Title Page

Title

Trends in births and the birth sex ratio in the vicinity of the Mainz research reactor in Germany.

Running title: The Mainz reactor and births

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Key words

Radiation
Birth Rate/*trends
Sex Ratio
Infant, Newborn

Abstract

Introduction

The human sex ratio or sex odds at birth (M/F) is influenced by many factors. Radiation is the only stressor known to elevate the ratio while dropping total births. The Mainz research nuclear reactor (FRMZ) underwent extensive refurbishment commencing in 1992 and upgrading in 2011. This study was carried out in order to investigate any possible effects of these events on M/F.

Methods

Annual municipality-specific births by sex were obtained from official government sources. Statistical methods used included ordinary linear logistic regression and Poisson regression.

Results

M/F rose significantly in 1993 only close to the FRMZ (<10km) with sex odds ratio (SOR) 1.023 (p=0.0074) and this sex ratio jump was associated with numerically equivalent drops in male births of 4.01% (p=0.0251) and female births of 6.17% (p=0.0005). Beyond 10km, no such effects were seen.

Discussion

These findings add to the corpus of evidence that man-made radiation may have significant effects on total births and on M/F with a skew toward male births. While the authors are certain that suitable precautions were taken when the reactor in Mainz was handled, the findings imply that these may not have been sufficient. Perhaps even greater care and even more stringent precautions need to be employed when dealing with radioactive elements. It clearly behoves humanity to exercise extreme caution when handling, processing, and storing radioactive materials and waste.

Introduction

The sex ratio at birth (the secondary sex ratio) is defined as the ratio of male to female births (M/F) and is equivalent to the sex odds. Several factors have been shown to influence this ratio. The most significant influence is iatrogenic: the deliberate culling of female infants, primarily by Asiatic cultures, since males are more prized, (xxsen) a process that has led to over a hundred million missing females. (xxbongaarts)

Unprogrammed and unplanned coital activity also skews the sex ratio towards the male as conceptions that occur earlier in the menstrual cycle favour male more than female offspring.(jamesgrechxx) Stress of all sort tends to reduce the sex ratio,(xxjamesgrech2) but radiation appears to be the only stressor that leads to antenatal female losses that exceed male losses, leading to a male excess.(xxhagen) This has been shown in relation to atomic bomb tests, after Chernobyl, after Windscale (Sellafield) and in the vicinity of nuclear facilities.(xxscherbvoigt1,xxscerbvoigt2,xxsherbvoigt3,xxgrechchernobyl,xxgrechsellafield).

The Mainz reactor (Forschungsreaktor Mainz - FRMZ) is a research reactor operated by the University of Mainz with special fuel elements, i.e. uranium enriched below 20% (non-weapon grade) and a zirconium hydride moderator that provides prompt negative temperature coefficients and therefore high levels of security. It is for this reason that these types of reactors are the most common research reactors worldwide.(xxstone)

The FRMZ is situated in a populated area, and the reactor underwent extensive refurbishment commencing in 1992 and these included cooling circuits, heat exchangers, and a cooling tower.(xxhampel) Furthermore, an ultra-cold neutron source was installed so as to increase neutron density and neutron velocity in 2011.(xxkarch) Despite precautions, it is possible that radioactive elements were inadvertently released or produced by neutron activation, and unnoticed, during or after the refurbishment or the upgrading of the reactor. This study was carried out in order to investigate this possibility that the sex ratio was affected within 25 km of the FRMZ, including Mainz, a city whose population weighted centre lies circa 3 km away from the FRMZ.

