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Increased infant mortality and decline in birth rate after Fukushima

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After the Fukushima nuclear disaster in March 2011, infant mortality rates in the most radioactively-contaminated Prefectures around Fukushima increased, showing a rise and fall, starting at the end of 2011, relative to the long term trend before March 2011. The increase is statistically significant. In December 2011, nine months after the accident, a highly significant 10% drop in live births occurred. The effect was limited to a single month which supports the hypothesis that it was a consequence of spontaneous early abortions caused by the radiation spike in the first days after the Fukushima nuclear accident.

Background

First evaluations of the monthly data for infant mortality rates in Japan after Fukushima showed significant peaks in May and December 2011 [1]. In addition, an analysis of the numbers of live births in Fukushima Prefecture found a highly significant 15% decrease in December 2011, nine months after the nuclear disaster [2]. These analyses, however, were based on preliminary data. Recently, the final data were published which made a re-evaluation of the data necessary.

The present work examines infant mortality rates in a defined study area around Fukushima. This study area was constructed by the author using official data on average cesium soil contamination levels. It consists of the seven Prefectures of Fukushima, Iwate, Miyagi, Gunma, Tochigi, Ibaraki and Chiba (see Figure 1). Infant mortality rates in the study area after the Fukushima disaster in March 2011 are compared with the expected trend of the data before Fukushima.

Health Data

Monthly data on live births and infant deaths from 2002 through to 2012, are available at http://www.e-stat.go.jp in Japanese [3]. The data were translated and 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 February 1987, 9.5 months after the accident [4]. Accordingly, a possible increase in infant mortality rates in Japan was 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 before 2012, a common logistic regression of the data in the study region and the control area (the rest of Japan outside the study region) was carried out with individual intercepts and a common parameter for the temporal trend of the data before March 2011.

Seasonal fluctuations occur each year in the monthly data on live births and infant deaths. The seasonal pattern is assumed to be equal in the study and control regions. Dummy variables indicate the 11 months February to December (in the form feb, mar, .. , dec); January is used as the reference month. Overall, the logistic regression model requires 14 parameters. It has the following form (notation according to statistical software R):
glm (y ~ x+feb+mar+apr+june+jun+jul+aug+sep+oct+nov+dec+study, family=binomial)

The time variable, x, is defined as calendar month minus 2000 where calendar month (t) is expressed in fractions of a year (e.g. January 2002 means t=2002+1/24). The dummy variable “study” denotes the data of the study area.

Figure 2 shows the trend of the data from the study and control regions and their respective trend lines; the lower panel plots the deviations of infant mortality rates from the expected trend 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.

The highly significant peak of infant mortality in March 2011 in the study region was likely caused by the earthquake and tsunami. In the course of the residuals after Fukushima, a significant maximum occurs in March 2012. In the period from December 2011 to September 2012, all residuals are positive. The increase of infant mortality in this period corresponds to 60 excess infant deaths.

Alternative approach: analysis of odds ratios

The regression model can be radically simplified if the ratio of infant mortality rates in the study region to the rates in the control area is analyzed. Then the seasonal variations, the time trend, and the dummy “study” can be omitted in the regression model, so only one parameter (intercept) is needed. For computational reasons, odds ratios were evaluated instead of rate ratios. The 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 logarithm of the odds ratio is used as the dependent variable in the regression model, the variance (var) takes the following simple form:

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

where 1 denotes the study region and 0 (zero) the control region.

The above regression showed that infant mortality rates were only increased in 2012 with a significant peak in March. To test whether this increase is significant, the excess is modeled by a bell-shaped function (lognormal distribution). Then the regression function takes the following form (nonlinear regression):

y ~ β1 + β2 * dmar11 + β3/t/exp((ln(t) - ln(β4))^2/β5)

The dependent variable is y = ln(OR), t is time, the dummy variable dmar11 indicates March 2011, and β1 through β5 are parameters.

The model fits the data well (deviance = 110.75 with 127 degrees of freedom). Table 1 shows the regression results.

