This Is Only a Test?
Long-Run and Intergenerational Impacts of Prenatal Exposure to Radioactive Fallout[1]

by

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Abstract

Research increasingly shows that differences in endowments at birth need not be genetic but instead are influenced by environmental factors while the fetus is in the womb. In addition, these differences may persist well beyond childhood. In this paper, we study one such environmental factor – exposure to radiation —that affects individuals across the socio-economic spectrum. We use variation in radioactive exposure throughout Norway in the 1950s and early 60s, resulting from the abundance of nuclear weapon testing during that time period, to examine the effect of nuclear exposure in utero on outcomes such as IQ scores, education, earnings, and adult height, as well as whether these effects persist into the next generation. We find that exposure to low-dose nuclear radiation, specifically during months 3 and 4 in utero, leads to a decline in IQ scores of men aged 18. Moreover, radiation exposure leads to declines in education attainment, high school completion, and earnings among men and women. We are also able to examine whether these effects persist across a second generation – Importantly, we find that the children of persons affected in utero also have lower cognitive scores, suggesting a persistent intergenerational effect of the shock to endowments. Given the lack of awareness about nuclear testing in Norway at this time, our estimates are likely to be unaffected by avoidance behavior or stress effects. These results are robust to the choice of specification and the inclusion of sibling fixed effects.

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Introduction

There is a large literature documenting the substantial persistence in early childhood endowments. Increasingly, the evidence shows that differences in endowments at birth need not be genetic but instead are influenced by environmental factors while the fetus is in the womb, and these differences can persist into adult life. This includes studies on the effects of the 1918 flu epidemic (Almond, 2006), the 1957 Asian flu pandemic (Kelly, 2011), the 1959 to 1961 Chinese famine (Almond, Edlund, Li, and Zhang, 2010), the Dutch famine in 1945-46 (Scholte, van den Berg, and Lindeboom 2012), and the effects of maternal smoking and drinking (Currie, Neidell and Schmieder, 2009; Fertig and Watson, 2009).[2] There is much less evidence on the intergenerational consequences of these environmentally-induced shocks to endowments, with some of the most convincing work showing that exposure to famine while in utero has effects on the birth weight and sex composition of the offspring of the exposed children (Almond *et al.,* 2010, Painter *et al.,* 2008). In this paper, we advance both of these literatures by studying the effects of one such environmental factor – exposure to radiation—on both the long-run outcomes of exposed children as well as the IQ scores of their adult offspring. Unlike other factors that disproportionately affect one part of society, nuclear exposure affects members of all socioeconomic groups.

This paper uses variation in radioactive exposure throughout Norway in the 1950s and early 1960s resulting from the extensive nuclear testing during that time period to examine the effect of low-dose nuclear exposure in utero on later-life outcomes such as IQ scores, education, height, and earnings. Importantly, we are also able to examine the effect of the radiation on IQ scores at age 18 of the next generation, allowing us to identify the extent to which the shock to endowments persists across generations.

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[2] See Currie (2011) for a review.

Norway provides an ideal laboratory for this type of analysis; because of its geographical location and topography, with high precipitation in coastal areas, Norway received considerable radioactive fallout from Russian atmospheric nuclear weapons tests in the 1950s and 60s (Storebø, 1958, Hvinden and Lillegraven, 1961). Regional fallout was determined by wind, rainfall, and topography; we use this variation across Norway and over time for identification.

Since the bombings of Hiroshima and Nagasaki, there has been much work in the medical literature studying the effect of nuclear fallout on health and on the cognitive ability of children in utero during the bombings (see, e.g., Otake and Schull, 1984). More closely related to our work are the studies outside the medical field that have examined the impact of the Chernobyl disaster on children who were in utero when it occurred. One important study was done by Almond, Edlund and Palme (2009), who find that low-dose exposure in utero leads to lower test scores in school.[3] Our paper adds to this literature by focusing on the longer-run effects of low doses of radiation from global nuclear fallout resulting from nuclear weapon testing. Because we are able to incorporate both cross-sectional as well as time-series variation in exposure over a longer period of time, we are able to verify the conclusions drawn by the medical literature (with much smaller samples) by documenting that it is months 3 and 4 of pregnancy that are most sensitive to exposure. Finally, we also add to the literature by studying cognitive scores of the second generation (the children of the generation affected in utero), thus identifying the intergenerational effects of exposure to radiation.

We find that exposure to nuclear fallout in the air or on the ground, even in low doses, leads to a decline in men's IQ scores at age 18, completed years of education, and earnings at age 35. Among women, radiation exposure leads to declines in educational attainment and high

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[3] More recently, Halla and Zweimuller (2014) study the effect of Chernobyl on Austrians who were in utero and find evidence of adverse effects; they also examine whether parents change their investment behavior and find some evidence of compensating parental responses.

school completion, and lower earnings at age 35. Additionally, there is evidence that the children of the affected generation also have lower cognitive scores, and we are able to calculate the degree of intergenerational transmission. These results are robust to the choice of specification, tests of selection, and the inclusion of sibling fixed effects.

Unlike the nuclear bombings of Hiroshima and Nagasaki in 1945 and the accident in the nuclear power plant in Fukushima in 2012, there was very little public awareness in Norway of the exposure to nuclear fallout resulting from nuclear testing taking place in foreign countries.[4] Moreover, the first medical studies analyzing the effect of nuclear fallout on cognitive achievement were only published in the 1980s (see, e.g., Otake and Schull, 1984).[5] Therefore, there is no reason to expect that avoidance behavior is important. This additionally implies that our health effects cannot be explained as resulting from stress due to worry about the effects of radiation.[6]

The paper unfolds as follows. Section II describes the relevant history of nuclear testing affecting Norway. Section III describes our empirical strategy and Section IV describes our data. Section V presents the results for the effects of exposure on children in utero along with a variety of robustness checks, and Section VI presents results for the second generation—the children of these children. Section VII then concludes.