Methods

Municipality-specific annual birth data by gender was obtained for the period 1975 to 2007 from the regional Statistical Offices of the respective "German Bundesländer" Hesse and Rhineland-Palatinate and from the "Statistisches Bundesamt, Gustav-Stresemann-Ring 11, 65189 Wiesbaden" (https://www.destatis.de/DE/Home/_inhalt.html). For the period from 2008 to 2016, the data were provided uniformly for all of Germany by "Information und Technik Nordrhein-Westfalen (IT.NRW) im Auftrag der Statistischen Ämter des Bundes und der Länder, Mauerstraße 51, D-40476 Düsseldorf" (https://www.regionalstatistik.de/genesis/online/data). Ordinary linear logistic regression was used in order to assess time trends in the probability of boys among live births, and to investigate whether there were changes in the trend functions after distinct events. This involved considering the male proportion among all male (m) and female (f) births: $p_m = m/(m+f)$. Important and useful parameters in this context are the sex odds $SO = p_m/(1- p_m) = m/f$ and the sex odds ratio (SOR), which is the ratio of two sex odds of interest, i.e. in exposed versus non-exposed populations. Dummy coding was used for single points in time and for time periods. Likewise, Poisson regression served to model the gender-specific birth counts directly in order to determine the significant drops or jumps in the counts that go along with the corresponding significant change-point in the sex ratio. For the statistical analyses of the male proportions and the absolute gender-specific birth counts we applied logistic regression (SAS LOGISTIC) and Poisson regression (SAS GENMOD), respectively. Software employed was: MS-Excel-365, R 3.5.1, and mostly Wolfram MATHEMATICA 11.3 and SAS/STAT software 9.4 (SAS Institute Inc: SAS/STAT User's Guide, Cary NC: SAS Institute Inc, 2014).

Results

Table 1 documents the municipality-specific birth counts from 1975 to 2016 within 25 km from the FRMZ stratified by (1) gender and (2) before/from January 1, 1993. Table 1 also includes the municipality-specific sex odds ratios (SOR) and the one-sided p-values for the Fisher tests of the null hypotheses: the sex ratio from 1993 onward is less than or equal to the sex ratio before 1993. Figure 1 shows the geographic positions and the dimensions of those municipalities within 25 km from the FRMZ. In addition, in Figure 2, the gray levels of the municipalities' polygons correspond to the one-sided p-values of the Fisher tests against no sex ratio increases from 1993 onward (as per Table 1). This provides a visual indication of the spatial distribution of the sex ratio changes in the vicinity of the FRMZ: 'black to medium gray' means diminishing increases, i.e. decreasing jump heights of the sex ratio in 1993, and 'medium gray to white' means increasing decreases, i.e. stronger drops of the sex ratio in 1993.

Figure 3A depicts the sex odds trend for the combined municipalities within 10 km distance from the FRMZ, and Figure 3B displays the sex odds trend for the combined municipalities within 10 to 25 km distance. Whereas the sex ratio trend near the FRMZ demonstrates a long-term significant jump from 1993 onward, at greater distances (>10 km), an expected trend is seen, which is a decline consistent with the known global decline in secular sex ratio.

Figure 4A shows the corresponding absolute birth counts by gender within a 10 km distance from the FRMZ. There is a drop in 1993 in males of 4.01% (p=0.0251), and a drop in females of 6.17% (p=0.0005). Figure 4B displays the absolute birth counts by gender within 10 to 25 km distance from the FRMZ. There is a minor insignificant increase in males of 0.46% (p=0.7903), and a small insignificant increase in females of 1.43% (p=0.4162). Solid lines indicate full models and broken lines are reduced null-effect models. The data again shows distinct significant deviations from the secular trends in the birth counts within 10 km from the FRMZ, and no significant deviations beyond 10 km distance.

Discussion

The non-random dark/light pattern in Figure 2 may imply that meteorological conditions (wind direction, precipitation) or commuter flow to/from Mainz City etc. influenced the distribution of radionuclides and subsequent human exposure, resulting in the observed autocorrelated pattern in Figure 2. Such comparisons of weaker and stronger affected partitions of the vicinity of a nuclear facility may assist in the identification of possible point sources and pathways of the presumable underlying exposures, if any.

That the observed effect near the FRMZ is stronger than farther away is compatible with the distance laws (Rayleigh functions) of the sex ratio described in our previous publications. (ScherbVoigtxx1, ScherbVoigtxx2, and Scherb,Kusmierz,Sigler,Voigt2016). It is also worth noting that the observed effect is especially strong in the City of Mainz itself: SOR 1.058 (p=0.0001) for the jump in 1993 (1st row of Table 1).

This paper continues to add to the corpus of evidence that man-made radiation may have significant effects on total births and on the sex ratio which, in these circumstances, is skewed toward male births. This is not to say that only man-made radiation influences the sex ratio. For example, Hurricane Katrina (2005) was also shown to have this effect due to a transient increase in ambient radiation that is associated with rainfall. (xxkatrina) Mankind has also unwittingly influenced the sex ratio even more drastically by above-ground atomic weapon testing prior to the Partial Test Ban Treaty of 1963, presumably due to increased background radiation levels.

