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Infant mortality after Fukushima

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After the Fukushima nuclear disaster in March 2011, infant mortality in 7 prefectures near Fukushima is significantly increased in 2012. A bell-shaped excess is found with a maximum in May 2012 which might be caused by the consumption of contaminated food, harvested in autumn 2011.

Background

The present work is an update of my study published in *Strahlentelex*, February 2014 [1]. The study compared infant mortality rates in a pre-defined study region near the Fukushima Daiichi nuclear power plant, the prefectures Fukushima, Iwate, Miyagi, Gunma, Tochigi, Ibaraki and Chiba (see Figure 1), with the rates in the rest of Japan, using data until December 2012. A significant 25% increase was found in the first 9 months of 2012.

In September 2014, the final data for 2013 were published. With the additional data, a more reliable assessment of the excess infant mortality is now possible.

Monthly data of live births and infant deaths, 2002 through 2013, are available at http://www.e-stat.go.jp in Japanese [2]. The data were translated, extracted as Excel files, and sent to the author by Masao Fukumoto from Berlin.

Trend analysis

After the Chernobyl nuclear disaster in April 1986, a first increase in perinatal mortality occurred in January/February 1987, 9 months after the accident [3]. The annual data exhibited an increase in 1987, but not thereafter. Therefore, a possible effect of the Fukushima accident on infant mortality is not expected before the end of 2011.

To test whether infant mortality rates in 2012 in the study region differ from the trend of the data 2002 through 2013, a combined logistic regression of the data in the study region and the control region is conducted. The time variable t is defined as calendar month minus 2000, expressed in fractions of a year, e.g. January 2002 is t=2+1/24 (mid-January). Dummy variables *d12S, d12C* denote the 2012 data in the study (S) and control (C) region, respectively. Dummies d*marS and dmarC* mark March 2011 in the study and control region, respectively, and *study*, *tstudy* allow for differences in intercept and trend parameter between the study and control region. Seasonal variations are accounted for by 11 dummy variables indicating the individual months of the year (February through December) with January as the reference month. The seasonal variations are assumed to be the same in the study and control region. Overall, the regression model requires 19 parameters. It has the following form:

```
y~t+feb+mar+apr+may+jun+jul+aug+sep+oct+nov+dec+study+tstudy+dmarS+dmarC+d12S+d12C
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The model fits the data well (deviance 286.7 with 269 degrees of freedom). Since the deviance is slightly greater than the number of degrees of freedom, overdispersion is accounted for by using the F test instead of a chi-square test (in statistical package R, option family=quasibinomial is chosen instead of family=binomial).

Since there is no noticeable difference in slopes between study and control region (tstudy=-0.0028 ± 0.0059, P=0.586), the parameter tstudy is omitted from the regression model, so the number of parameters reduces to 18. The results of the regression analysis are shown in Table 1.

Table 1: Result of the combined regression of infant mortality rates

parameter	estimate	SE	t value	P value
(Intercept)	-5.6746	0.0224	-253.1	0.0000
t	-0.0329	0.0018	-18.38	0.0000
feb	-0.0070	0.0273	-0.255	0.7986
mar	-0.0014	0.0273	-0.053	0.9578
apr	0.0019	0.0269	0.071	0.9437
may	0.0143	0.0266	0.537	0.5915
jun	-0.0463	0.0272	-1.701	0.0901
jul	-0.1154	0.0272	-4.235	0.0000
aug	-0.1136	0.0273	-4.165	0.0000
sep	-0.1500	0.0276	-5.431	0.0000
oct	-0.0861	0.0272	-3.164	0.0017
nov	-0.0187	0.0272	-0.688	0.4920
dec	0.0301	0.0267	1.130	0.2596
study	0.0397	0.0164	2.412	0.0165
mar11S	0.6469	0.1383	4.677	0.0000
mar11C	0.1109	0.0758	1.462	0.1448
d12S	0.1792	0.0555	3.228	0.0014
d12C	-0.0184	0.0261	-0.707	0.4805

There is a highly significant 91% increase of infant mortality in March 2011 ($P<0.0001$) which is likely an immediate effect of the earthquake and tsunami. In 2012, a significant 20% increase is found in the study region (P=0.0014) and a 2% decrease in the control region (P=0.480).

Figures 2 and 3 show the trend of infant mortality rates in the study and control area, and the trend lines; the panels below show the deviations of infant mortality rates from the trend line in units of standard deviations (standardized residuals). Almost all residuals fall within the range of ±2 standard deviations which shows that the model fits the data well.

Alternative approach: evaluation of the odds ratios

The number of parameters can be radically reduced when the ratio of infant mortality rate in the study region to the rate in the control region is analyzed. Then seasonal effects can be neglected. The dummy variables dmar11 and d2012 are used to estimate the effects in March 2011 and in 2012.

For computational reasons, odds ratios (OR) are evaluated instead of rate ratios. The odds ratio is the ratio of two odds where odds are defined as $p / (1-p)$ with rate $p = ID / LB$. Here ID is the number of infant deaths and LB is the number of live births.

When the natural logarithm of the odds ratio, ln(OR), is used as the dependent variable, the variance (var) takes the following simple form:

```
var = 1/ID0 + 1/(LB0-ID0) + 1/ID1 + 1/(LB1-ID1)
```

Index 1 denotes the study region and 0 (zero) the control region.
Now the regression model has only 3 parameters:

```
y ~ β1 + β2*dmar11 + β3*d2012, weights=1/var
```

Here, the dependent variable is y=ln(OR), and β1 through β3 are parameters.

The results are shown in Table 2. The regression yields a 69% increase in March 2011 (P=0.0011) and a 22% increase in 2012 (P=0.0014). The increase translates to 64 excess infant deaths in 2012.

Table 2: Results of regression of odds ratios with excess in 2012

parameters	estimate	SE	t value	P value
β1	0.0531	0.0167	3.178	0.0018
β2	0.5227	0.1570	3.330	0.0011
β3	0.1981	0.0607	3.264	0.0014

After the Chernobyl accident, peaks of perinatal mortality were observed in Germany that could be associated with the time trend of cesium concentration in pregnant women. No information on the time trend of cesium burden in pregnant women from the Fukushima region is available to the author. Therefore a bell-shaped term (normal distribution) is used to model a possible peak of infant mortality in the study region at some time after March 2011. The regression function is non-linear and has the following form:

```
y ~ β1 + β2*dmar11 + β3/t/exp((t-β4)^2/2/β5^2), weights=1/var.
```

Here β1 through β5 are parameters.

The model fits the data well (deviance = 147.4 with 139 degrees of freedom). Table 3 shows the regression results.

Table 3: Results of regression of odds ratios with bell-shaped excess

parameter	estimate	SE	t value	P value
β1	0.0528	0.0167	3.171	0.0019
β2	0.5229	0.1559	3.353	0.0010
β3	0.3598	0.1130	3.184	0.0018
β4	12.337	0.0781	158.0	0.0000
β5	0.2137	0.0818	2.613	0.0100

An F test with 3 and 139 degrees of freedom is used to test the significance of the excess term. It yields P=0.0029, so the effect is clearly significant. Figure 4 displays the monthly odds