II. Background

Nuclear Testing

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[4] It was not the Norwegian government that established test stations in Norway during the 1950s but the US and British military who were interested in collecting information about test activity in the Soviet Union.

[5] There were indicative studies prior to this suggesting health risks from radiation. However, there was no broad public knowledge about this.

[6] Stress during pregnancy has been linked to poor infant health outcomes (Kuzawa and Sweet, 2009; Black, Devereux, and Salvanes, 2014).

There was intensive nuclear weapon testing worldwide in the periods 1952–1954, 1957–1958, and 1961–1962 (see Appendix Figure A1), with deposition rates peaking in 1963.[7] According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 520 tests were conducted in the atmosphere - most of them prior to 1963. These atmospheric nuclear weapons tests are considered to be the most significant source of radioactive fallout; contamination resulting from underground nuclear weapon testing is, from a global perspective, negligible.

A nuclear weapon test produces about 150 fission products with half-lives long enough to contribute to radioactive fallout. In general, the fallout can be divided into three components: 1. large particles that are deposited from the atmosphere within hours of the test, 2. smaller particles that remain in the troposphere only a few days, and 3. longer-lived particles such as Cesium (CS-137), Strontium (Str-90), Rubidium (Ru-103), Xenon (Xe-133), Iodine (I-131) and Barium (Ba-140), that are injected into the stratosphere (Bergan, 2002). Radioactive debris injected into the stratosphere -- so-called “global fallout” -- trickles down slowly to the troposphere; from there, debris is deposited on the ground mainly through precipitation. Differences in the rate of deposition across locations can thus primarily be explained by temporal and spatial variation in precipitation. Because the fallout cloud disperses with time and distance from the explosion, and radioactivity decays over time, the highest radiation exposures are generally in areas of local fallout.[8]

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[7] On October 10, 1963, a partial test ban treaty came into force, banning nuclear tests in the atmosphere, underwater and in space. The treaty was not signed by France and China; as a result, the last atmospheric explosion was performed by China as late as October 1980.

[8] According to UNSCEAR (1993) fallout activity deposited close to the test sites accounts for 12% of total fallout, tropospheric fallout, which is deposited in a band around the globe at the latitude of the test site, for 10%, and global fallout, which is mainly deposited in the same hemisphere as the test site, for 78%. As most tests were carried out in the northern hemisphere, most of the radioactive contamination is also found there.

Immediately following a nuclear explosion, the activity of short-lived radionuclides is much greater than that of long-lived radionuclides. However, the short-lived radionuclides such as Iodine-131 with a half-life of 8 days decay substantially during the time it takes the fallout cloud to reach distant locations like Norway, and the more long-lived radionuclides such as Ruthenium-103 or Zirconium-95 with half-lives of several months become relatively more important. In the polar region, radionuclides remain in the stratosphere on average from 3 to 12 months (UNSCEAR, 1982).[9] Bergan (2002) estimates the average age of the fallout in Norway to be between 3 and 5 months during the intensive testing periods.

The western Norwegian coastline was particularly exposed to atomic fallout coming from nuclear testing taking place in Novaya Zemlya in the Russian arctic archipelago, one of the most intense test regions between 1955 and 1962. The macro weather system is the primary force that moved long-lived radionuclides from Russian test stations to their ultimate deposition along the Norwegian coast: cold air over the poles creates high pressure zones taking the air to lower latitudes.[10]

Figure 1 shows estimates of the *in situ* total Beta fallout in each municipality in Norway in 1958, 1960, 1962, and 1964.[11] The activity of fallout in the air or on the ground or other surfaces is measured in becquerels (Bq), which is defined as the number of radioactive

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[9] The polar region is down to the 60 degree latitude (about where Bergen is located in south west Norway), and most of the time the radionuclides from the test sites in Northern Russia were transported in this zone.

[10] Due to the Coriolis forces, the cold dry air moves away from the pole twisting westward resulting in the so-called polar easterlies. Thus, these winds carry air from Northern Russia southwest towards the Norwegian Sea and Iceland. At around 60 degrees north, the airstream enters the low pressure zone and the air is brought eastwards again towards the Norwegian coast. Moreover, the polar jet streams located right below the stratosphere at around 60 degrees north also distributed long-lived nuclear debris over the globe.

[11] We use the phrase "*in situ*" to denote nuclear fallout that has been deposited to the ground (as distinct from being suspended in the air).

disintegrations per second.[12] The fallout varies significantly by municipality and also over time. There was an international moratorium on nuclear testing from November 1958 to September 1961 so Norway received almost no fallout in the second half of 1959, in 1960, and throughout most of 1961. The partial test ban treaty in October 1963 led to very little fallout in 1964 or in subsequent years. However, there is significant fallout in 1957 and 1958 and, even more so, in 1962 and 1963 because the explosions after the expiration of the moratorium were much larger than before. This results in substantial time series variation in addition to that across municipalities.

Prenatal Radiation Exposure and Cognitive Damage

Following the deposition of fallout into the air and on the ground, there are different means by which people absorb radiation. Irradiation might come from penetrating gamma rays emitted by particles in the air and on the ground. In this case, simply staying inside a building reduces exposure. Moreover, people inhale fallout or absorb it through skin. A further source is the consumption of contaminated food. Vegetation can be contaminated when fallout is directly deposited on the surface of plants, or when it is deposited on the ground and plants absorb it through their roots. People can also be exposed when they eat meat and drink milk from animals grazing on contaminated vegetation or if they drink contaminated water.