The authors are certain that precautions were taken when the reactor in Mainz was handled. However, our findings imply that perhaps even greater care with more stringent precautions need to be employed when dealing with radioactive elements. It clearly behoves humanity to exercise extreme caution when handling, processing, and storing radioactive materials and radioactive waste.

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End of references

Tables

Table 1. Births from 1975 to 2016 within 25 km from the FRMZ; birth counts stratified by gender and before/from 1993; sex odds ratio (SOR) and one-sided p-value for the Fisher test of no sex ratio increase from 1993 onward.

Municipality	No.	Distance from FRMZ	male births		female births		SOR	p-value (one-sided)
			< 1993	≥1993	< 1993	≥1993		
Mainz	1	2.7	15931	23175	15573	21421	1.058	0.0001
Budenheim	2	5.8	702	1089	668	998	1.038	0.2945
Klein-Winternheim	3	6.3	287	392	269	347	1.059	0.3054
Ober-Olm	4	6.8	330	440	304	434	0.934	0.7435
Ginsheim-Gustavsburg	5	6.3	1396	1940	1327	1804	1.022	0.3312
Heidesheim am Rhein	6	8.8	559	761	495	714	0.944	0.7628
Wackernheim	7	8.8	188	323	190	266	1.227	0.0606
Bodenheim	8	8.7	656	741	570	779	0.827	0.9934
Walluf	9	7.3	493	570	456	524	1.006	0.4725
Essenheim	10	8.9	257	376	224	386	0.849	0.9196
Bischofsheim	11	8.4	1164	1436	1087	1438	0.933	0.8925
Harxheim	12	10.0	154	250	167	234	1.159	0.1537
Gau-Bischofsheim	13	9.0	163	210	166	209	1.023	0.4380
Nieder-Olm	14	9.5	656	1012	623	934	1.029	0.3456
Wiesbaden	15	9.9	21917	34538	20915	32546	1.013	0.1548
Hochheim am Main	16	8.6	1384	1871	1305	1696	1.040	0.2203
Stadecken-Elsheim	17	11.8	333	505	354	437	1.228	0.0203
Nackenheim	18	11.3	458	608	417	628	0.881	0.9231
Zornheim	19	11.5	345	415	311	385	0.972	0.6072
Lörzweiler	20	11.3	181	228	169	246	0.865	0.8473
Schwabenheim an der Selz	21	12.2	188	263	150	258	0.813	0.9297
Mommenheim	22	12.5	194	392	164	390	0.850	0.8982
Ingelheim am Rhein	23	11.9	1941	2836	1907	2609	1.068	0.0590
Sörgenloch	24	12.4	88	138	80	113	1.110	0.3004
Eltville am Rhein	25	9.2	1253	1858	1147	1695	1.003	0.4742
Trebur	26	14.1	1015	1405	984	1348	1.010	0.4298
Engelstadt	27	15.8	47	78	43	75	0.951	0.5741
Bubenheim	28	13.7	52	100	52	88	1.136	0.3005
Kiedrich	29	12.2	275	390	255	411	0.880	0.8733
Flörsheim am Main	30	14.0	1632	2341	1575	2207	1.024	0.3059
Rüsselsheim	31	12.5	5340	7709	5029	7490	0.969	0.8894
Selzen	32	14.5	121	171	118	139	1.200	0.1457
Udenheim	33	15.0	90	157	67	160	0.730	0.9449
Nierstein	34	15.2	537	853	570	819	1.106	0.0978
Hahnheim	35	14.5	152	170	111	160	0.776	0.9362
Saulheim	36	14.4	567	842	547	749	1.085	0.1498
Partenheim	37	16.8	128	202	108	175	0.974	0.5630
Jugenheim in Rheinhessen	38	15.4	74	149	99	166	1.201	0.1686
Raunheim	39	15.9	1110	1983	1068	1925	0.991	0.5660
Köngernheim	40	16.4	75	184	67	123	1.336	0.0781
Hofheim am Taunus	41	18.4	2994	4544	2933	4276	1.041	0.1158
Schornsheim	42	16.8	139	173	116	180	0.802	0.9095
Nieder-Hilbersheim	43	16.5	32	69	32	67	1.030	0.4614
