
Observations	2444	1316	1128
Adjusted R-square	0.98	0.95	0.90

Note: Numbers in parentheses are t-statistics, which are calculated based on robust standard errors. *, ** and ** indicate significance at 10, 5, and 1 percent levels, respectively.

Table 5
Determinants of BMI based on splitting sample into 2010 and 2012 (OLS Model)

	2010			2012		
	(1)	(2)	(3)	(4)	(5)	(6)
	5–17 years old	5–11 years old	12–17 years old	5–17 years old	5–11 years old	12–17 years old
Fukushima dummy	0.21***	0.11**	0.33***	0.31***	0.39***	0.19***
	(4.06	(2.21)	(4.37)	(6.12)	(7.02)	(3.20)
Iwate dummy	0.26***	0.30***	0.18***	0.27***	0.25***	0.25***
	(5.43)	(5.67	(2.63)	(5.78)	(6.87)	(2.83)
Miyagi dummy	0.25***	0.21***	0.30***	0.24***	0.27***	0.21***
	(5.52)	(5.61)	(3.80)	(4.97)	(4.69)	(3.21)
Observations	1222	658	564	1222	658	564
Adjusted R-square	0.98	0.95	0.89	0.98	0.95	0.91

Note: Numbers in parentheses are t-statistics, which are calculated based on robust standard errors. *, ** and ** indicate significance at 10, 5, and 1 percent levels, respectively. Apart from year dummy, the set of dependent variables is the same for Table 3, although their results are not reported to save space.

Table 6
Determinants of BMI based on full sample (OLS Model)

	Males		
	(1)	(2)	(3)
	5–17 years old	5–11 years old	12–17 years old
*Fukushima dummy * 2012 year dummy*	0.09	0.28***	-0.13
	(1.28)	(3.97)	(-1.44)
*Iwate dummy * 2012 year dummy*	0.01	-0.03	0.06
	(0.17)	(-0.52)	(0.58)
*Miyagi dummy * 2012 year dummy*	-0.01	0.06	-0.09
	(-0.17)	(0.96)	(-1.00)
Fukushima dummy	0.21***	0.11**	0.33***
	(4.17)	(2.39)	(4.54)
Iwate dummy	0.26***	0.30***	0.18***
	(5.66)	(5.81)	(2.86)
Miyagi dummy	0.35***	0.21***	0.30***
	(5.59)	(5.74)	(3.94)
2012 year dummy	-0.03***	-0.03***	-0.03**
	(-3.45)	(-3.27)	(-2.02)
Observations	2444	1316	1128
Adjusted R-square	0.98	0.95	0.90

Note: Numbers in parentheses are t-statistics, which are calculated based on robust standard errors. *, ** and ** indicate significance at 10, 5, and 1 percent levels, respectively. The set of dependent variables is the same for Table 3, although their results are not reported to save space.