Table 1: Regression results for odds ratios

parameter	estimate	SE	t value	*P* value
β1	0.0413	0.0156	2.649	0.0091
β2	1.2450	0.1222	10.19	0.0000
β3	3.6680	1.2630	2.903	0.0044
β4	12.370	0.0884	139.9	0.0000
β5	0.0007	0.0005	1.207	0.2298

An F test with (3, 127) degrees of freedom is used to test the significance of the excess term. It yields *P* = 0.0086, so the increase of infant mortality in 2012 is clearly significant.

Figure 3 shows the monthly odds ratios and the deviations of the odds ratios from the expected trend.

Birth deficit in December 2011

To estimate the effect on live births in December 2011, the monthly data of live births (LB) from January 2006 to December 2011 is analyzed using Poisson regression. A dummy variable ddec11 marks December2011. The regression model allows for a linear-quadratic time trend (variables x, x2) seasonal fluctuations (dummy variables feb, mar, .. , dec). Thus, the regression model has the following form (R notation):

glm (LB ~ x+feb+mar+apr+june+jun+jul+aug+sep+oct+nov+dec+x2+ddec11, family=quasipoisson)

Since live birth data usually show considerable overdispersion, an F test is used instead of a Chisquare test to determine the *P* values which is achieved by the option “family=quasipoisson”. The regression results are shown in Table 2.

Table 2: Birth deficit in December 2011 in the study area

parameter	estimate	SE	t value	*P* value
Intercept	9.3822	0.0554	169.452	0.0000
x	0.0341	0.0127	2.696	0.0092
x2	-0.0026	0.0007	-3.724	0.0005
feb	-0.1038	0.0091	-11.434	0.0000
mar	-0.0185	0.0089	-2.077	0.0423
apr	-0.0194	0.0089	-2.177	0.0336
may	0.0104	0.0088	1.18	0.2429
jun	-0.0067	0.0089	-0.753	0.4543
jul	0.0427	0.0088	4.864	0.0000
aug	0.0390	0.0088	4.431	0.0000
sep	0.0341	0.0088	3.874	0.0003
oct	0.0310	0.0088	3.512	0.0009
nov	-0.0330	0.0090	-3.671	0.0005
dec	0.0079	0.0093	0.852	0.3980
ddec11	-0.1063	0.0189	-5.627	5.8E-7

The decrease of live births in December 2011 is 10.1% and is highly statistically significant (*P* = 5.8 E-7).

Figure 4 shows the trend of the live births, 2006 through 2012, and the standardized residuals. The drop of live births is limited to December 2011, no appreciable deviation of live births is observed in the previous (November 2011) and the following month (January 2012) which supports the hypothesis that the birth rate is caused by an increase in spontaneous early abortions in March 2011.

To check whether the drop of live births is associated with radiation exposure, the data from the seven prefectures of the study area are evaluated individually. The results are shown in Table 3.

Table 3: Birth deficit in the Prefectures of the study area

Prefecture	%change	*P* value	birth deficit
Iwate	-5.2%	0.1567	39
Miyagi	-18.1%	<0.0001	274
Fukushima	-15.3%	0.0002	190
Gunma	-6.8%	0.1009	86
Tochigi	-11.3%	0.0061	151
Ibaraki	-6.7%	0.0026	129
Chiba	-8.8%	0.0002	382
study region	-10.1%	5.8E-7	1251
rest of Japan	-3.0%	0.0459	2329
all of Japan	-4.0%	0.0090	3572

The greatest decreases are found in the 3 prefectures with greatest soil contamination, the Prefectures of Miyagi (-18.1 %, $P < 0.0001$), Fukushima (-15.3 %, $P = 0.0002$), and Tochigi (-11.3 %, $P = 0.0061$). The overall number of missing births in the study region is 1,251; for Japan as a whole it is 3,572 ($P = 0.0090$).

Discussion

The infant mortality rate was significantly increased in the 7 prefectures around Fukushima with largest cesium soil contamination during the first three quarters of 2012. The decline in the number of live births in December 2011 is highly statistically significant.

