Impact of the Fukushima nuclear accident on obesity of children in Japan, using data from 2008 to 2014.

Yamamura, Eiji

21 September 2015

Impact of the Fukushima nuclear accident on obesity of children in Japan, using data from 2008 to 2014.

Eiji Yamamura*

Department of Economics, Seinan Gakuin University, 6-2-92 Nishijin, Sawara-ku, Fukuoka 814-8511, Japan

---

*Corresponding author: Department of Economics, Seinan Gakuin University, 6-2-92 Nishijin, Sawara-ku Fukuoka 814-8511, Japan
E-mail address: yamaei@seinan-gu.ac.jp
Tel: +81 92 823 4543; Fax: +81 92 823 2506

ABSTRACT

This study uses prefecture-level panel data from Japan for the period 2008–2014 to investigate the influence of the 2011 Fukushima nuclear accident on the z-score of body mass index (BMI z-score) and obesity rates of children over time. A difference-in-differences approach was used to show that: (1) For cohorts aged between 5 and 7 years old in 2010, BMI z-score and obesity rates in disaster-damaged areas were higher than those in other areas, although this was not observed for other cohorts; (2) For cohorts aged between 5 and 7 years old in 2010, the influence of the accident persisted even after 3 years; and (3) The differences in BMI z-score and obesity rate before and after the accident were larger for Fukushima Prefecture than other damaged areas (Iwate and Miyagi prefectures). We infer that health-conscious parents, whose children had lower BMIs, may have moved from Fukushima, increasing the BMI z-score of the population of children living in Fukushima by around 0.05 for the cohort aged 5–7. The enforced reduction in physical activity increased the BMI z-score of children living in Fukushima by around 0.19 for the cohort.

1. Introduction

On March 11, 2011, Japan was struck by a large-scale natural disaster combining both an earthquake and tsunami. These damaged the Fukushima Daiichi nuclear plant located on the Fukushima coast in northeast Japan. A level-7 nuclear disaster rating was assigned, a level reached only once before, in the Chernobyl disaster. Inevitably, Fukushima's residents had to manage the danger of radiation exposure, and a number of people left the area (Japan Times, 2012; Matsuda et al., 2015).

The Great East Japan Earthquake and the Fukushima nuclear accident had a substantial impact on economic conditions (Ando and Kimura, 2012; Hayashi, 2012) and happiness levels (Uchida et al., 2014; Rehdanz et al., 2015; Yamamura et al., 2015) in Japan. According to media reports, the nuclear accident led to "a lack of physical exercise and stress stemming from prolonged living in shelters and restrictions on playing outside" (Yomiuri, 2012). Consequently, "an alarming trend toward obesity has been found among children in Fukushima Prefecture, which has the highest rate of obese children in every age group between 5 and 9 years old" (Yomiuri, 2012). Existing studies assessing other nuclear accidents such as Three Mile Island and Chernobyl provide evidence that nuclear accidents have both short-term and long-term detrimental effects on human lives[1]. However, little is known about how and to what extent the Fukushima accident has affected body mass index (BMI) z-score and changes in obesity rates. Overweight children are thought to have a higher risk of developing various diseases in the future. This raises the possibility that the Fukushima accident has indirectly influenced residents' health status through rising obesity. It is therefore valuable to assess the effect of the Fukushima accident on children's physical condition. This study draws on prefecture-level panel data covering 2008–2014 and uses a difference-in-differences approach to assess the long-term effect of the nuclear accident on the BMI z-score and obesity rate of children in Japan.

Section 2 of this paper provides an overview of the data and empirical method. Section 3 presents and discusses the major findings. The last section draws conclusions.

2. Data and methods

2.1. Data

The Japanese Ministry of Education, Culture, Sports, Science and Technology conducts an annual school health survey across the country. This survey collects data on the height, weight and obesity rate of school-aged children. There are 47

---

[1] The Chernobyl accident was found to reduce happiness levels (Danzer and Weisshaar, 2009) and the performance of the labor market in the Ukraine (Lehmann and Wadsworth, 2011). The effects of the accident have also been observed in other European countries. For instance, Germans were found to be more likely 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 produced poorer performances at secondary school (Almond et al., 2009). Other major disasters have been shown to influence the outcomes of elections and policies in the United States (Eisensee and Strömberg, 2007; Kahn, 2007).

prefectures in Japan and the ministry releases the average heights and weights for each prefecture[2]. Height and weight data are further broken down for boys and girls between the ages of 5 and 17.

This study used a difference-in-differences method. To test the validity of the method, it is necessary to conduct a systematic pre-trend test, requiring inclusion of data from several years before the accident. The data used in this paper therefore covered the period 2008–2014. The sample areas (those damaged in the 2011 disaster) were Fukushima, Iwate and Miyagi prefectures because the Great East Japan Earthquake directly hit those areas. Data from these three prefectures were not collected in 2011 because of the impact of the disaster. To assess the effect of the Fukushima accident on young children over time, we conducted estimations by cohort groups. The composition of the dataset used in this paper is shown in Table 1.

We used BMI as a measure of fatness. This measure is flawed because it ignores the distinction between fat and muscle (Burkhauser and Cawley, 2008), and so physical activity that builds muscle and burns fat will have an ambiguous effect on BMI. However, Cawley et al. (2013) argued that such this is less relevant for elementary school students, whose physical activity involves less muscle-building exercise and who are less prone than adolescents to adding muscle mass. Younger children are more likely to be influenced by circumstance than older ones, so we focused on children under 10 years of age. Data used in this analysis were divided into three cohort groups, those aged 5–7, 8–10, and 11–17 in 2010. In the same cohort, for instance, children who were aged 7 in 2010 were 9, 10 and 11 years old in 2012, 2013 and 2014. Separate data were available for boys and girls. The sample sizes were slightly different between cohorts because of data availability.

Average BMI values were calculated. These reflect the average level of overweight and obese children in each cohort but may be influenced by outliers in the sample. To control for this, earlier studies used BMI z-score, which is standardized by age-specific BMI averages (Cawley et al., 2013; Inokuchi et al., 2011). We therefore also calculated BMI z-score based on mean BMI values and standard deviations for each age (Inokuchi et al. 2007). The method of calculation of BMI z-score is shown in Table 2. As shown in Table 3, BMI z-score, unlike BMI, does not increase with age of children. Using BMI z-score therefore allows us to compare obesity rates between different age groups. We also assessed the obesity rate to determine the robustness of the BMI z-score data. The obesity rate is defined in Table 2. We focused on the BMI z-score and obesity rates from 2008 to 2014, and compared them between disaster-affected and other areas.

Figure 1 shows how the difference between the average BMI z-score in disaster-damaged and other areas for each cohort changed from 2008 to 2014. Throughout the period studied, the difference in z-score BMI was consistently larger than 0. This implies the average BMI z-score of children in disaster-damaged areas was higher than in other areas. For all cohorts, the difference decreased consistently from 2008 to 2010. After the accident, the difference in BMI z-score increased consistently from 2010 to 2014 for cohorts aged 5–7, unlike other cohorts. The difference in BMI z-score for the cohorts aged 8–10 was almost the same as that of the cohorts aged 11–17 in each of 2010, 2013 and 2014. The difference in BMI z-score declined from 2013 to 2014 for the cohorts aged 8–10 and 11–17. The value of the difference in 2014 was

---

[2] A Japanese prefecture is roughly equivalent to a state in the United States or a province in Canada.

around 0.18, which is lower than pre-accident levels. Figure 2 demonstrates the difference in obesity rate for each cohort. It clearly shows that differences in obesity rate after the accident were larger than those before for the cohorts aged 5–7. For the other cohorts, however, the difference in obesity rate in 2008 and 2009 was almost the same as in 2013 and 2014. Obesity rate and BMI show similar patterns.