It is well established that ionizing radiation can lead to molecular, cellular, and tissue damage (see, e.g., Hall, 2009). Importantly, actively dividing cells are known to be more sensitive to ionizing radiation than cells that have completed division (see, e.g., ICRP, 1986). As

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[12] The initial measurements in Norway were made in picoCurie. We have converted these into Bq as this is the current standard unit of measurement.

cell cycling and division occur more rapid early in life, the age at the time of exposure to ionizing radiation is an important factor in determining the damage to the developing brain.

While formation of most human organs is largely complete by the 8th week after conception, the development of the cerebral cortex occurs rapidly from weeks 8 to 15 post-conception. The neocortex is the part of the cerebral cortex that is involved in higher functions such as sensory perception and generation of conscious thought and language, and medical evidence suggests prenatal exposure to ionizing radiation is particularly harmful if it occurs during this 2-month period of time (see, e.g., Otake and Schull, 1998). By the 16th week of pregnancy, the normal number of neurons in the cerebral neocortex of the human adult has been established (see Dobbing and Sands, 1973). During weeks 16 to 25 after conception, the differentiation of cells accelerates, and after the 25th week, the central nervous system becomes quite resistant to radiation. At that point, major fetal brain damage becomes highly improbable (see, e.g. ICRP, 1991; Otake and Schull, 1998).

The first studies indicating that iodizing radiation causes cognitive abnormalities were analyses of individuals exposed in utero to diagnostic X-ray procedures in the 1980s (see, e.g., Brent, 1989). However, most evidence on the effects of acute exposure to ionizing radiation has been obtained from studies on the survivors of the atomic bombs at Hiroshima and Nagasaki. Different studies using a variety of measures of cognitive function, such as the occurrence of severe mental retardation, the intelligence quotient (IQ) and school performance, find a significant effect on individuals exposed during weeks 8 to 15 and weeks 16 to 25 after conception. However, no evidence of a radiation effect has been seen among children exposed prior to the 8th week or subsequent to the 25th week after conception (see, e.g., Otake and Schull, 1984; Otake, Yoshimaru, and Schull, 1989; Miller and Mulvihill, 1956). Moreover, Otake and

Schull (1998) report that the risk of severe mental retardation was 5-times greater for persons exposed during weeks 8 to 15 post-conception than for individuals exposed during weeks 16 to 25 post-conception. It is important to note that this literature is quite removed from our framework given the extreme circumstances.

However, these survivor studies are limited in that they analyze the effects of a single, relatively high dose and not of small, intermittent, or continual doses typical of medical, professional, or environmental exposure. Studies evaluating the impact of smaller doses of radiation, such as those experienced in Sweden after the reactor incident in Chernobyl, on early health outcomes such as spontaneous abortion, stillbirth, length of gestation, birth weight, and neonatal mortality, are not conclusive. Some find effects of prenatal exposure, while others do not (see, e.g., Lüning *et al.*, 1989; Ericson and Källén, 1994; Sperling *et al.*, 1994; Scherb, Weigelt, and Brüske-Hohlfeld, 1999; Auvinen *et al.*, 2001, Laziuk *et al.*, 2002). However, studies focusing on cerebral dysfunctions do suggest that the prenatal exposure to radioactive fallout after Chernobyl resulted in detectable brain damage or lower schooling performance and fetal death (see, e.g., Nyagu *et al.*, 2004; Almond *et al.*, 2009, Halla and Zweimuller, 2014).

The potential to extrapolate the Japanese or Ukrainian findings to those from the nuclear weapon testing fallout is limited. The global fallout from the testing yielded no fatal doses in Norway, but during periods of the 50s and 60s the population was continuously exposed to radionuclides. In contrast, the Japanese population was acutely irradiated by γ-rays and neutrons and the Ukrainian population also received a high dose of radioiodine. Because of the different situations, it is not easy to predict the radiobiological effect of the global fallout received by Norway from the Japanese or Ukrainian results. Importantly, unlike most of the literature, we are able to confirm that, even with low-dose exposure, it is months 3 and 4 of the pregnancy that matters.[13]

III. Empirical Strategy

To measure the long-run effects of nuclear fallout on cognitive test scores, height, education and income, we exploit the variation in radioactive fallout in Norway within geographic areas over time. We use a similar approach to that in the Chernobyl study of Almond *et al.* (2009) but incorporate the fact that we have variation over a relatively long period of time as well as across space. The amount of fallout experienced by any individual depends on their month of birth, year of birth, and municipality of birth.

Basic Specification

We estimate the following equation:

$$H_{ict} = \alpha_0 + \alpha_1 F_{ct} + \beta X_{it} + \gamma_t + \lambda_c + \epsilon_{ict}. \quad (1)$$

Here H_{ict} represents outcomes such as education, IQ score, height and earnings for child i born in municipality c at time t. We will use the same specification in the intergenerational analysis where H_{ict} then represents the outcomes of the offspring of the exposed children. F is a vector indicating fallout in each month of pregnancy, beginning 3 months before conception (as a placebo) and ending three months post-birth. X is a vector of controls that includes parental education, the county level unemployment rate when the child was in utero, and birth order

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[13] Oftedal (1989) evaluates the effect of radiation exposure on scholastic achievement of the 1965 cohort in Norway by hypothesizing that children from the west of Norway should have been more exposed than those from the east and the degree of exposure should vary by season of birth. He compares school test grades from a 10 percent sample of seventh graders in the two regions and finds deviations by region that differ by month-of-birth. He concludes that scholastic achievement is reduced in children exposed in utero to radiation. Unfortunately, the work is limited in that he studies only one cohort that is born two years after the test-ban treaty, and he has no measures of geographic dispersion of radiation.

indicators (family size at birth of child). We also include controls for year of birth by month of birth indicators (γ_t) and municipality fixed effects (λ_c); we are therefore comparing individuals born within the same municipality but born in different month/year of birth (and thus exposed to different levels of radiation in utero).[14] We use OLS estimation; in the case of high school completion, we are estimating a linear probability model.