After Chernobyl, a highly significant 17% drop of live births was observed in Belarus in January 1987, about 9 months after the accident in April 1986 (unpublished analysis by the author, see Figure 5). It was paralleled by a highly significant increase of Down syndrome in Belarus in January 1987 [5]. A significant trisomy 21 peak was also found in West Berlin in the same month [6].

The decrease of live births in Japan and the trisomy 21 peaks after Chernobyl are limited to a single month. Therefore it seems unlikely that the effect can be explained exclusively by the reluctance to have children in the aftermath of the Fukushima accident; public worry would be expected to last for several months, as is the case in Belarus, see Figure 5. Immediately after fertilization, the zygote is extremely sensitive. Radiation damage to the zygote from the high initial radiation spike following the nuclear accident can trigger early spontaneous abortions which in turn manifest as a drop of live births 9 months later.

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[2] Körblein A. Rückgang der Geburten in Japan 9 Monate nach Fukushima. Strahlentelex 628-629 / 2013:2-3. http://www.strahlentelex.de/Stx_13_628-629_S02-03.pdf

[3] http://www.e-stat.go.jp/SG1/estat/NewList.do?tid=000001028897

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[6] Sperling K, Pelz J, Wegner RD, Dörries A, Grüters A, Mikkelsen M. Significant increase in trisomy 21 in Berlin nine months after the Chernobyl reactor accident: temporal correlation or causal relation? BMJ. 1994 Jul 16;309(6948):158-62.