Tables 4(a), (b) and (c) show the difference in BMI z-scores of children before and after the Fukushima accident in 2011 by comparing disaster-damaged and other areas for each cohort. Table 4(a) shows that after the accident, the average BMI z-score was significantly higher in children in both damaged and other areas. The difference between periods for damaged areas was 0.26, larger than for other areas (0.17). The difference between areas before the accident shows that the BMI z-score of children in damaged areas was higher than other areas. Fukushima, Iwate and Miyagi are considered rural areas. The above result is consistent with the finding that children's BMI z-scores are more likely to be high in rural areas than urban ones (Yamamura, 2012a). After the accident, the average BMI z-score of children living in damaged areas was higher (by 0.27) than for children in other areas. Tables 4(b) and 4(c) show the figures for older children, with statistically significant differences between damaged and other areas for both periods. BMI z-scores after the accident were not significantly higher for any groups. This suggests that the accident had no effect on BMI z-scores for older cohorts. For the robustness check, using an alternative proxy for degree of obesity, Tables 5(a), (b) and (c) show the difference in obesity rate before and after the Fukushima accident in 2011 by comparing disaster-damaged and other areas. These are similar to using BMI z-scores. These tables show that for the cohorts aged 5–7, there was a significant increase in obesity after the Fukushima accident in both damaged and other areas, although the effect was more pronounced in damaged areas than other areas. We suggest that a decrease in physical exercise as a consequence of the Fukushima accident resulted in an increase in BMI z-scores throughout Japan for younger children, with those closer to the accident site most affected. However, the accident is unlikely to be related to changes in obesity among older children.

2.2. Econometric framework to examine impact of the disaster

Table 2 shows the definition of the variables used in the estimation and the mean values and standard deviation for each cohort group. Table 2 shows that BMI increased with age of children. After standardizing BMI by age, values of z-score BMI were 0.53, 0.67 and 0.62 for cohorts aged 5–7, 8–10 and 11–17. Hence, the relationship between z-score BMI and age is not linear.

The estimated function therefore takes the following form:

BMI z-score (or Obesity rate) $_{itga}$ = α_1Damaged area $_i$ * 2012 year dummy $_t$ + α_2 Damaged area $_i$ * 2013 year dummy $_t$ + α_3Damaged area $_i$ * 2014 year dummy $_t$ + α_4Damaed area $_i$ + $\alpha_5$2012 year dummy $_t$ + $\alpha_6$2013 year dummy $_t$ + $\alpha_7$2014 year dummy $_t$ + α_8Male $_g$ + Y' $_{itga}$B $_{itga}$ + e_a + k_i + u_{itga},

where BMI z-score (or Obesity rate) $_{itga}$ represents the dependent variable in prefecture i, year t, sex g and cohort a. To control for the effects of years, year dummies were included and the reference group was 'before the accident' (2008, 2009 and 2010), reflecting conditions before the Fukushima accident in 2011.

Using data from 2008 to 2014 to scrutinize the effect of the Fukushima accident on the BMI z-score (or obesity rate) of children, changes in BMI z-scores (or obesity rate) after the accident were compared between disaster-damaged and other areas. A difference-in-differences approach was used to examine the impact of the disaster on children's BMI z-scores (or obesity rate). The interaction terms between *Damaged area* and *Year dummies* were key variables to examine the changing effect of the accident over time. The interaction terms show how and to what extent the BMI z-score or obesity rate is larger than in the base period (2008–2010). If the BMI z-score increased after the Fukushima accident and the effect was observed in 2012, the coefficient of *Damaged area $_i$ * 2012 year dummy $_t$* will be positive.

The three prefectures were damaged not only by the nuclear accident but also by the tsunami and earthquake themselves. It is therefore possible that any effect on obesity observed may be from the tsunami and earthquake, rather than the accident. Fukushima was most affected by the accident because of its proximity to the nuclear plant. We therefore divided damaged areas into 'Fukushima' and 'other'. The key variables here were cross terms between *Fukushima* and year dummies (for instance, *Fukushima $_i$ * 2012 year dummy $_t$*), and those between *Other damaged* and year dummies. Their coefficients were expected to be positive. If the influence on obesity was mainly from the accident, then the coefficients of cross terms will be larger for *Fukushima* than *Other damaged*.

Male is included to represent sex differences. The vectors of the control variables (including unemployment rate, per capita income, rate of expenditure for cooked food and expenditure for food) were denoted by Y $_{itga}$. Per capita income and unemployment rate capture economic conditions. BMI z-scores and obesity rates depend on calorific intake, but this could not be obtained. The Japanese statistics bureau defines cooked food as various fast food options, which are considered high-calorie. *Cooked* (percentage of food expenditure spent on cooked food) is therefore included to capture calorie intake. *Snack* (percentage of food expenditure spent on snack food) is also included to supplement this. The coefficients of *Cooked* and *Snack* are therefore expected to be positive. The regression parameters are denoted by a, and B is the vector of the regression parameters for the control variables. e_a represents cohort effects, which are controlled by including cohort dummies, k_i represents time invariant prefecture effects, which are controlled by the fixed effects model and the error term is denoted by u_{itga}.

2.3. Econometric framework to examine outward migration.

According to reports of Japan's National Police Agency, 18,404 people died or became untraceable in Fukushima, Iwate and Miyagi prefectures as a consequence of the Great East Japan disaster. It seems plausible that the nuclear accident give people an incentive to leave the area, reducing the population in the damaged area. This holds not only for adults but also children. To assess the change in the population, we used:

$$[1 - \{Population\ of\ students\ in\ (2010 + t\ year)/Population\ of\ students\ in\ 2010\} \times 100],$$

in the damaged area for each cohort by age in 2010. t is years that have passed since the accident.

The reference year was 2010, before the accident. Compared with the reference

year, the index suggests a decrease in the number of students after the accident. The left part of Table 6 shows cohorts aged 5–7 and 8–10 during the period 2010–2014. In Japan, compulsory education covers primary school and junior high school, from 5 to 14 years old. We were therefore unable to obtain data for the population aged over 15. This means that the decrease in 2014 could not be calculated for the cohort aged 11 in 2010, and changes were therefore not reported for any of the cohort aged 11–17. The upper part of Table 6 shows data for the whole damaged area, covering Fukushima, Iwate and Miyagi prefectures. There was a definite decrease in population, which was larger for the cohort aged 8–10 than for those aged 5–7. For cohorts aged 5–7, the decrease in 2011 was far larger than in later years, implying the impact of accident did not persist. For the cohort aged 8–10, however, the different between the years was small. After the sample was divided into Fukushima and other damaged areas, a clear difference between them was observed. For Fukushima, the decrease rate for the cohorts aged 5–7 was higher than for those aged8–10. The rate decreased steadily over time for cohorts aged 5–7 and cohorts aged 8–10. This implies that those who relocated to other prefectures later returned to Fukushima. In contrast to Fukushima, for other damaged areas, the rates were negative for the cohorts aged 5–7 but positive for those aged 8–10. This seems to imply that younger smaller children (aged 5–7) were evacuated from Fukushima to Iwate and Miyagi because Iwate and Miyagi were safer from nuclear leakage even though they had suffered from the tsunami and earthquake.