ratios and the deviations of the odds ratios from the expected trend. The peak position of the bell-shaped excess term is in May 2012 (t=β4=12.34) and the peak excess mortality is exp(β3)-1 = 43%. The standard deviation is β5=0.214 years.

Discussion

The fact that infant mortality peaks in May 2012, more than one year after the Fukushima accident, suggests that the increase is an effect of internal rather than external radiation exposure. In Germany, perinatal mortality peaks followed peaks of cesium burden in pregnant women with a time-lag of seven months [2]. May 2012 minus seven month is October 2011, the end of the harvesting season. Thus, consumption of contaminated foodstuff during autumn 2011 could be an explanation for the excess of infant mortality in the Fukushima region in 2012.

References

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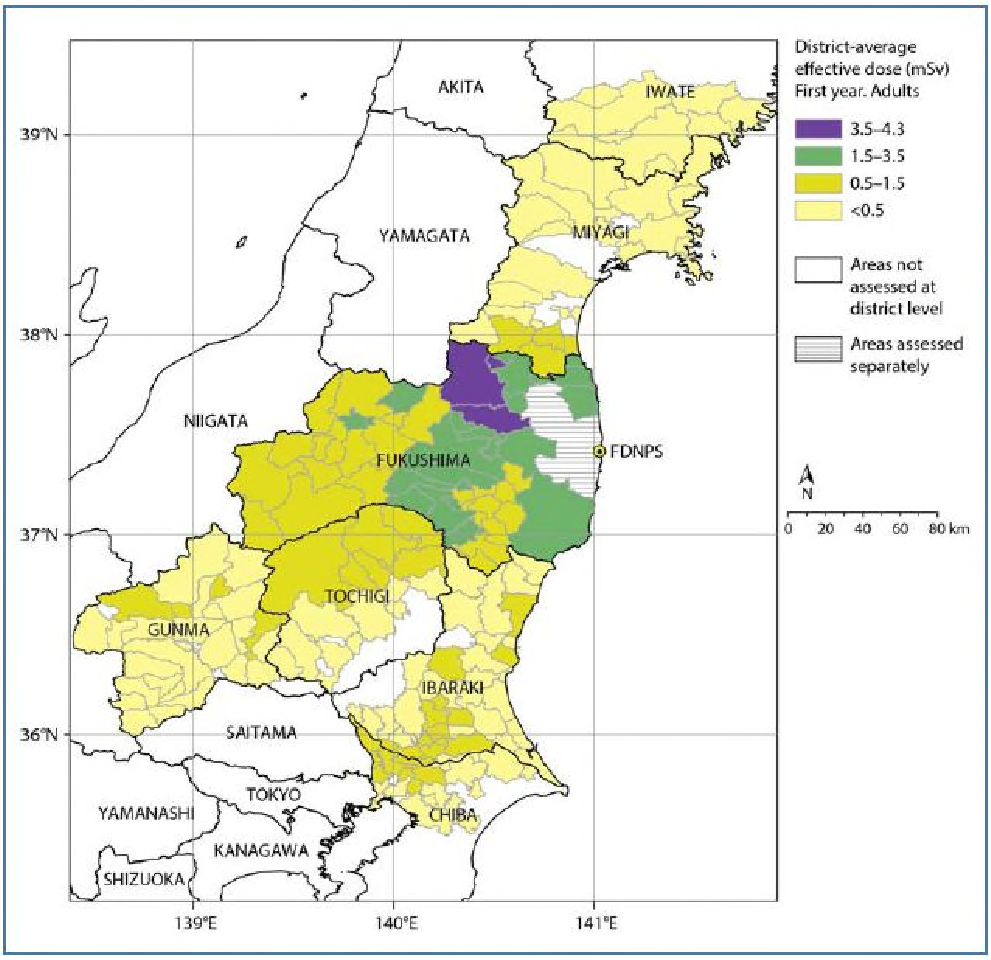