Specification with Municipality-Specific Trends

One concern might be that our results are driven by different trends in municipalities that are exposed to high doses of radiation relative to those that are not. While we examined this directly and found no evidence of differential trends in the observable control variables during this time period, we also report estimates from a specification that allows for municipality-specific linear trends.[15] These trends are included in addition to the year of birth by month of birth indicators.

Specification with Interactions

As a further robustness check, we also estimate a richer model that adds interactions of the municipality dummies with month of birth (to allow for seasonal factors that differ by area) and interactions of the municipality dummies with year of birth (to allow cohort effects to differ by municipality). Note that we cannot include the interaction of year of birth by month of birth

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[14] An alternative to this difference-in-difference type strategy is to use time-series variation in fallout. We have tried this approach by replacing the year of birth by month of birth dummies with a time trend and found effects that have the same sign and statistical significance but smaller magnitudes. Because this is a period of rapid changes in educational infrastructure and in compulsory schooling laws, we have more faith in specifications that include cohort effects.

[15] Results on differential trends for control variables are available from the authors upon request.

by municipality, as that is our identifying variation. Letting y denote year of birth and m denote month of birth, we estimate

$$H_{ict} = \alpha_0 + \alpha_1 F_{ct} + \beta X_{it} + \gamma_t + \lambda_{cy} + \mu_{cm} + \epsilon_{ict}. \quad (2)$$

This model is still well identified as there is much variation in fallout over the course of any particular year that is not driven by seasonal factors but instead by the timing of nuclear tests in the Soviet Union.

Sibling Fixed Effects Model

While exposure is arguably exogenous to family and neighborhood characteristics within municipalities, one might still worry that non-random migration might change the composition of people in the municipality over time. Furthermore, the composition of the sample could be correlated with the fallout if there are changes over time and region in the types of people who give birth and these are, by chance, correlated with fallout levels.[16] While we have no evidence that this is the case, we also estimate a specification that includes sibling fixed effects. Variation is then based on differences in exposure within families across children, thereby differencing out anything that is constant within families such as socio-economic status.[17]

IV. Data

Data are compiled from a number of different sources. Our primary data source is the Norwegian Registry Data, a linked administrative dataset that covers the population of

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[16] In the U.S., birth selectivity by socio-economic status has been found to differ by month of birth (Buckles and Hungerman, 2010) and by economic conditions (Dehejia and Lleras-Muney, 2004).

[17] Because nuclear radiation may affect later fertility, as a specification check, we have estimated the sibling fixed effects model on a subset where the exposed child is not the first-born and compare this child to existing children and find similar results. We also look at fertility directly and find no effects of exposure on later fertility behavior; this is unsurprising, given the lack of knowledge about exposure at the time.

Norwegians up to 2009 and is a collection of different administrative registers such as the education register, family register, and the tax and earnings register. These data are maintained by Statistics Norway and provide information about educational attainment, labor market status, earnings, and a set of demographic variables (age, gender) as well as information on families.[18] We include data for cohorts born 1956-1966.

Using month and year of birth, and assuming that a pregnancy lasts 266 days, we can identify the months of pregnancy (ranging from 1-9). Importantly, we assume that exposure to low-dose radiation does not affect the duration of a pregnancy, which is consistent with the findings of the Chernobyl study of Almond *et al*. (2009).[19] We allocate a municipality to each child born between 1956 and 1964 using the 1960 Census by assuming that the municipality during pregnancy is the mother's municipality of residence in 1960. For individuals born in 1965 and 1966, we are able to use register data on the exact municipality where the mother lived when the child was born.

Military Data

The IQ score and height data are taken from the Norwegian military records that cover all the cohorts we study. Before young men enter the service, their medical and psychological suitability is assessed; this occurs for the great majority between their eighteenth and twentieth birthday. In Norway, military service is compulsory for every male; as a result, we have military data for men only.

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[18] See Møen, Salvanes and Sørensen (2004) for a description of these data.

[19] If radiation did decrease gestational length, this would cause us to overestimate the effects of radiation in later months and understate it in earlier months.

The IQ measure is the mean score from three IQ tests -- arithmetic, word similarities, and figures (see Sundet *et al*. [2004, 2005] and Thrane (1977) for details). The arithmetic test is quite similar to the arithmetic test in the Wechsler Adult Intelligence Scale (WAIS) (Sundet *et al*. 2005; Cronbach 1964), the word test is similar to the vocabulary test in WAIS, and the figures test is similar to the Raven Progressive Matrix test (Cronbach 1964). The IQ score is reported in stanine (Standard Nine) units, a method of standardizing raw scores into a nine point standard scale that has a discrete approximation to a normal distribution, a mean of 5, and a standard deviation of 2.[20]

Education

We measure educational attainment in 2009 and use two measures of education achievement. High school graduation is an indicator equal to one if the child obtained a three-year high school diploma. We also consider the years of education completed by the individual. The data are based on school reports sent directly to Statistics Norway by educational institutions, thereby minimizing any measurement error due to misreporting.

Earnings

Earnings are measured as annual earnings for taxable income as reported in the tax registry when the individual is aged 35. These are not topcoded and include labor earnings, taxable sick benefits, unemployment benefits, parental leave payments, and pensions.[21]

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[20] The correlation between this IQ measure and the WAIS IQ score has been found to be 0.73 (Sundet *et al*., 2004).