The decrease included not only those who left but also any deaths, which may be different in different areas. We therefore broke down the decrease into 'dead and missing' and 'migration'. The percentage dead and missing was calculated as:

$$\frac{\text{Number of dealths and missing persons}}{\text{total population in 2010}} \times 100 \ .$$

Unfortunately, because of lack of data, this rate cannot be calculated for each cohort. We therefore assumed that the dead and missing rate would be the same for all cohorts in a prefecture. The rate of dead and missing people across all damaged areas was 0.32, but broke down further into 0.09 for Fukushima and 0.45 for other damaged areas. This suggests that the death rate in Fukushima was much lower than elsewhere, even though the nuclear accident occurred there. This implies that the tsunami and earthquake were more likely to have caused deaths than the nuclear accident.

The outward migration rate was defined as "decrease minus the dead and missing rate". The larger the value, the larger the number of children relocated. Table 6 shows the outward migration rate, which was positive for both cohorts in Fukushima. The rate for the cohorts aged 5–7 was approximately twice as big as that for those aged 8–10. The outward migration rate in 2011 was 1.92 for those aged 5–7 and 0.92 for those aged 8–10. These values reduced steadily over time to 0.52 and 0.33 in 2014. In other damaged areas, the outward migration rate was negative for those aged 8–10 in 2011 and 2012, and became positive in 2013 and 2014. This suggests that in 2012 and 2013, children moved from Fukushima to other damaged areas, but returned to Fukushima in 2013 and 2014.

The Fukushima accident may have caused a substantial number of residents to relocate. Some may have chosen to move to safer regions (Yamamura et al., 2014). For example, if better educated parents with lower BMI children tend to migrate to other unaffected areas, the levels of obesity in the more damaged areas will go up.

This means it is necessary to take into account selective migration of health-conscious parents. The estimated function takes the following form:

$$\text{z-score BMI (or Obesity rate)}_{itga} = \beta_1 \text{Decrease}_{ita} * \text{Damaged area}_i + \beta_2 \text{Decrease}_{ita} + \alpha_8 \text{Male}_g + Y'_{itga} C_{itga} + e_a + k_i + u_{itga}.$$

In this equation, the reference year is 2010, where *Decrease* is 0. The decrease can be calculated for each age cohort *a*, in each prefecture *i* and in each year *t*. There were no data to assess changes in numbers of boys and girls[3]. The cross term *Decrease * Damaged area* were key variables to examine how the effect of *Decrease* on obesity is different from other areas. If health-conscious parents in damaged areas decided to move elsewhere, the cross term would be positive. Apart from the covering period and key variables, the control variables and estimation model (the fixed effects model) were the same as the function given earlier.

3. Results and Discussion

3.1. The impact of the disaster

Before interpreting the results of the regression estimations, we checked the validity of the difference-in-differences method. The assumption used to identify the treatment effect in difference-in-differences estimators is the Parallel Paths assumption. This states that the average change in outcome would have been the same for those treated, had the treatment not happened, as for those not treated. Testing for systematic pre-trends has also become standard to check the validity of the method (Mora and Reggio, 2012; 2014). The condition for this test is that the data must include more than one pre-treatment period. In this paper, there were three periods before the accident, 2008, 2009, and 2010, and three afterwards, 2012, 2013, and 2014. The results of the p-value of the Wald test for the Parallel Paths are shown in Table 7, and suggest that we cannot reject common pre-treatment dynamics, so the Parallel Paths assumption holds.

Tables 8 and 9 show the estimation results of the fixed effects model. In each table, columns (1) and (4) show the results for the cohorts aged 5–7, columns (2) and (5) show cohorts aged 8–10, and columns (3) and (6) cohorts aged 11–17. Columns (1)–(3) report results of key variables about the cross term between *Damaged area* and year dummies. In Columns (4)–(6), key variables are the cross term between year dummies and either *Fukushima* or *Other damaged*.

The positive and significant values in column (1) of Table 8 show that the effect of the Fukushima accident persisted throughout the 2012–2014 period for younger children. The other columns suggest that the accident had different effects on obesity in different age cohorts, with an increase in obesity seen in younger children, but a decrease in older children.

Column(4) of Table 8 shows that the accident therefore appears to have had a larger effect on BMI z-scores for children aged 5–7 years old living in Fukushima than in other damaged areas, although children in other damaged areas were also more likely to become obese after the accident. For children aged 8–10 years old, the

---

[3] Number of students of each sex in each cohort was available from 2010 to 2013, but not for 2014.

impact of the accident was observed in Fukushima but was smaller than for those aged 5–7 years old, and the effect was not seen in other damaged areas. The effect on BMI z-score is therefore larger for younger children living nearer to the Fukushima nuclear plants. The accident appears to have decreased BMI z-scores for young people aged 11–17 years old.

Unemployment was negative and statistically significant in all columns and *Ln(Income)* was not significant. This may be because low income households could not afford enough junk and snack food to increase the weight of their children. *Snack* was positive and significant for cohorts aged 5–7 and 8–10. We suggest that consumption of snack food increased obesity in younger children because it was added to three meals (breakfast, lunch and dinner), resulting in intake of excess calories. *Snack* was negative and significant for cohorts aged 11–17. One possible interpretation is that older children are less likely to spend time with their parents and eat meals with them than younger children, so less likely to eat three full meals. Instead, they tend to snack, reducing their intake of calories. *Male* was significant and positive only in columns (3) and (6). This indicates that for cohorts aged 11–17, boys have larger BMI z-scores than girls, but this difference is not seen in younger cohorts. This suggests that older boys' physical activity tended to involve more muscle-building exercise, which increased their BMI z-scores above that of their female peers.

As a whole, the results in Table 9 are very similar to those in Table 8. This indicates that the findings are robust when an alternative index of obesity (obesity rate) is used as the dependent variable. In summary, the results suggest that the accident had an effect on the obesity of children in the cohorts aged 5–7, that this effect endured over time, and that it was larger in Fukushima than in other damaged areas. We can derive from this that the effect was from the nuclear accident, rather than the tsunami and earthquake.

3.2. Effect of outward migration

Tables 10 and 11 show how population changes influenced BMI z-scores and obesity rate. Overall, outward migration from the damaged area had no effect (see Table 10). Once the damaged area is divided into Fukushima and Other areas, as shown in columns (3) and (4) of Table 10, however, the results changed. These findings suggest that the population decrease increased BMI z-score in Fukushima but not in other damaged areas. This may be because health-conscious parents, who therefore had healthier children with lower BMI, moved away from Fukushima after the nuclear accident, but not from other damaged areas. That is, they were responding directly to concerns about the degree of exposure to nuclear leaks. As mentioned earlier, the rate of dead and missing people in Fukushima was far smaller than in other damaged areas. This also suggests that a selective migration by health-conscious parents was triggered by the nuclear accident not by the natural disasters, even though the natural disasters caused a larger number of deaths.