Schlangenbad	44	15.0	458	635	415	562	1.024	0.3960
Gau-Algesheim	45	16.4	506	689	499	704	0.965	0.6659
Appenheim	46	16.2	101	146	87	150	0.838	0.8270
Friesenheim	47	17.4	54	93	42	54	1.340	0.1374
Undenheim	48	17.0	136	300	132	325	0.896	0.7740
Dexheim	49	17.2	112	249	94	248	0.843	0.8485
Nauheim	50	16.3	879	988	837	979	0.961	0.7265
Dalheim	51	18.9	87	103	66	95	0.823	0.8166
Oppenheim	52	18.1	457	752	458	715	1.054	0.2663
Ober-Hilbersheim	53	18.2	71	111	74	91	1.271	0.1356
Hattersheim am Main	54	19.9	2453	2998	2278	2938	0.948	0.9161
Taunusstein	55	19.6	2449	3125	2290	2964	0.986	0.6428
Vendersheim	56	18.6	36	59	33	68	0.795	0.7776
Wörrstadt	57	19.2	579	834	571	734	1.121	0.0715
Kriftel	58	19.4	995	1236	844	1123	0.934	0.8645
Gabsheim	59	18.8	68	77	69	86	0.909	0.6603
Weinolsheim	60	19.8	62	88	55	80	0.976	0.5405
Wolfsheim	61	19.3	61	87	44	73	0.860	0.7245
Ockenheim	62	19.8	196	266	184	237	1.054	0.3504
Dienheim	63	18.9	131	234	120	187	1.146	0.1968
Groß-Gerau	64	19.3	2105	2785	2054	2764	0.983	0.6608
Sulzheim	65	19.5	85	129	62	119	0.791	0.8684
Oestrich-Winkel	66	16.5	913	1285	864	1131	1.075	0.1234
Bechtolsheim	67	21.1	125	213	111	172	1.100	0.2832
Aspisheim	68	20.7	55	71	62	99	0.808	0.8103
Niedernhausen	69	19.7	1115	1675	1084	1587	1.026	0.3201
Uelversheim	70	20.8	102	124	95	103	1.121	0.2787
Sankt Johann	71	21.1	59	116	51	116	0.864	0.7348
Kelsterbach	72	22.3	1492	1680	1346	1687	0.898	0.9821
Gau-Weinheim	73	21.2	51	78	41	62	1.011	0.4833
Eppstein	74	20.1	1189	1546	1036	1551	0.869	0.9943
Ludwigshöhe	75	21.0	38	64	36	51	1.189	0.2814
Dolgesheim	76	22.1	86	110	87	107	1.040	0.4238
Wallertheim	77	22.0	117	183	92	173	0.832	0.8536
Bad Schwalbach	78	20.4	843	1162	850	1089	1.076	0.1282
Spiesheim	79	21.8	58	94	55	104	0.857	0.7432
Horrweiler	80	22.2	62	73	59	79	0.879	0.7009
Sprendlingen	81	23.2	402	445	410	413	1.099	0.1680
Bingen am Rhein	82	24.6	2087	2569	1999	2518	0.977	0.7080
Biebelnheim	83	22.3	49	79	63	62	1.638	0.0265
Eimsheim	84	22.2	34	49	31	54	0.827	0.7248
Guntersblum	85	23.0	306	474	279	455	0.950	0.6871
Kelkheim (Taunus)	86	22.0	2294	3234	2084	2965	0.991	0.5917
Welgesheim	87	23.4	49	71	52	71	1.061	0.4098
Zotzenheim	88	23.4	60	65	66	53	1.349	0.1220
Büttelborn	89	22.1	1026	1672	1005	1646	0.995	0.5355
Ensheim	90	22.4	28	52	33	55	1.114	0.3684
Geisenheim	91	19.5	907	1125	850	1079	0.977	0.6415
Liederbach am Taunus	92	23.0	675	1092	610	970	1.017	0.4046
Riedstadt	93	23.3	1680	2552	1483	2503	0.900	0.9898
Gau-Odernheim	94	23.4	264	414	247	389	0.996	0.5150
Gau-Bickelheim	95	23.4	179	265	178	250	1.054	0.3511
Hillesheim	96	23.9	58	62	69	66	1.118	0.3290
Armsheim	97	24.2	132	270	117	261	0.917	0.7135
Mörfelden-Walldorf	98	23.5	2741	3667	2481	3340	0.994	0.5679
Wintersheim	99	24.1	16	44	20	33	1.667	0.1047
Hohenstein	100	24.3	548	625	467	577	0.923	0.8256
Gensingen	101	24.7	286	370	270	359	0.973	0.5961
Grolsheim	102	24.9	110	154	92	125	1.030	0.4358
Rüdesheim am Rhein	103	22.4	754	1035	751	925	1.114	0.0570
Total vicinity of FRMZ < 25 km			**98669**	**142730**	**93646**	**134625**	**1.006**	**0.2954**