[21] An individual is labeled as employed if currently working with a firm, on temporary layoff, on up to two weeks of sickness absence, or on maternity leave. We later test the sensitivity of our results to the choice of income measure.

Data on Nuclear Fallout

In the period from 1956 to 1984, the Norwegian Defense Research Establishment (FFI) monitored radioactivity in the air and on the ground at 13 stations across Norway.[22] They collected two primary measures of radiation: (i) a measure of the total beta radiation in the air expressed as Bq/m^3, and (ii) a measure of the total beta radiation *in situ* (ie on the ground) expressed in Bq/m^2.[23] Radioactivity in the air was measured 2 meters above ground level using air filters, and the filters were changed every 24 hours. The samples were sent to the main laboratory of FFI near Oslo, and a Geiger-Müller counter measured the total beta activity 72 hours after the samples were collected.[24] Precipitation (rain, snow) and dry particles were also collected at each test station for the measure of ground deposition.[25] Beta activity came from many isotopes with half-lives of less than a year such as Rubidium (Ru-103), Xenon (Xe-133), Iodine (I-131) and Barium (Ba-140), and also longer-lived ones such as Strontium (Str-90) and Cesium (CS-137), with half-lives of 28 and 30 years respectively.

These two measures of deposition (air and ground) have a correlation coefficient of 0.75, implying that they are highly -- but far from perfectly -- correlated. Figures 2a and 2b show the two measures for Oslo and Bergen. One can see that the temporal pattern differs for the two measures. This is not surprising as ground deposition is largely determined by rainfall while

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[22] The locations of measurement stations for radioactivity are (from North to South in Norway): Vadsø, Tromsø, Bardufoss, Bodø, Værnes (close to Trondheim in mid Norway), Røros, Ålesund, Bergen, Finse, Sola (close to Stavanger), Gardermoen (close to Oslo), Kjeller (also close to Oslo), Kjevik (close to Kristiansand).

[23] We obtained the raw data collected for deposition in air and ground measured in picoCurie/m^3 and picoCurie/m^2, respectively. Bergan digitalized the original protocols to obtain the radiation data (Bergan, 2002, 2010, Bergan and Steenhuisen, 2012).

[24] This implies that the short-lived radioisotopes from the decay of Radon had already died out. This is important since Radon is not randomly distributed across regions and its presence might contaminate our estimates of the effects of the fallout from the nuclear tests.

[25] These samples were sent to the same laboratory and total beta activity was measured with the Geiger-Müller counter. In order to identify the source of the radioactive rays, a gamma ray spectrometer was used to identify the different isotopes. See Bergan (2002) for further details about radiation measurement.

fallout in the air is more related to the presence of centers of high air pressure as well as influxes of warm subtropical air (Bergan and Steenhuisen, 2012).

There are 13 test stations and about 730 municipalities in Norway during this period. To minimize the measurement error in our measure of nuclear fallout, we limit our sample to municipalities within 20km of a test station.[26] We have tested the sensitivity of our results to different distance cutoffs and find the results are insensitive to this choice.

For radiation in the air, we estimate the fallout for each municipality in our sample in each month by using the fallout at the geographically closest measuring station. For radiation on the ground, we estimate the fallout for each municipality in each month by using the fallout at the geographically closest measuring station and then weight that by the precipitation in that month in the municipality relative to the precipitation in that month at the measuring station.[27] This is equivalent to:

$$F_{ct} = F_{st} \frac{P_{ct}}{P_{st}}, \quad (3)$$

where F_{ct} measures the nuclear fallout in municipality c at time *t* and F_{st} represents the nuclear fallout at the closest test station s at time t. P_{it} measures the precipitation in month *t* in municipality c or s. The reason for weighting by the precipitation relative to that at the test station is that the measured ground deposition is already affected by the amount of rain in the test station area. The re-weighting implies that there will be more fallout in areas of relatively heavier rain and less in areas of relatively less rain.[28]

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[26] This leaves 42 municipalities. See Table 1 for a comparison of our sample to the total population.

[27] Hvinden, Lillegraven and Lillesæter (1965) claim that removal of debris from the troposphere is proportional to precipitation in Norway and tropospheric concentration (see also Lillegraven and Hvinden, 1982). Moreover, Bergan (2002) states that "The fallout is correlated to the amount of precipitation and concentration in air, and the deposited radioactivity is proportional to monthly precipitation." (page 206).

[28] We have also tried using the in situ total beta directly without weighting by the relative rainfall and obtained very similar results. This is unsurprising as we only include municipalities that are within 20km of a test station.

The rain measures come from the Norwegian Meteorological Institute and are available by month for each municipality. The precipitation map of Norway (Figure A2) demonstrates that there are large differences in annual precipitation; precipitation is higher along the west and north coast of the country. Some of the measuring stations along the west coast have more than 3000mm average precipitation per year, while other stations measure yearly precipitation of less than 400mm. This massive variation in rainfall (as shown in Figure A2) is due to the mountain range that divides the country; this resulted in large local variations in deposited radioactivity.[29]

In Figure 3a and 3b we present the monthly beta fallout at the measuring stations in or close to 5 Norwegian cities from 1956 to 1975.[30] The figures show substantial variation over time and location.

Summary statistics for our first-generation sample are presented in Table 1a, along with descriptive statistics for the whole country. Because our sample is disproportionately urban, education levels are higher in our sample than in the country as a whole. Table 1b presents summary statistics for the sons of the exposed generation (second generation) and describes the sample we use to analyze whether our findings persist into the next generation.