For the two cohort groups aged 5–7 and 8–10, a 1% decrease in population of children led to an increase in BMI z-score of 0.058 and 0.089. Similar effects are shown for obesity rate. The outward migration effect can be calculated as:

Effect of outward migration on obesity $=$ (Coefficient of *Fukushima* $*$ *Decrease*) $\times$ outward migration rate

9

The effects of outward migration on BMI z-score and obesity rate were calculated from figures in Table 6 and reported in Tables 12(a) and 12(b). As the outward migration effect was only seen in Fukushima, only this area is shown.

The effects of the disaster can be broken down into outward migration and "other effects". In this paper, we assume that "other effects" is chiefly the effect of lack of physical activity, which can therefore be calculated as:

Effect of lack of physical activity
$$= \text{Ceofficient of } Fukushima * year \; dummy - \text{outward migration effect}$$

The outward migration effect was not observed for *Damaged areas* and *Other damaged areas*, so in Tables 12(a) and (b), the coefficients in Tables 8 and 9 are reported as effect of lack of physical activity when they are statistically significant. Table 12(a) shows that for the cohorts aged 5–7, the effect of lack of physical activity increased over time, not only for Fukushima but also for other damaged areas, whereas the outward migration effect decreased from 2012 to 2014. Lack of physical activity had more than twice as large an effect on BMI z-score in Fukushima than in other damaged areas. Compared with the cohorts aged 8–10, lack of physical activity had an effect four or five times larger on BMI z-score for the cohorts aged 5–7. For the cohorts aged 8–10, the outward migration effect was almost the same as the effect of lack of physical activity. Table 12(b) shows the results are similar when obesity rate is the dependent variable, meaning that the results are robust. It seems likely that those who left Fukushima gradually returned over time and so the outward migration effect declined. However, lack of physical activity continued, and has a persistent and growing effect for younger children.

3.3. Discussion

Our results suggest that the Fukushima accident increased BMI z-scores for children younger than 10, and decreased them for children of 11 and over. This may suggest that a decrease in physical activity increases fat in young children because physical activity does not build muscle. For older children, physical activity may lead to increased muscle bulk, burning fat, and therefore increasing BMI. In other words, physical activity has opposite effects on BMI in younger and older children. The total effect of physical activity depends on whether the effect of building muscle is larger than that of burning fat. Reduction in physical activity reduces muscle and increases fat. Our results show the former effect is larger than the latter, resulting in a reduction in BMI z-score. This suggests that BMI z-score is unlikely to suffer a measurement error and so is reliable in this paper.

Literature on Chernobyl has never found any strong significant effects on physical activity (Lehmann and Wadsworth, 2011). The Soviet Union, however, could control information about the accident and so those who lived near to the Chernobyl nuclear plant were not given the necessary information to change their activity levels. This might be one of the reasons why the accident did not have any obvious physical effects on BMI. In Japan, however, people can obtain information from multiple sources, including the internet. The Japanese government could not control information about the accident and so people's physical activity changed in

response[4].

Cawley et al. (2013) indicated that time spent on physical education in primary school reduces the BMI z-score. The findings of our study are consistent with those of Cawley et al. (2013) although we did not directly examine the effects of the time spent on physical activity. Cawley et al. (2013) used instruments to control for the endogeneity bias of time spent on physical activity, and provided strong evidence. The advantage of our paper is that the occurrence of a natural disaster and nuclear accident can be considered as an exogenous event. Although tsunami and earthquakes tend to occur in the north east part of Japan, the unobserved time invariant feature has been controlled by the fixed effects estimations. Hence, the accident is unlikely to cause any endogeneity bias even though instruments were not used.

We suggest that our results support an argument that in response to the nuclear accident in Fukushima, outdoor exercise was restricted for children. As a consequence, younger primary school children could not burn calories. This had a greater effect on younger children than older ones. One policy implication from our findings is the importance of promoting physical exercise for younger children to help develop good habits and maintain proper weight and good health in the future.

4. Conclusion

The Great East Japan Earthquake and linked tsunami affected the people living in the north east parts of Japan, particularly Fukushima, Iwate and Miyagi prefectures. It caused a massive radiation leak from the Fukushima nuclear plant. Radiation leaks influence human behavior because exposure to radiation has a detrimental effect on health. After the earthquake, in the affected areas, schools and parents prevented children from playing outside because of the risk of radiation exposure (Yomiuri 2012). A decrease in outdoor exercise is thought to reduce calorie burn-off, causing an increase in BMI z-score and obesity (Yomiuri 2012). The impact of the accident on BMI z-scores and obesity rates was expected to differ between damaged areas and other areas in Japan. By employing a difference-in-differences approach, this study investigated the long-term impact of the Fukushima accident on children's BMI z-scores.

Using prefecture-level panel data from Japan for the period 2008–2014, this study investigated how the 2011 Fukushima nuclear accident affected the BMI z-score (and obesity rate) of children aged 5–7 in 2010 and whether its effect changed over time. A difference-in-differences approach was used to show that for cohorts aged between 5 and 7 years old, BMI z-score and obesity rates in disaster-damaged areas were higher than those in other areas, although this was not seen for other cohorts. For cohorts aged between 5 and 7 years old, the influence of the accident persisted even after 3 years. For cohorts aged between 8 and 10 years old, this tendency was seen in Fukushima Prefecture, but not in the wider damaged area. The impact of the accident was also larger for cohorts aged between 5 and 7 than for those aged between 8 and 10. We infer that health-conscious parents with lower BMI children probably moved out of Fukushima, increasing the levels of obesity seen in Fukushima. This effect was, however, far smaller than the effect of lack of physical

---

[4] In various countries, sufficient information is provided by free media for peer views to play an important role in forming individual opinions about nuclear energy (Yamamura, 2012b).

activity.

These findings suggest that restrictions placed on outdoor exercise as a result of the nuclear accident in Fukushima prevented younger primary school children from burning calories. These children developed a habit of inactivity, leading to persistently higher BMI z-scores than before the accident. This was not the case for older children. This suggests it may be important for young children to get enough physical exercise to maintain a proper weight and enjoy good health in the future. However, in this paper, we did not use individual-level data and so cannot examine data more closely. We also did not examine a proxy for degree of physical activity although we argue that the increase in obesity is probably due to reduction in physical activity. To check that this is genuinely the case, it would be necessary to use individual level panel data. Future studies should also use individual level data, and control for access to healthy food and time spent by parents with children, as this changes children's activity levels（Wronka and Pawlinska-Chmar 2007; Yaniv et al. 2009）. Because of the lack of data, these factors were not considered in this study, which may have caused omitted variables bias.

References

Almond, D., Edlund, L., Palme, M., 2009. Chernobyl's subclinical legacy: pre-natal exposure to radioactive fallout and school outcomes in Sweden. Quarterly Journal of Economics 124(4), 1729-1772.

Ando, M., Kimura, F., 2012. How did the Japanese exports respond to two crisis in the international production networks? The global financial crisis and the Great East Japan earthquake. Asian Economic Journal 26(3), 261-287.

Berger, E.M. 2010. The Chernobyl disaster, concern about the environment and life satisfaction. Kyklos 63, 118.

Burkhauser, R.V. and Cawley, J., 2008. Beyond BMI: the value of more accurate measure of fatness and obesity in social science research. Journal of Health Economics 27(2), 519-529.

Cawley, J., Fisvold, D. and Meyerhoefer, C., 2013. The impact of physical education on obesity among elementary school children. Journal of Health Economics 32(4), 743-755.

Danzer A., Weisshaar, N., 2009. The long run consequences of the Chernobyl catastrophe on subjective well-being and its set-point. Evidence from two Ukrainian data sets. Working Paper, WPEG Conference.