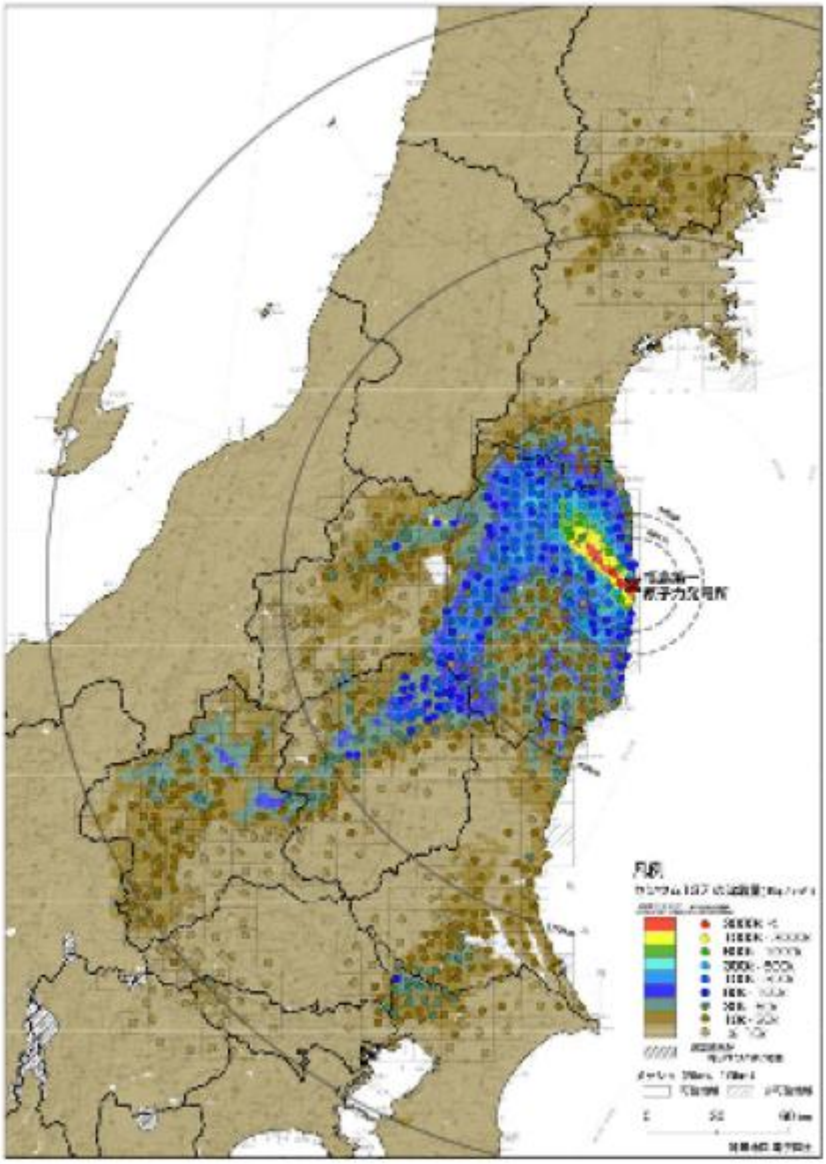

Figure 1: Cesium soil contamination in the study region (prefectures Fukushima, Iwate, Miyagi, Gunma, Tochigi, Ibaraki und Chiba). Source: Press communication by MEXT (Ministry for Education and Research). September 12, 2012