Figures

Figure 1. Geographic positions in Gauß-Krüger coordinates (GK3) of the municipalities within 25 km from the FRMZ (small central ring); the inner, medium, and outer circles indicate 5, 10, and 25 km distances, respectively (see Table 1 for the indexes of the municipalities).

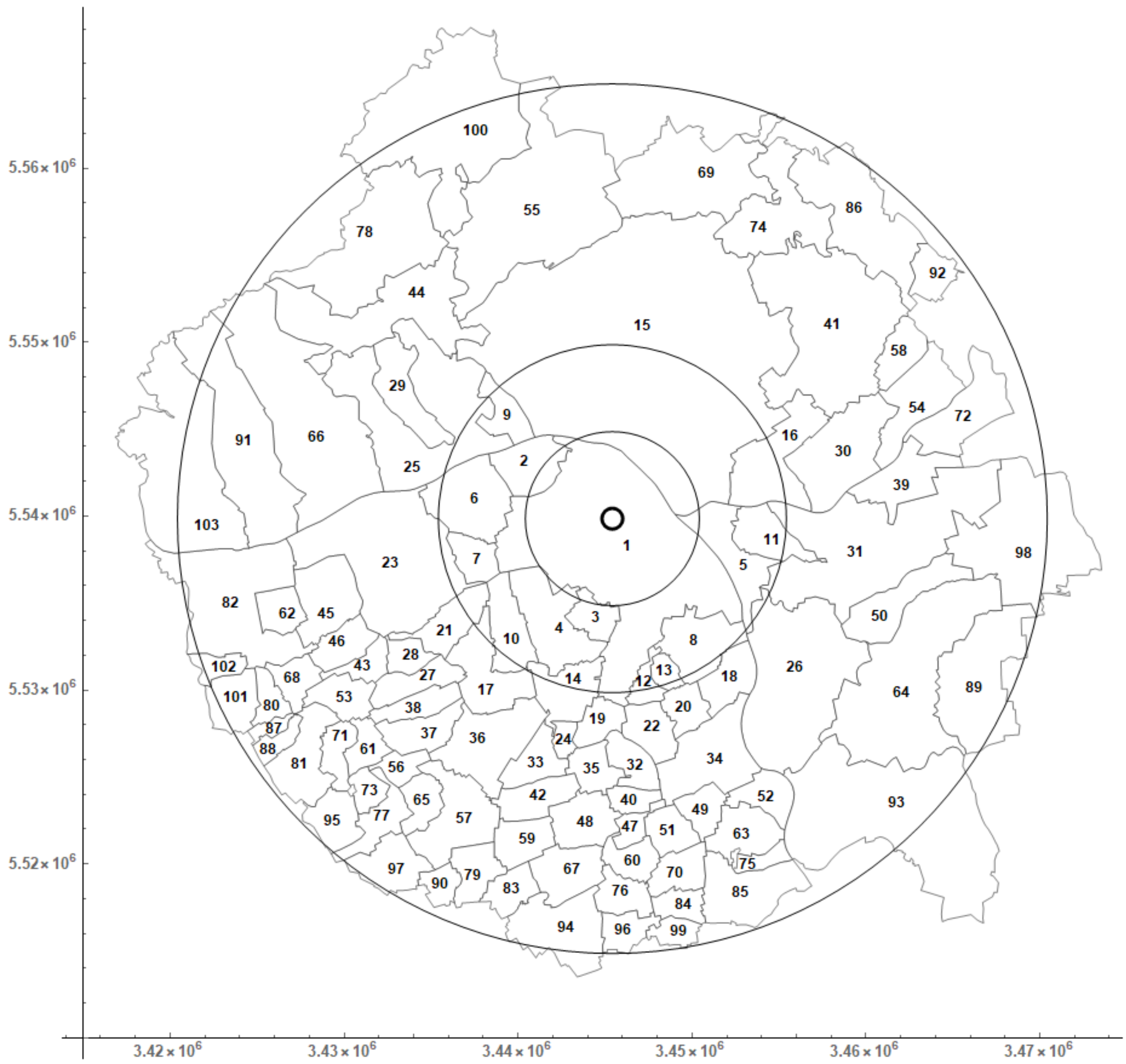

Figure 2. The municipalities' polygon areas in Gauß-Krüger coordinates (GK3) colored