Eisensee, T., Strömberg, D., 2007. News droughts, news floods, and U.S. disaster relief. Quarterly Journal of Economics 122(2), 693-728.

Hayashi, T., 2012. Japan's post-disaster economic reconstruction: from Kobe to Tohoku. Asian Economic Journal 26(3), 189-210.

Inokuchi, M., Matsuo, N., Anzo, M., Hasegawa, T., 2007. Body mass index reference values (mean and SD) for Japanese children. Acta Paediatrica 96(11), 1674-1676.

Inokuchi, M., Matsuo, N., Takayama, J.I., Hasegawa, T., 2011. BMI z-score is the optimal measure of annual adiposity change in elementary school children. Annals of Human Biology 38(6), 747-751.

Japan Times, 2012. The Japan Times Special Report. 3.11 one year on: a chronicle of Japan's road to recovery. Tokyo: The Japan Times.

Kahn, M., 2007. Environmental disasters as risk regulation catalysts? The role of Bhopal, Chernobyl, Exxon Valdez, love canal, and Three Mile Island in shaping U.S. environmental law. Journal of Risk and Uncertainty 35(1), 17-43.

Lehmann, H., Wadsworth, J., 2011. The impact of Chernobyl on health and labour market performance. Journal of Health Economics 30(5), 843-857.

Matsuda, Y., Kawasaki, K., Hashimoto, S., Tsuga, T., Kino, T., Yoshida, C., Oshiro, S., Fukuda, K., Eguchi, T. ., 2015. White paper of evacuation from the nuclear accident (in Japanese). (Gempatsu Hinan Hakusho. Jinbun Shoin Publishing: Tokyo.

Mora, R., Reggio, I., 2012. Treatment effect identification using alternative parallel assumptions. Economics Working Papers we1233, Universidad Carlos III de Madrid, Departamento de Economía.

Mora, R., Reggio, I., 2014. dqd: A command for treatment effect estimation under alternative assumptions. Economics Working Papers we1407, Universidad Carlos III de Madrid, Departamento de Economía.

Rehdanz, K., Welsch, H., Narita, D., Okubo, T., 2015. Well-being effects of a major natural disaster: the case of Fukushima. Journal of Economic Behavior & Organization 116, 500-517.

Uchida, Y., Takahashi, Y., Kawahara, K., 2014. Changes in hedonic and eudaimonic well-being after a severe nationwide disaster: the case of the Great East Japan Earthquake. Journal of Happiness Studies 15(1), 207-221.

Wronka, I., Pawlinska-Chmara, R. 2007. Childcare, height and BMI among female Polish university students, 2005. Economics and Human Biology 5 (3), 435-442.

Yamamura, E., 2012a. Influence of body image in urbanized areas: differences in long-term changes in teenage body mass index between boys and girls in Japan. Journal of Bioeconomics 14(3), 243-256.

Yamamura, E., 2012b. Effect of free media on views regarding nuclear energy after the Fukushima accident. Kyklos 65(1), 132-141.

Yamamura, E., Tsutsui, Y., Yamane, C., Yamane, S., 2014. Effect of major disasters on geographical mobility intentions: the case of the Fukushima nuclear accident. ISER Discussion Paper 0903, Institute of Social and Economic Research, Osaka University, Osaka.

Yamamura, E., Tsutsui, Y., Yamane, C., Yamane, S., Powdthavee, N. 2015. Trust and happiness: comparative study before and after the Great East Japan Earthquake. Social Indicators Research, forthcoming.

Yaniv, G., Rosin, O., Tobol, Y. 2009. The effect of the fat tax and the thin subsidy. Journal of Public Economics 93(5-6), 823-830.

Yomiuri, 2012. Obesity rising for Fukushima kids / 5- to 9-year-olds show highest rates of obese children across the nation. Yomiuri, December 27, 2012.
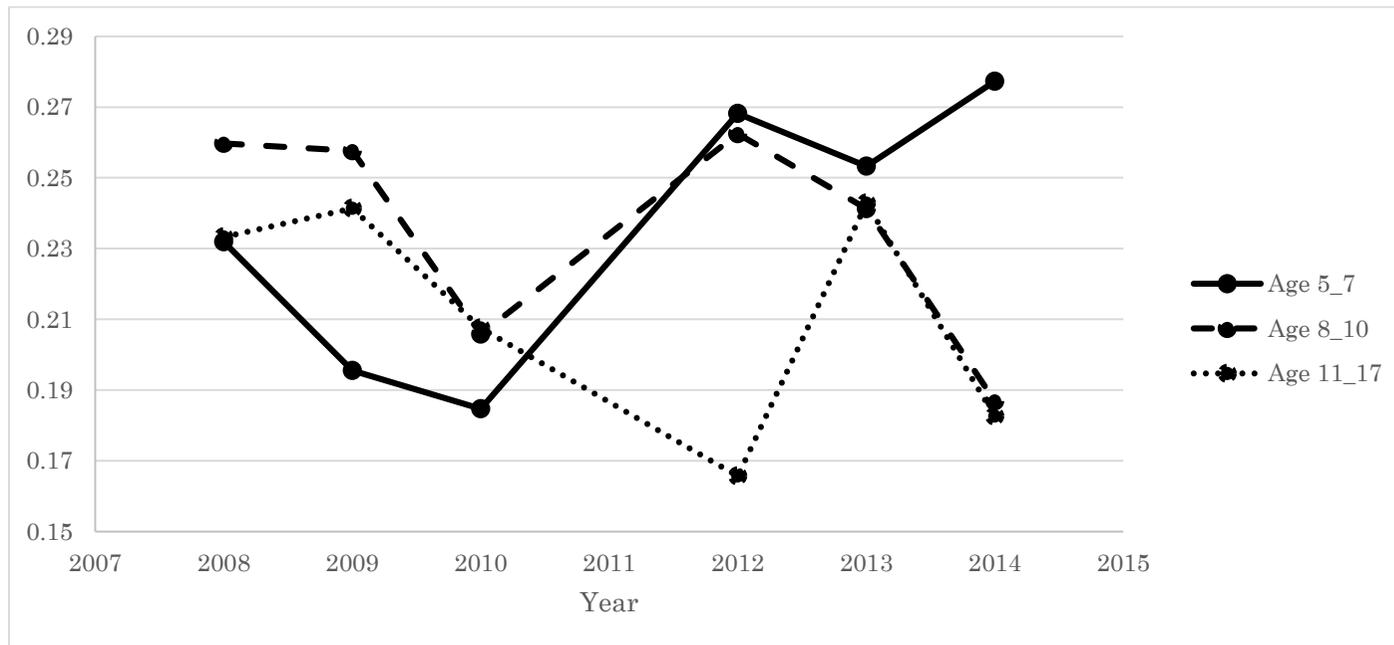
Figure 1. Difference in average BMI between children from damaged and other areas for each cohort
Note: Cohorts denote the children's ages in 2010.
The difference in average BMI is calculated using the following formula for each year:
(Average value of BMI z-score for children from damaged areas – Average value of BMI z-score for children from other areas).
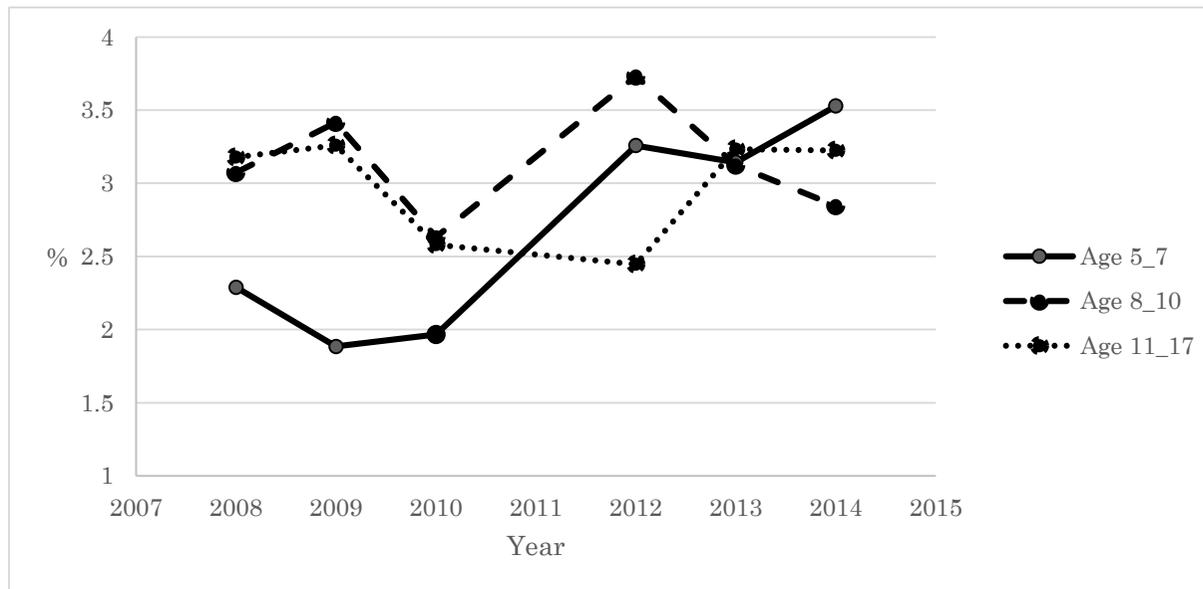
Figure 2. Difference in obesity rate between children from damaged and other areas for each cohort (%)