V. Results-First Generation

Basic Specification

We first present the results for IQ scores for men using the two different measures of radiation exposure (in separate regressions), the beta radiation from the air and the in situ, or

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[29] Similarly Mattsson and Vesanen (1988) report that 99% of deposition from Chernobyl in western Sweden was due to rainfall (see Almond *et al.*, 2009).

[30] There is a measuring station located within the municipality border of Bergen, Røros (central Norway) and Vadsø (northern Norway). The measuring station close to Stavanger is located in the Sola municipality, a neighboring municipality of Stavanger, and is located about 10km from the city center of Stavanger. The measuring station in Kjeller is the closest to Oslo and it is about 20 km away from the city center.

ground, radiation. For ease of interpretation, when included in regressions, both measures of radioactive exposure are standardized to have mean zero and variance one.

Table 2 presents the results for men when IQ score is the outcome. Each column is a separate regression that includes the standardized measure of exposure in each month of pregnancy, in the 3 months before conception and the 3 months after birth. The first 4 columns present the results using in situ exposure and the second 4 columns use air exposure.

Each regression also includes individual control variables, including indicators for mother's and father's education, birth order controls, and the unemployment rate in the year of birth in the county of birth. However, the results are insensitive to the inclusion of these controls.[31] As the IQ score is taken from the Norwegian military records and military service is compulsory only for men, this analysis is restricted exclusively to men. We cluster the standard errors by municipality and so allow arbitrary correlations of the error terms for people born in the same municipality. However, we also tested the sensitivity of our conclusions to various assumptions about the standard errors and found them to be quite robust.[32] We have also verified that the results are robust to the exclusion of any individual measuring station, a potential concern given the existence of only 13 stations in our sample.

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[31] For parsimony, we don't report results without controls in the tables. These are available from the authors upon request.

[32] It is natural to cluster at the municipality level, as most shocks are likely to be common to people in the same municipality (for example, elementary and middle schools are run at the municipality level). We have also tried clustering the standard errors at the level of the 13 measuring stations, at the level of measuring station by year, and at the level of measuring station by subperiod where we define 4 subperiods as the initial testing period, the low-fallout moratorium period, the intensive post-moratorium testing period, and the post-test ban treaty period. All these clustering schemes give similar standard errors to those we report. One final approach we take is to consider clustering at the station level using the wild cluster bootstrap percentile-t approach (Cameron, Gelbach, and Miller, 2008) to generate p-values, as there is some evidence that this method performs well with small numbers of clusters. Because it is recommended to impose the null hypothesis when using this method, we have implemented this on a specification where we have a single fallout variable in the regression – average fallout in months 3 and 4. Using this conservative method, our estimates for IQ score, years of education, and high school graduation remain statistically significant but our estimates for earnings do not.

Columns 1 and 5 present results from our basic specification that controls for municipality and month of birth by year of birth fixed effects. Columns 2 and 6 then show the results when we add municipality-specific time trends. Columns 3 and 7 present the results from the most saturated model, including municipality-specific month of birth and municipality-specific year of birth controls. In all specifications, we find that radioactive exposure in months 3 and 4 of pregnancy, even the relatively small doses experienced in Norway from the Russian nuclear testing in the 1950s and 1960s, appears to have a significant negative effect on the IQ score of exposed males. This is true regardless of the measure of exposure that we use.[33] To get a sense of the magnitude from the standardized measure, a one standard deviation increase in ground exposure leads to a decline in the IQ score of about 0.04. Given the standard deviation of the IQ score is about 2, this is an effect size of about 0.02 of a standard deviation. The effect of air exposure is larger with a one standard deviation increase in exposure leading to about 0.06 of a standard deviation fall in the IQ score. This is equivalent to about 1 IQ point on a standard IQ scale.

The other key finding from this table is that there is no systematic evidence of effects of radiation exposure in any other pregnancy month. One partial exception to this is that there is some evidence for a smaller adverse effect from radiation in month 5. However, in general, the findings are consistent with adverse effects of radiation being confined to months 3 and 4.

Sibling Fixed Effects

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[33] It is also interesting to note that we find the same effects when we include the radioactive exposure of each month of the pregnancy in separate regressions; this is a more rigorous test, as it demonstrates that there is not a significant amount of persistence across time in the measures of fallout.

We also estimate a specification that includes sibling fixed effects, restricting the sample to families in which there are at least two children born during the period.[34] The control variables included in these fixed effects estimates are birth order, the unemployment rate, and year of birth by month of birth dummies. These results are presented in Columns 4 and 8 of Table 2.[35] The sibling fixed effects results are similar to our earlier findings, with IQ score at age 18 significantly affected by exposure in months 3 and 4 but with little evidence of any effects in other months.

Other Outcomes

Given the robustness of our IQ score results to our choice of specification, the remaining tables present the results from the primary specification that includes both year by month of birth fixed effects and municipality fixed effects.

Tables 3a and 3b present the results for the other outcomes for both men and women (estimated separately) with the two different measures of exposure—Table 3a uses in situ exposure and Table 3b uses air exposure. Importantly, it is clear again that it is months 3 and 4 in utero when exposure has a significant effect on education and earnings. When we look at the results for educational attainment and high school completion, we find that radioactive exposure seems to have a negative and statistically significant effect on education among men. Similarly, there is a significantly negative effect of exposure on the educational attainment of women; again, this is robust to the measure of exposure used. The magnitudes suggest that a one standard deviation increase in ground exposure during months 3 and 4 reduces educational attainment by 0.08 years for men and 0.1 years for women, with effects on high school completion of less than

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[34] We also restrict the sample to siblings who were born in the same municipality. This restriction affects very few families and has little impact on the results.

[35] We do not report OLS estimates for the fixed effects sample, but they are similar to those for the full sample.