Figure 1: District average effective dose (mSv) in the first year in the study region (prefectures Fukushima, Iwate, Miyagi, Gunma, Tochigi, Ibaraki und Chiba). Source: UNSCEAR

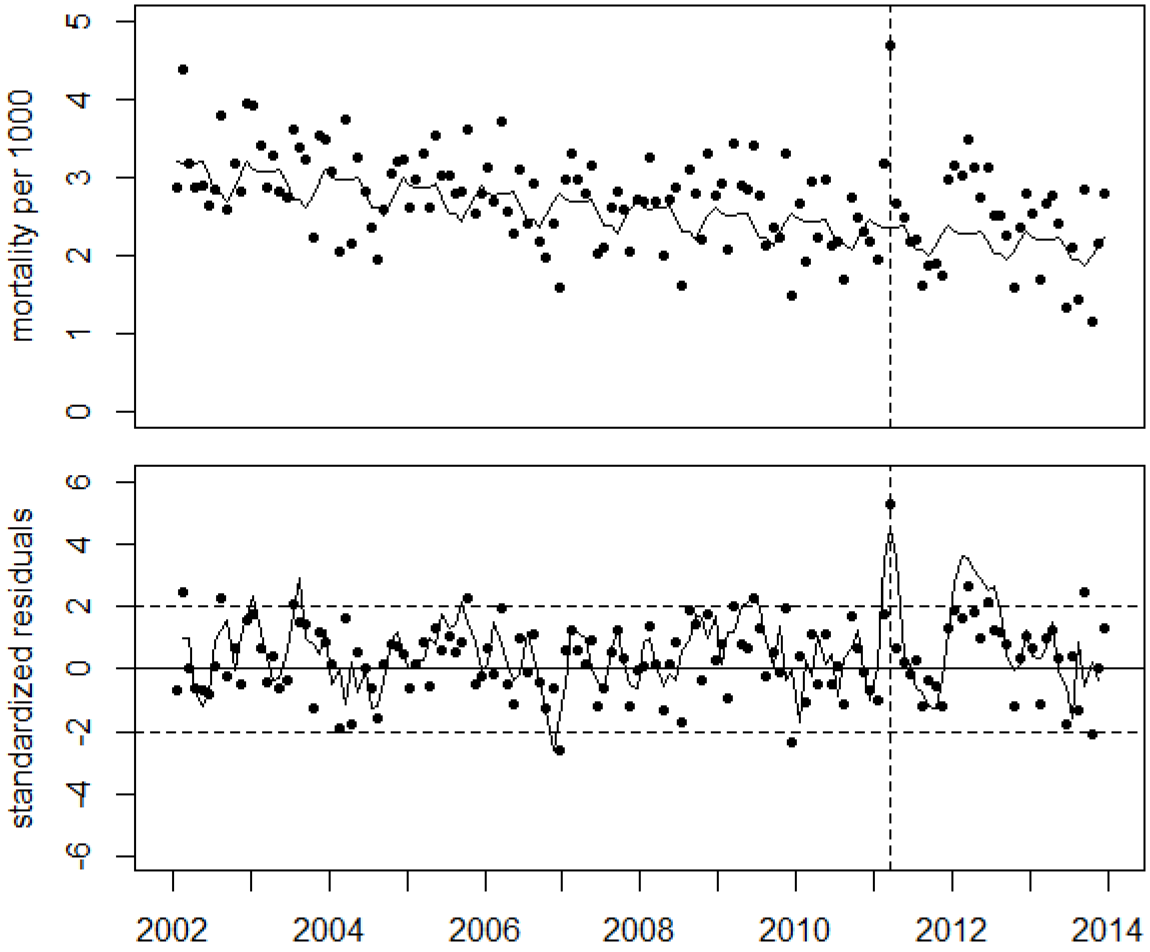

Figure 2, upper panel: Trend of monthly infant mortality rates in the study region and regression line. Lower panel: Deviations of infant mortality rates from the trend, in units of standard deviations (standardized residuals). Solid line: 3-month moving average. The vertical lines indicate March 2011.

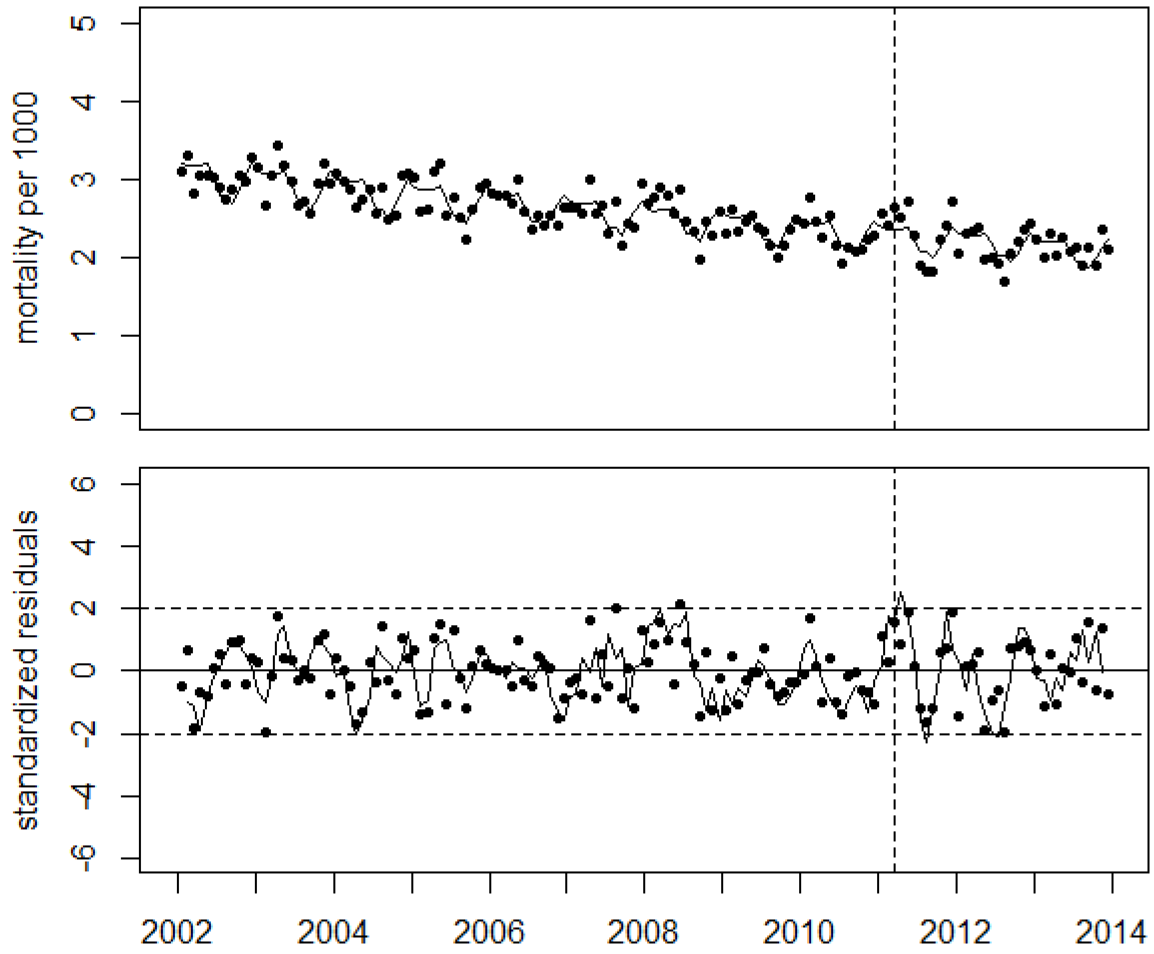

Figure 3, upper panel: Trend of monthly infant mortality rates in Japan and regression line. Lower panel: Standardized residuals and 3-month moving average.

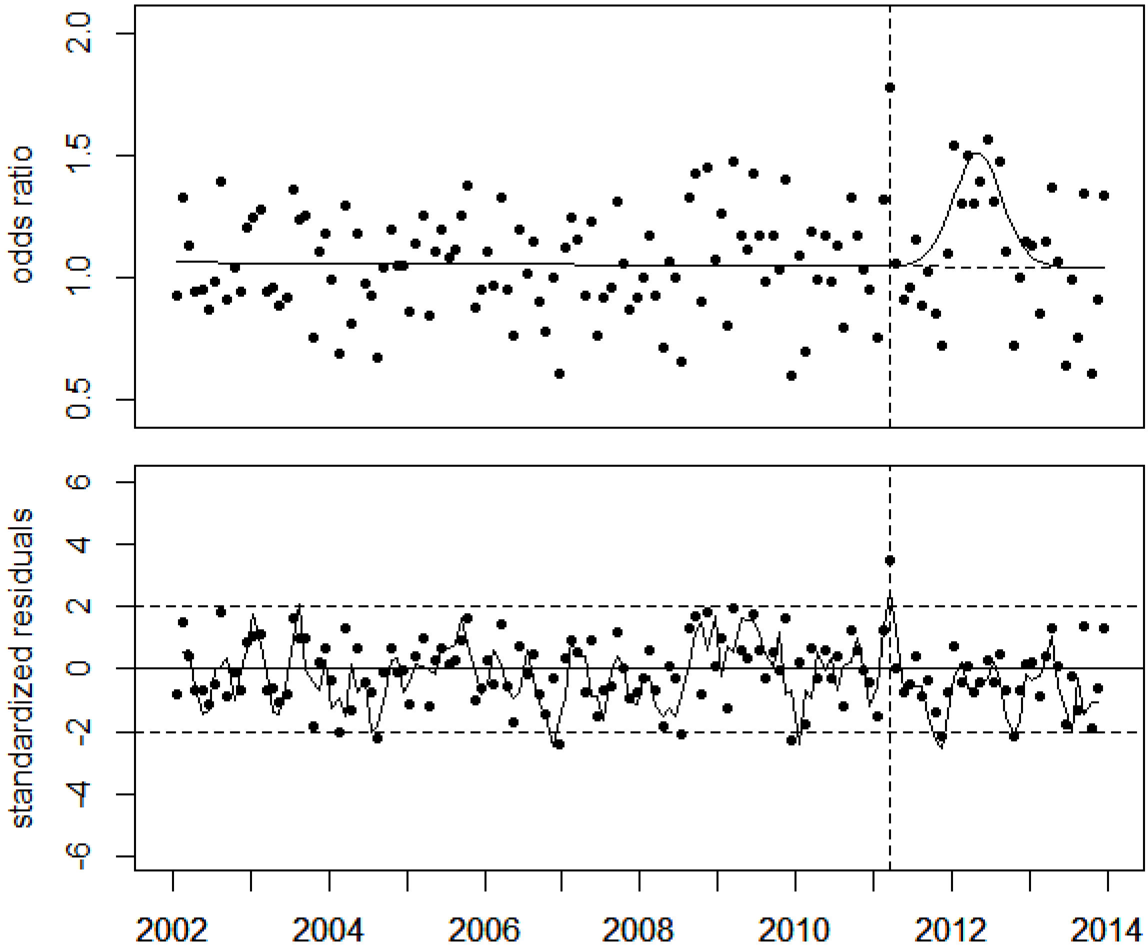

Figure 4, upper panel: Ratio of infant mortality rates in the study region to the rates in the control region (rest of Japan) and regression line. Lower panel: Standardized residuals and 3-month moving average.