Note: Cohorts denote the children's ages in 2010.

Table 1. Data structure (showing the number of data units)

	Prefectures	Years [a] (2008–2014)	Sex (male and female)	Cohorts[b]	Observations
Ages 5–7 in 2010	47	6	2	3	1,410
Ages 8–10 in 2010	47	6	2	3	1,692
Ages 11–17 in 2010	47	6	2	6	3,384

Note: Prefectures × Years × Sex × Cohorts = Total observations

a. Data for 2011 were unavailable.
b. In the group aged 5–7 in 2010, data were unavailable for 2008 and 2009 for the cohort aged 5 in 2010 and for 2008 for the cohort aged 6 in 2010. In the group aged 11–17 in 2010, data were unavailable for 2012, 2013 and 2014 for the cohort aged 17 in 2010 and so cannot be used to check differences before and after the disaster. The cohort aged 17 in 2010 was therefore excluded. Data were also unavailable for 2013 and 2014 for the cohort aged 16 in 2010, and for 2014 for the cohort aged 15 in 2010.

Table 2. Basic statistics of variables used in the estimation and its mean values and standard deviations according to each sub-sample.

Variables	Definition	(1) Ages 5–7 in 2010 Mean (SD)	(2) Ages 8–10 in 2010 Mean (SD)	(3) Ages 11–17 in 2010 Mean (SD)
BMI Z score [a, b]	z-score of body mass index, calculated by using the formula: $$\frac{Measured\ value - Average\ value\ in\ the\ reference\ population}{Standard\ deviation\ of\ the\ reference\ population}$$	0.53 (0.26)	0.67 (0.17)	0.62 (0.19)
BMI [a]	Body mass index	16.4 (0.87)	17.7 (1.38)	20.1 (1.33)
Obesity rate [a]	Obesity rate (%) A child is considered obese if the following value is larger than 20: $$\frac{(Weight - Standard\ weight\ in\ each\ height)}{Standard\ weight\ in\ each\ height} \times 100$$ Obesity rate is the percentage of obese children in each age group.	6.61 (0.89)	8.48 (2.64)	9.90 (2.68)
2012 year dummy	1 if 2012, otherwise 0	---	---	---
2013 year dummy	1 if 2013, otherwise 0	---	---	---
2014 year dummy	1 if 2014, otherwise 0	---	---	---
Damaged area	1 if Fukushima, Iwate or Miyagi prefectures, otherwise 0	---	---	---
Fukushima	1 if Fukushima prefecture, otherwise 0	---	---	---
Other damaged	1 if Iwate or Miyagi prefectures, otherwise 0	---	---	---
Ln(Income) [c]	Log of Per capita income (million yen)	7.90 (0.14)	7.90 (0.14)	7.91 (0.14)
Unemployment [d]	Unemployment rate (%)	4.41 (0.95)	4.38 (0.95)	4.31 (0.98)

Snack [e]	Expenditure on snack food as a percentage of total food spend (%)	8.99	8.95	8.91
	(Annual Expenditure on snack food per household	(0.59)	(0.59)	(0.60)
	/annual total expenditure on food per household)			
Cooked [e]	Expenditure on cooked food as a percentage of total food spend (%)	11.5	11.4	11.3
	(Annual Expenditure on cooked food per household	(0.90)	(0.91)	(0.92)
	/annual total expenditure on food per household)			
Male	1 if male, otherwise 0	---	---	---
Decrease [f]	Change in population of children (%).	0.13	0.38	---
	$[1 - \{Population\ of\ students\ in\ (2010 + t\ year)/Population\ of\ students\ in\ 2010\} \times 100]$	(0.61)	(1.07)	

Note: Values in parentheses are standard deviation. Sample of *Decrease* covers the period 2010–2014.

Sources of data are:

a. Children's heights and weights from the Report on School Basic Survey, which 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 May 10, 2015).

b. Mean values and standard deviations for Japanese BMIs from Inokuchi et al. (2007).

c. Per capita income data from 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 May 10, 2015).

d. Unemployment rates from 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 May 10, 2015).

e. Percentage of expenditure on cooked food, snack food and food expenditure from 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?lid=000001064772 (accessed May 10, 2015).

f. Numbers of children from the Report on School Basic Survey, 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=000001061932&cycode=0, (accessed September 1, 2015).

Table 3. Comparison between BMI and z-score of BMI by age

Age	BMI	z-score of BMI
5	15.5	0.12
6	15.7	0.44
7	16.0	0.57
8	16.5	0.72
9	17.0	0.75
10	17.6	0.67
11	18.2	0.68
12	19.1	0.76
13	19.6	0.62
14	20.2	0.60
15	21.0	0.67
16	21.3	0.56
17	21.5	0.51

Table 4 (a). Mean difference test for z-score of BMI between children from damaged and other areas for cohorts aged 5–7 in 2010.

	Before accident (1)	After accident (2)	Difference in BMI (2)−(1)	Absolute t-values
Damaged (I)	0.55	0.82	0.26	3.89***
Other (II)	0.37	0.55	0.17	10.3***
Difference in BMI z-score (I)−(II)	0.18	0.27		
Absolute t-values	3.07***	8.86***		

Note: *** significant at the 1% level.