by gray-levels proportional to the one-sided p-values for the Fisher tests of no sex ratio increases from 1993 onward; FRMZ (central white dot) and 5, 10, and 25 km circles respectively (per Table 1 and Figure 1)

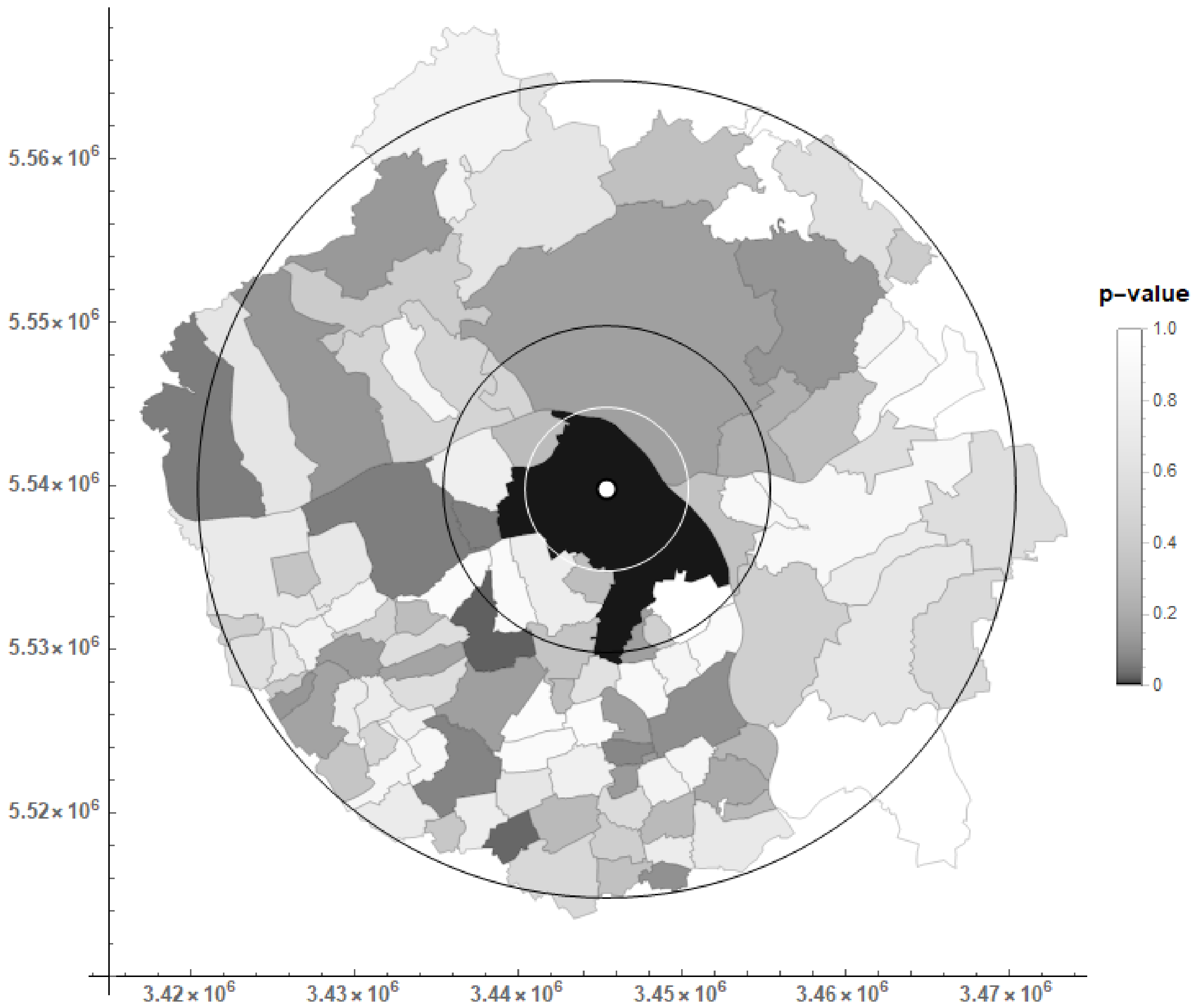

Figure 3 A. Sex odds trend for the combined municipalities within 10 km from the FRMZ allowing for a jump in 1993 (per Table 1 and Figure 2).