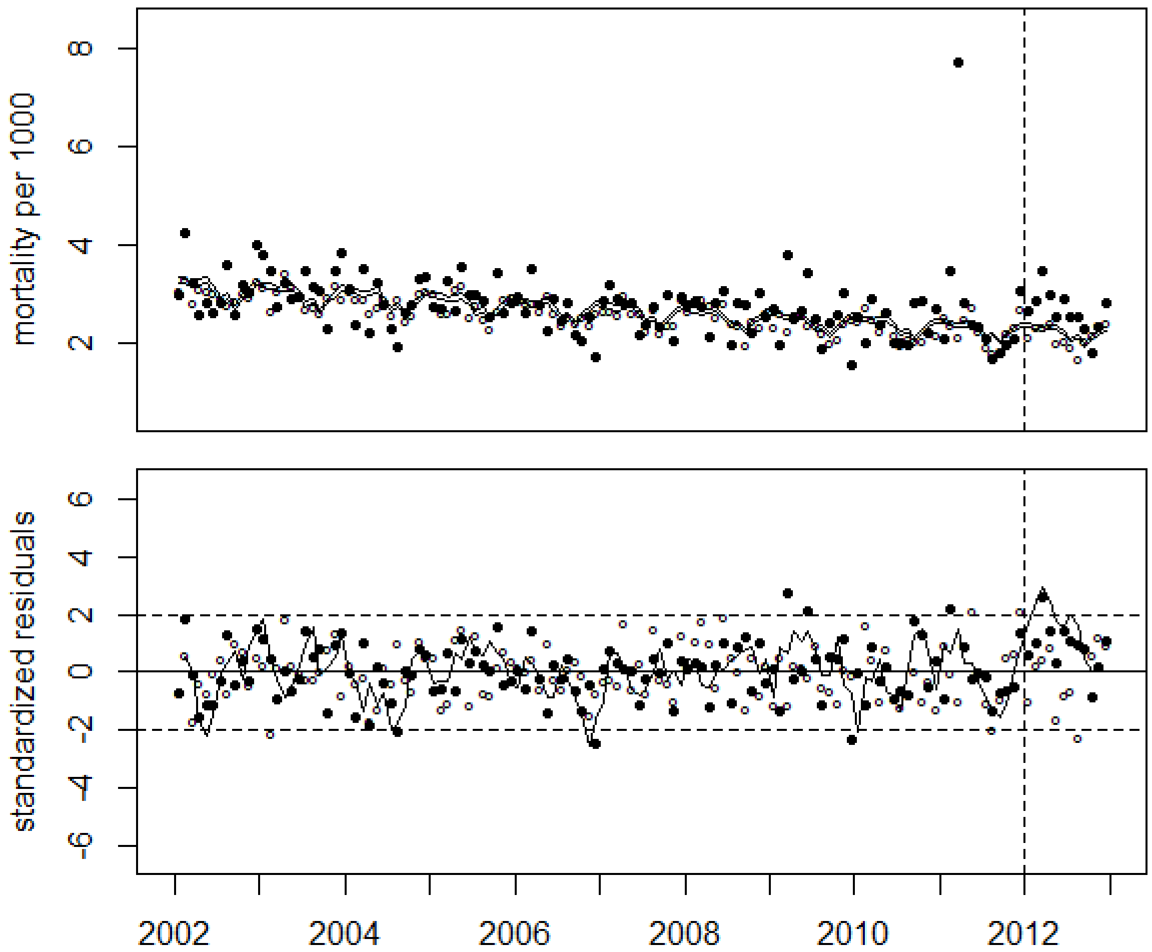

Figure 2, upper panel: Trend of monthly infant mortality rates in the study region (black dots) and in the rest of Japan (open circles), and regression lines. Lower panel: Deviations of infant mortality rates from the trend, in units of standard deviations (standardized residuals). Solid line: 3-month moving average. The vertical lines mark the beginning of 2012.

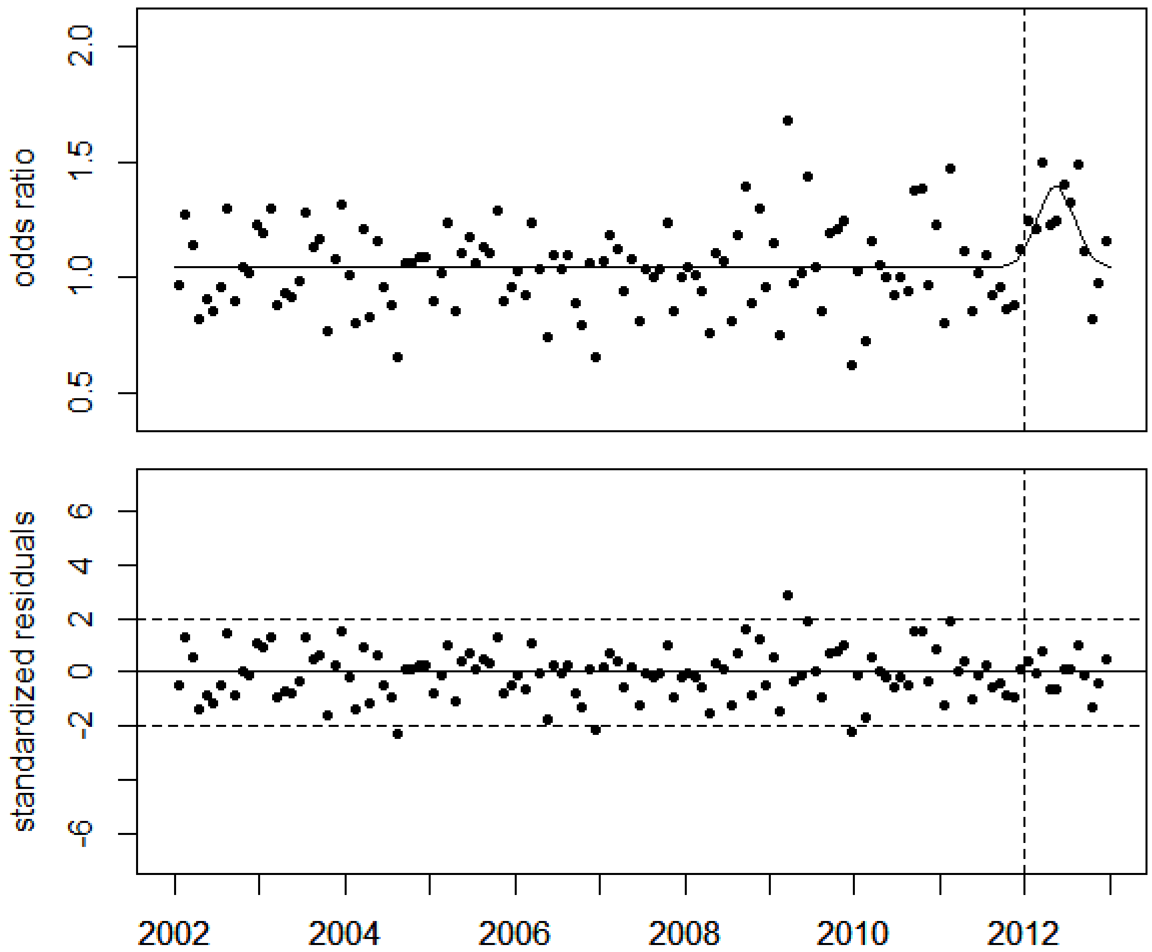

Figure 3, upper panel: Ratio of infant mortality rates in the study region to the rates in the control region (rest of Japan) and regression line. Lower panel: standardized residuals