Table 4 (b). Mean difference test for z-score of BMI between children from damaged and other areas for cohorts aged 8–10 in 2010.

	Before accident (1)	After accident (2)	Difference in BMI (2)−(1)	Absolute t-values
Damaged (I)	0.91	0.88	−0.02	0.68
Other (II)	0.70	0.64	−0.06	5.52***
Difference in BMI z-score (I)−(II)	0.20	0.24		
Absolute t-values	5.20***	13.5***		

Note: *** significant at the 1% level.

Table 4 (c). Mean difference test for z-score of BMI between children from damaged and other areas for cohorts aged 11–17 in 2010.

	Before accident (1)	After accident (2)	Difference in BMI (2)−(1)	Absolute t-values
Damaged (I)	0.82	0.83	0.01	0.21
Other (II)	0.61	0.61	−0.01	0.68
Difference in BMI z-score (I)−(II)	0.20	0.21		
Absolute t-values	6.92***	14.9***		

Note: *** significant at the 1% level

Table 5 (a). Mean difference test for obesity rate (%) between children from damaged and other areas for cohort ages 5–7 in 2010.

	Before accident (1)	After accident (2)	Difference in obesity rate (2)−(1)	Absolute t-values
Damaged(I)	6.38	10.4	4.09	4.31***
Other(II)	4.41	6.91	2.49	12.4***
Difference in obesity rate (I)−(II)	1.96	3.56		
Absolute t-values	3.85***	9.35***		

Note: *** significant at the 1% level.

Table 5 (b). Mean difference test for obesity rate (%) between children from damaged and other areas for cohort ages 8–10 in 2010.

	Before accident (1)	After accident (2)	Difference in obesity rate (2)−(1)	Absolute t-values
Damaged(I)	11.1	11.4	0.36	0.52
Other(II)	8.48	8.24	−0.24	1.42
Difference in obesity rate (I)−(II)	2.63	3.23		
Absolute t-values	4.43***	11.6***		

Note: *** significant at the 1% level.

Table 5 (c). Mean difference test for obesity rate (%) between children from damaged and other areas for cohort ages 11–17 in 2010.

	Before accident (1)	After accident (2)	Difference in obesity rate (2)−(1)	Absolute t-values
Damaged(I)	12.2	12.8	0.58	1.38
Other(II)	9.64	9.72	−0.08	0.69
Difference in obesity rate (I)−(II)	2.57	3.08		
Absolute t-values	6.28***	15.2***		

Note: *** significant at the 1% level

Table 6. Changes in population of children and outward migration rate (%)

Damaged area

	Decrease		Outward migration rate	
	Age 5–7 in 2010	Age 8–10 in 2010	Age 5–7 in 2010	Age 8–10 in 2010
2010	0	0	0	0
2011	0.48	0.47	0.16	0.15
2012	0.16	0.52	−0.16	0.20
2013	0.02	0.59	−0.30	0.27
2014	0.11	0.52	−0.21	0.20

Fukushima

	Decrease		Outward migration rate	
	Age 5–7 in 2010	Age 8–10 in 2010	Age_5–7 in 2010	Age 8–10 in 2010
2010	0	0	0	0
2011	2.24	1.24	1.92	0.92
2012	1.67	1.04	1.35	0.72
2013	1.20	0.81	0.88	0.49
2014	0.84	0.65	0.52	0.33

Other damaged areas

	Decrease		Outward migration rate	
	Age 5–7 in 2010	Age 8–10 in 2010	Age 5–7 in 2010	Age 8–10 in 2010
2010	0	0	0	0
2011	−0.41	0.08	−0.73	−0.24
2012	−0.59	0.27	−0.91	−0.05
2013	−0.57	0.47	−0.89	0.15
2014	−0.25	0.45	−0.57	0.13

Note: Outward migration rate is "decrease − death rate". "Death rate" was "number of deaths (and missing people) in each prefecture / total population in each damaged prefecture in 2010". Deaths (and missing people) data used in this paper were obtained from the website of the National Police Agency of Japan, http://www.npa.go.jp/archive/keibi/biki/higaijokyo.pdf (accessed September 1, 2015). Missing people are those who were untraceable after the Great East Japan earthquake but whose body has not been found. They consisted of about 10% of the total number of dead and missing.

Population data used in this paper were obtained from the website of the Statistics Bureau, Ministry of Internal Affairs and Communications http://www.stat.go.jp/data/kokusei/2010/index.htm (accessed September 1, 2015).

Table 7. Test of pre-trend

H₀: Common Pre-dynamics	(1) Age 5–7 in 2010	(2) Age 8–10 in 2010	(3) Age 11–17 in 2010
BMI z-score	0.73	0.51	0.63
Obesity rate	0.67	0.64	0.40

Note: Sample period is from 2008 to 2014. Treatment period is from 2012 to 2014. Numbers in Table show p-value.

Table 8. Determinants of BMI z-score (fixed effects model)

	(1) Age 5–7 in 2010	(2) Age 8–10 in 2010	(3) Age 11–17 in 2010	(4) Age 5–7 in 2010	(5) Age 8–10 in 2010	(6) Age 11–17 in 2010
Damaged area *2012 year dummy	0.10** (2.37)	0.03 (0.54)	−0.06*** (−2.98)			
Damaged area *2013 year dummy	0.12*** (2.86)	0.01 (0.24)	−0.01 (−0.42)			
Damaged area *2014 year dummy	0.11*** (3.71)	−0.04 (−0.86)	−0.05** (−2.16)			
Fukushima *2012 year dummy				0.20*** (11.2)	0.09*** (11.7)	−0.09*** (−9.79)
Fukushima *2013 year dummy				0.23*** (9.47)	0.09*** (8.70)	0.05*** (3.79)
Fukushima *2014 year dummy				0.20*** (6.79)	0.06*** (3.70)	−0.11*** (−4.94)
Other damaged *2012 year dummy				0.05** (2.16)	−0.001 (−0.02)	−0.04* (−1.95)
Other damaged *2013 year dummy				0.07*** (7.14)	−0.02 (−0.67)	−0.04*** (−3.15)
Other damaged *2014 year dummy				0.08*** (7.17)	−0.10* (−1.96)	−0.02** (−2.42)
2008 -2011year dummy		<Reference>				
2012 year dummy	0.40*** (19.1)	0.06 (0.31)	−0.10*** (−5.47)	0.41*** (18.6)	0.01 (0.66)	−0.10*** (−5.36)
2013 year dummy	0.43*** (25.3)	−0.01 (−0.41)	−0.13*** (−7.66)	0.43*** (24.3)	−0.001 (−0.09)	−0.14*** (−7.51)
2014 year dummy	0.38*** (24.5)	−0.04** (−2.47)	−0.17*** (−9.31)	0.39*** (23.1)	−0.03** (−2.15)	−0.17*** (−9.13)
Ln(Income)	0.05 (0.39)	−0.07 (−0.53)	−0.06 (−0.46)	0.09 (0.63)	−0.01 (−0.11)	−0.08 (−0.59)

Unemployment	−0.05***	−0.01*	−0.01***	−0.05***	−0.01*	−0.01***
	(−6.54)	(−1.74)	(−3.36)	(−6.46)	(−1.72)	(−3.41)
Cooked	−0.004	−0.01	0.01**	−0.01	−0.01**	0.01*
	(−0.31)	(−1.52)	(2.08)	(−0.60)	(−2.19)	(1.97)
Snack	0.08***	0.03***	−0.05***	0.08***	0.03***	−0.05***
	(6.41)	(3.91)	(−5.49)	(6.56)	(3.98)	(−5.49)
Male	−0.01	0.001	0.14***	−0.01	0.001	0.14***
	(−0.79)	(0.08)	(20.3)	(−0.78)	(0.08)	(20.2)
Observations	1410	1692	3384	1410	1692	3384
R-squared	0.70	0.14	0.39	0.63	0.07	0.39

Note: Cohort dummies were considered as time invariant variables and controlled via a fixed effects model. Prefecture dummies were included but their results are not reported. Numbers in parentheses are t-statistics calculated using robust standard errors clustered at the prefecture level. *, ** and *** indicate significance at the 10%, 5% and 1% level.