1 percentage point for men and about 1 percentage point for women. We also find statistically significant negative effects on earnings at age 35 for both men and women.[36]

For boys, we can also study height at around age 18. The evidence for adverse effects on height is much weaker, with little evidence of a consistent pattern. These weaker results for height are unsurprising as the scientific research speaks to the effects of radiation on cognitive rather than physical development.

Given that there is no guidance from the medical literature as to the appropriate functional form, we also estimate our results using the log of fallout as the variable of interest. These results are presented in Tables 4a and 4b. The same pattern of results emerges with exposure in months 3 and 4 having a negative effect on IQ score, education, and earnings. However, there is no evidence that radiation during these months affects male height. Also, there is little evidence for any effect of radiation during other months on any of the outcomes. The magnitudes are such that a 10% increase in in situ radiation reduces education by about .01 of a year and decreases earnings by about one fifth of a percentage point.

Further Robustness Checks

We also conducted a number of further robustness checks. In one case, we include a direct measure of rainfall in addition to the other controls in our regressions. If one worries that it is the rainfall itself, and not the associated fallout, that is driving our results, this would address that concern. (Note that the municipality-specific month of birth effects would likely pick up these effects already, to the extent that this is a seasonal effect.) Not surprisingly, the results are largely unaffected by the inclusion of this variable. As a further test, we also examined the effect

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[36] Our findings on educational outcomes are consistent with Oftedal's (1989) results for the effect of radioactive fallout on scholastic achievement at age 14.

of rainfall on child outcomes during the period of the moratorium (October 1958 to May 1961) when Norway received very little fallout. We find no effect of rainfall during this period.

We also tested the sensitivity of our results to the choice of income measure. One might be concerned about the arbitrary nature of our choice of income at age 35. As a robustness check, we estimated results with the average income between ages 30 and 35 and average income between 35 and 40. The results are very similar.

Finally, we also tried including both measures of fallout (air and ground) in the same regression. For ease of exposition, in the following results, we limit our measure of exposure to the average of that in months 3 and 4 of the pregnancy. These results are presented in Table 5. Surprisingly given the high correlation between the two measures, we find statistically significant effects for both measures. This suggests that there may be adverse effects both from inhaling radiation from the air, and from ingesting ground radiation through food or water.

Tests for Selection

One possible selection issue arises if fallout exposure leads to miscarriages, stillbirths, or infant mortality. To the extent that the weakest fetuses are affected, this would tend to lead to an underestimate of the negative effect of exposure. Although there are no birth registers for the cohorts we study, we do have some data that allow us to study whether exposure to radiation affected the probability of survival of children in-utero. Using county-level data (there are 19 counties in Norway) from the Norwegian vital statistics, we find no effects of average radioactive fallout in the air or in situ on the live birth/still birth ratio or the gender ratio at birth in that county in that year. This is consistent with the findings of Almond *et al*. (2009), who found no evidence that the Chernobyl radiation had an impact on birth outcomes in Sweden.[37]

To the extent that radioactive exposure during one pregnancy changes future fertility decisions, estimates of the effects of radioactive exposure (especially those using sibling fixed effects) may be biased. To test for this, we used administrative registry data to examine whether future childbearing decisions were affected by in-utero exposure of existing children. We found that radioactive exposure of the first or second child has no significant effect on completed family size or on later fertility. It is not surprising that we find no evidence of fertility effects, as, at the time, there was no public awareness of the dangers arising from nuclear testing, particularly testing taking place so far away.

Nonlinearities and Heterogeneous Effects

Quintiles

While we have already estimated specifications with two different functional forms of the fallout measure, we next examine whether there might be other non-linearities in the effects. To do so, we estimate a specification where we split fallout levels into quintiles. Again, for ease of exposition, we limit our measure of exposure to the average of that in months 3 and 4. These results are presented in Table 6 using the original specification (with municipality dummies and year of birth by month of birth effects). We find little evidence for non-linearities, in that the estimates are monotonically increasing in magnitude with quintile and it is only for quintiles 3-5 of exposure that there are any significant negative impacts of radioactive fallout. This result is the same for men and women and for both air and ground fallout.

Varying Intensity of Exposure

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[37] In contrast, Halla and Zweimuller (2014) find evidence of effects of Chernobyl on birth outcomes in Austria.

One might expect effects to be larger in months with more sunlight when individuals are more likely to be outside. As another check, we also estimate specifications where we include an interaction indicating whether the exposure (during months 3 and 4 in utero) occurred during spring or summer months (April-September). Table A1 presents these results. We find statistically significant interaction effects for both ground and air fallout, suggesting that exposure is more harmful during spring and summer months.

Family Background

Finally, the negative effect of poor childhood health on human capital accumulation is often found to be stronger for individuals growing up in a less educated or low-income family (see, e.g., Currie and Hyson, 1999; Currie and Moretti, 2007; Currie, 2011; Almond and Currie, 2010). When we interact the nuclear fallout measures with an indicator variable equal to one if the individual's mother had a high school degree or more, we find that the interaction term is not statistically significant in most cases and the coefficient on the level effect of exposure is quite similar to the earlier estimates (see Table A2). Interestingly, the effect of exposure is actually greater for individuals born to more highly educated parents when we look at years of education for both men and women. This is contrary to what the existing literature would suggest but given the general insignificance of the interaction terms we do not put too much weight on this finding.

Magnitudes

While what we observe is the nuclear radiation in the environment, the most important issue for health effects is the estimated dose individuals absorb. The basic unit to characterize this type of radiation dose is the Sievert (Sv), which is designed to measure biological effects of ionizing radiation. Unfortunately, this dose is very difficult to measure. Bergan and Steenhuisen

(2012) estimate that the annual doses of radiation that resulted from the nuclear fallout in Norway in the 1960s were about 23mSv in Bergen, 5mSv in Stavanger and 4mSv in Oslo. To put this into perspective, the external dose received from natural sources of radiation—from primordial radionuclides in the earth's crust and from cosmic radiation—is of the order of 2mSv per year. The dose from a whole-body computed tomography (CT) examination is about 10mSv, and the external dose from a mammogram breast X-ray is about 0.4mSv.