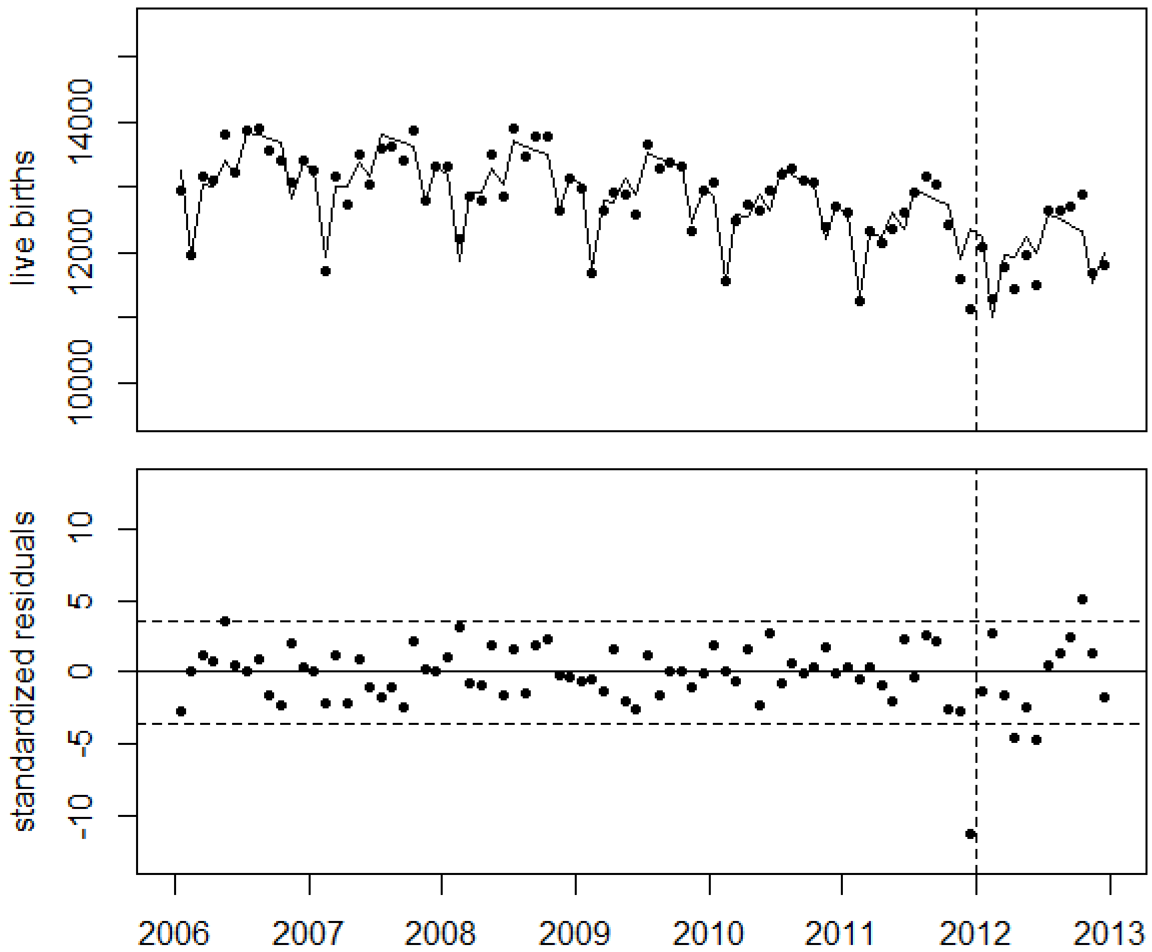

Figure 4, upper panel: Monthly number of live births in the study region and regression line.
Lower panel: standardized residuals