Table 9. Determinants of obesity rate (fixed effects model)

	(1) Age 5–7 in 2010	(2) Age 8–10 in 2010	(3) Age 11–17 in 2010	(4) Age 5–7 in 2010	(5) Age 8–10 in 2010	(6) Age 11–17 in 2010
Damaged area *2012 year dummy	1.98** (2.24)	0.83 (1.06)	−0.55 (−1.48)			
Damaged area *2013 year dummy	2.23*** (2.94)	0.36 (0.50)	0.09 (0.26)			
Damaged area *2014 year dummy	2.58*** (3.71)	0.04 (0.06)	0.19 (1.33)			
Fukushima *2012 year dummy				4.28*** (23.6)	1.79*** (11.3)	−0.90*** (−7.69)
Fukushima *2013 year dummy				4.17*** (15.9)	2.06*** (9.09)	0.93*** (5.99)
Fukushima *2014 year dummy				4.14*** (13.1)	2.05*** (6.23)	0.16 (0.57)
Other damaged *2012 year dummy				0.90*** (6.49)	0.39 (0.36)	−0.36 (−0.74)
Other damaged *2013 year dummy				1.35*** (5.12)	−0.41 (−0.90)	−0.32** (−2.40)
Other damaged *2014 year dummy				1.88*** (3.28)	−0.86 (−1.38)	0.21 (1.35)
2008 -2011year dummy		<Reference>				
2012 year dummy	3.94*** (14.4)	2.19*** (6.93)	−0.43* (−1.78)	4.05*** (14.8)	2.31*** (7.36)	−0.42* (−1.68)
2013 year dummy	5.03*** (20.4)	2.01*** (8.29)	−0.33 (−1.50)	5.11*** (20.6)	2.11*** (8.84)	−0.32 (−1.42)
2014 year dummy	5.49*** (22.3)	1.39*** (6.33)	0.04 (0.21)	5.59*** (22.5)	1.49*** (6.89)	0.05 (0.25)
Ln(Income)	3.48* (1.70)	1.43 (0.77)	0.50 (0.29)	4.22** (2.04)	2.40 (1.31)	0.48 (0.27)

Unemployment	−0.38***	−0.21*	−0.13*	−0.37***	−0.21*	−0.13*
	(−3.73)	(−1.85)	(−1.88)	(−3.60)	(−1.85)	(−1.92)
Cooked	0.01	−0.12	−0.01	−0.05	−0.19	−0.02
	(0.12)	(−0.87)	(−0.20)	(−0.38)	(−1.37)	(−0.33)
Snack	0.77***	1.02***	−0.37***	0.79***	1.02***	−0.37***
	(5.15)	(6.61)	(−3.20)	(5.17)	(6.74)	(−3.22)
Male	0.85***	1.19***	2.22***	0.87***	1.19***	2.22***
	(7.39)	(13.3)	(22.3)	(7.37)	(13.1)	(22.3)
Observations	1410	1692	3384	1410	1692	3384
R-squared	0.63	0.34	0.30	0.63	0.34	0.30

Note: Cohort dummies were considered as time invariant variables and controlled via a fixed effects model. Prefecture dummies were included but their results are not reported. Numbers in parentheses are t-statistics calculated using robust standard errors clustered at the prefecture level. *, ** and *** indicate significance at the 10%, 5% and 1% level.

Table 10. Determinants of BMI z-score (fixed effects model)

	(1) Age 5–7 in 2010	(2) Age 8–10 in 2010	(3) Age 5–7 in 2010	(4) Age 8–10 in 2010
Damaged area * Decrease	0.004 (0.14)	−0.002 (−0.85)		
Fukushima* Decrease			0.058*** (3.22)	0.089*** (9.23)
Other damaged* Decrease			0.025 (1.14)	0.054 (1.35)
Decrease	0.0001 (0.02)	0.002 (0.06)	0.0003 (0.05)	−0.001 (−0.74)
Observations	1128	1410	1128	1410
R-squared	0.46	0.12	0.46	0.13

Note: Control variables reported in Table 7 are also included. Cohort dummies were considered as time invariant variables and controlled via a fixed effects model. Prefecture dummies were included but these results are not reported. Numbers in parentheses are t-statistics calculated using robust standard errors clustered at the prefecture level. *, ** and *** indicate significance at the 10%, 5% and 1% level.

Table 11. Determinants of obesity rate (fixed effects model)

	(1)	(2)	(3)	(4)
	Age	Age	Age	Age
	5–7 in 2010	8–10 in 2010	5–7 in 2010	8–10 in 2010
Damaged area *	0.21	0.42		
Decrease	(0.30)	(0.98)		
Fukushima*			1.16***	1.58***
Decrease			(3.94)	(11.7)
Other damaged*			0.33	0.05
Decrease			(0.56)	(1.23)
Decrease	0.23	0.04	0.23	0.05
	(1.35)	(0.98)	(1.37)	(1.03)
Observations	1128	1410	1128	1410
R-squared	0.45	0.12	0.45	0.24

Note: Control variables reported in Table 7 are also included. Cohort dummies were considered as time invariant variables and controlled via a fixed effects model. Prefecture dummies were included but these results are not reported. Numbers in parentheses are t-statistics calculated using robust standard errors clustered at the prefecture level. *, ** and *** indicate significance at the 10%, 5% and 1% level.

Table 12 (a). Decomposition of the accident effect on BMI z-score

	Lack of physical activity	Outward migration	Lack of physical activity	Outward migration
Damaged Area*2012	0.10	----	----	----
Damaged Area*2013	0.12	----	----	----
Damaged Area*2014	0.10	----	----	----
Fukushima*2012	0.12	0.08	0.03	0.06
Fukushima *2013	0.19	0.05	0.05	0.04
Fukushima *2014	0.20	0.03	0.03	0.03
Other damaged *2012	0.05	----	----	----
Other damaged *2013	0.07	----	----	----
Other damaged *2014	0.08	----	----	----

Table 12 (b). Decomposition of the accident effect on obesity rate (%)

	(1) Age 5–7 in 2010		(2) Age 8–10 in 2010	
	Lack of physical activity	Outward migration	Lack of physical activity	Outward migration
Damaged Area*2012	1.98	----	----	----
Damaged Area*2013	2.23	----	----	----
Damaged Area*2014	2.58	----	----	----
Fukushima*2012	2.71	1.57	0.65	1.44
Fukushima *2013	3.15	1.02	1.29	0.77
Fukushima *2014	3.54	0.60	1.53	0.52
Other damaged *2012	0.90	----	----	----
Other damaged *2013	1.35	----	----	----
Other damaged *2014	1.88	----	----	----