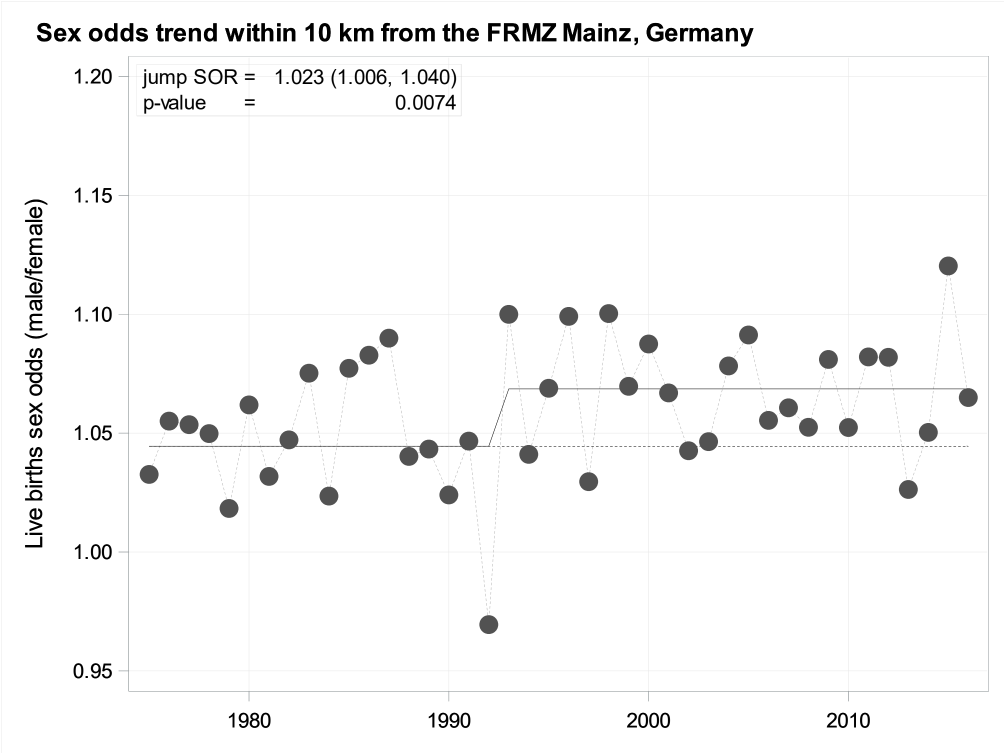

Figure 3 B. Sex odds trend for the combined municipalities within the 10 to 25 km ring around the FRMZ allowing for a jump in 1993 (per Table 1 and Figure 2).