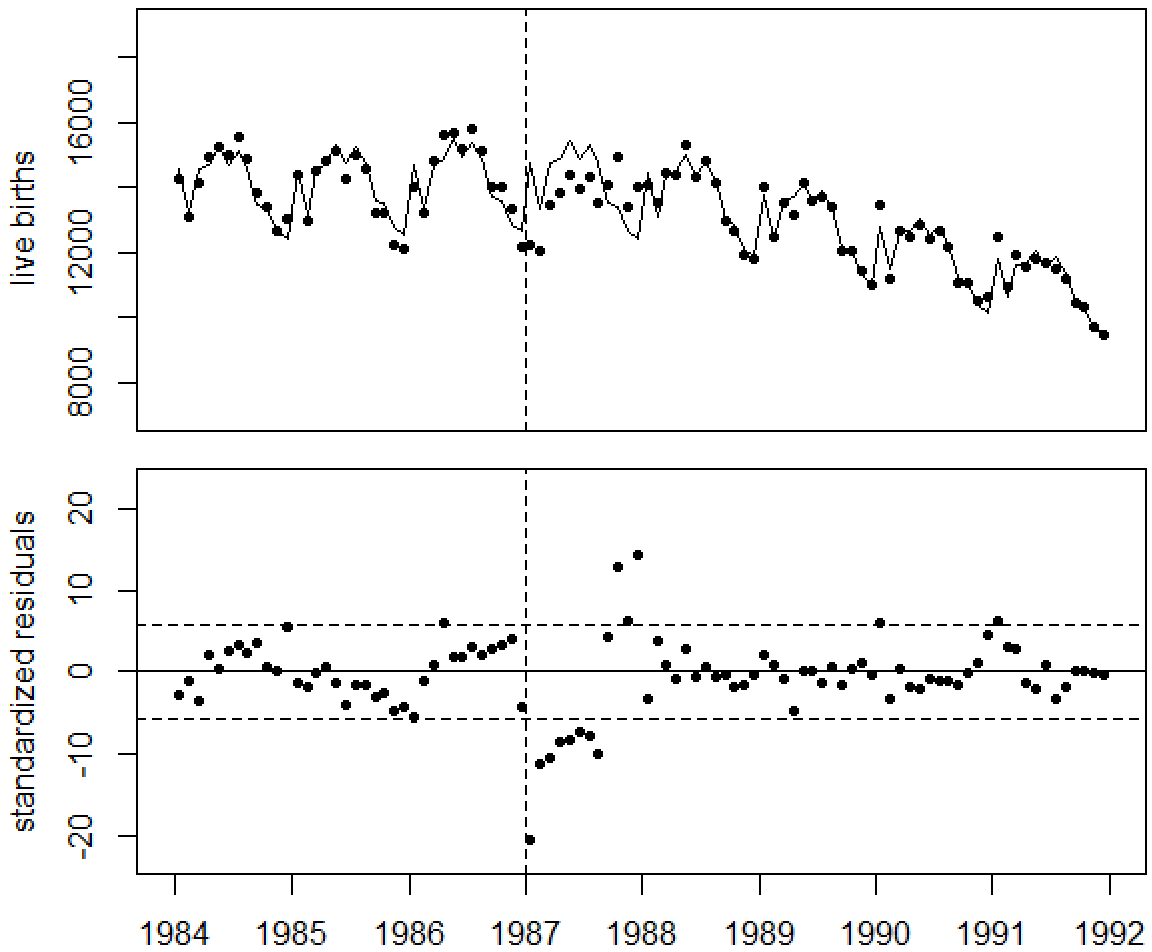

Figure 5, upper panel: Monthly number of live births in Belarus and regression line.
Lower panel: standardized residuals