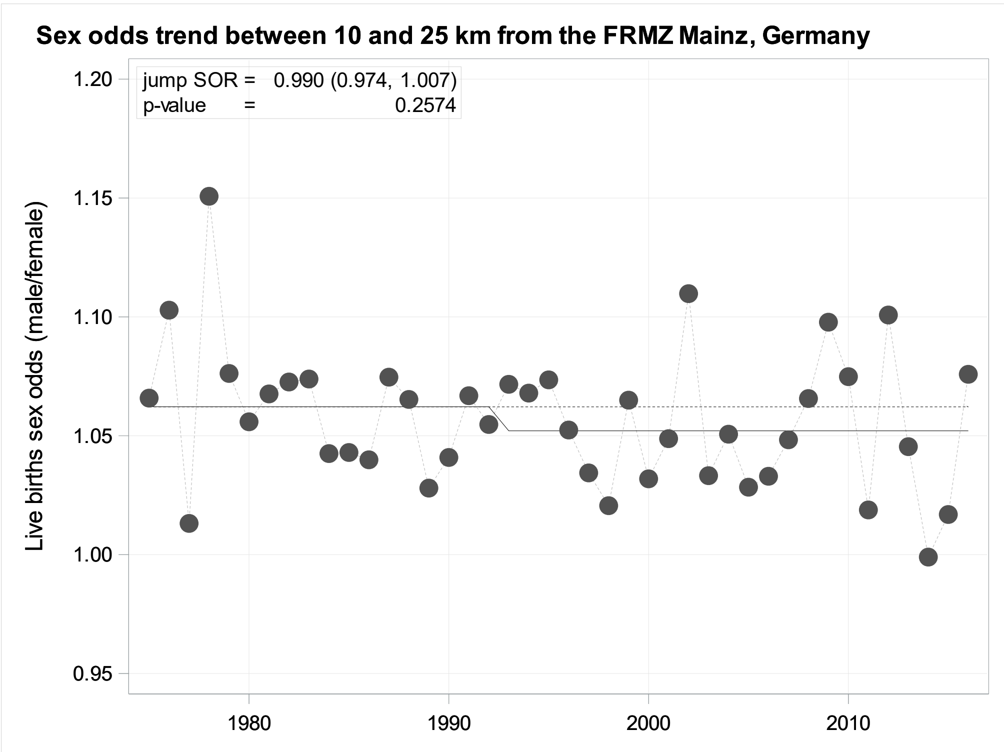

Figure 4 A. Absolute gender-specific birth counts for the combined municipalities within 10 km around the FRMZ allowing for changes in 1993: drop in boys 4.01%, p-value 0.0251, and drop in girls 6.17%, p-value 0.0005; solid line: full model, broken line: reduced null-effect model.

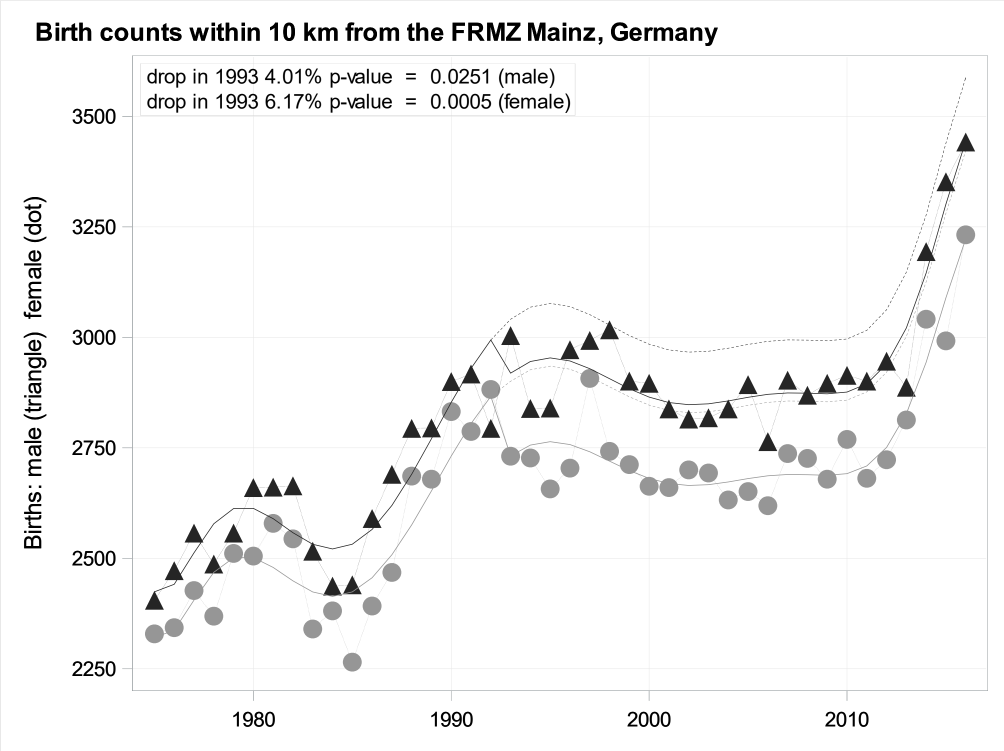

Figure 4 B. Absolute gender-specific birth counts for the combined municipalities within 10 to 25 km around the FRMZ allowing for changes in 1993: increase in boys 0.46%, p-value 0.7903, and increase in girls 1.43%, p-value 0.4162; solid line: full model, broken line: reduced null-effect model.