To get a sense of how our results compare to the existing research, such as that by Almond *et al.* (2009), it is important to first understand the relative magnitude of the exposure to radioactive fallout. The maximum total beta deposited per month in Norway is lower than the maximum CS-134 fallout in Sweden after Chernobyl. To give a better sense of this: The highest ground deposition of CS-134 Almond *et al.* (2009) report is 54kBq/m^2. The highest level of monthly total beta fallout reported by the measuring station in Bergen is 32.7kBq/m^2 in January 1962, 29.9kBq/m^2 in Kristiansand in October 1961, and 16.3kBq/m^2 in Trondheim in October 1958. Moreover, the Swedish population was also exposed to other radionuclides in 1986.

While our estimates are not directly comparable to those of Almond *et al.* (2009), as their main specifications use discrete measures of the degree of exposure of particular regions and they use different measures of radioactive fallout, it is still useful to try to get a sense of relative magnitudes. When they study the effect of log fallout (both air and ground) on compulsory school math scores, they estimate coefficients that are similar in magnitude to the standard deviation of the dependent variable. Our log coefficients for IQ score are about -.04 for ground and about -0.25 for air. These are approximately 2% and 12% of a standard deviation of the dependent variable. This suggests that our magnitudes are much smaller than those of Almond *et al*. (2009) although they are more precisely estimated.[38]

VI. Results-Second Generation

Our rich dataset allows us to link across generations and provides a rare opportunity to examine the effects of in-utero exposure to a pollutant on the children of those exposed in utero. As noted earlier, there is little known about the intergenerational consequences of shocks in utero, with the most compelling work examining the effects of a shock in utero on the birth outcomes of their offspring; we are able to examine the effects on the IQ of the offspring at age 18.[39]

There are two possible mechanisms through which exposure could be transmitted across generations. The first and most direct is through biological changes; primordial germ cells, which are the predecessors of women's ovaries or men's sperm cells, develop in the fetal stage; as a result, in utero experiences that affect these cells could be passed on to later generations.[40] The other is a more indirect mechanism; because parents exposed in utero have worse socioeconomic outcomes, this could lead to worse outcomes for their children.[41]

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[38] There are multiple reasons why these differences might arise: the age at which the outcome is measured is different, there are differences in the chemical composition of the nuclear fallout, and the estimated specifications differ.

[39] Almond *et al.* (2010) estimate what they describe as "echo effects" of the 1959-61 Chinese famine on birth weight and sex composition of babies born to women who were in-utero during the famine. We are unaware of any study that has looked at cognitive scores of children born to parents who were exposed to adverse conditions in-utero.

[40] These biological effects have been documented for environmental toxins by Altshuler et al. (2003) and Franklin and Mansuy (2010).

[41] To our knowledge, there is no evidence from the medical literature on the intergenerational transmission of in utero radiation exposure. There are, however, studies analyzing the intergenerational (genetic) damage due to direct exposure to nuclear bombing of Hiroshima and Nagasaki (Satoh et al., 1996), radiotherapy due to cancer (Winther et al., 2003), and of nuclear industry workers (Maconochie et al., 2001). None of these studies finds evidence for health hazards among the survivors' offspring in terms of genetic damages or shifts in gender ratio at birth..

To avoid confusion, we will refer to persons in-utero between 1956 and 1966 as the first generation and refer to their children as the second generation. As mentioned earlier, we have data on IQ test scores for men at age 18/19 up through 2010. This allows us to study the effect of nuclear fallout on IQ for second-generation men (i.e. for sons of the first generation, but not for their daughters).

Of our sample of persons born between 1956 and 1966, 23% of men and 30% of women have at least one male child that has taken the military tests by 2010. A likely explanation for this disparity is that women have children at a younger age than men do, increasing their likelihood of having sons who are old enough to be in our sample.[42]

A key issue that arises in this analysis is whether there is selection into the sample. To address this, Appendix Table A3 shows that the exposure in pregnancy months 3 and 4 has no effect on the probability of having a son that has taken the military exams by 2010 and thereby on the probability of having a child in the second-generation sample. In addition, we find that the fertility behavior (i.e. the probability of having children, number of children, and age at first birth) of the first generation is not affected by the exposure to nuclear fallout. This suggests that selection into our sample is unlikely to be an issue.

We estimate the intergenerational effects of exposure to nuclear fallout using two different specifications. The first includes the same control variables that we used when studying outcomes for the first generation that were pre-determined at the time of the fallout. The second specification includes additional controls for child-specific factors that are likely to have direct effects on IQ scores (family size, birth order, year of birth). While we have found no systematic effects of fallout on fertility behavior of the first generation, there may still be some variation in these control variables that is correlated with exposure of the first generation to radiation. For

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[42] In our sample, the mean age at first child is 28.8 for men and 25.9 for women.

comparability of the estimates across generations, the regressions are weighted such that each first generation parent gets equal weight. We run separate regressions for the sons of first generation men and women and then provide estimates when both are combined. Note that we studied the effects of radiation exposure for both men and women of the first generation but, because our IQ score comes from military tests, it is available only for second generation men (i.e. for sons of the first generation but not for their daughters).

Our intergenerational results are in Table 7a (for in-situ radiation) and Table 7b (for radiation in the air). Note again that the results are showing the effect of exposure of *parents* in utero on the outcomes of their children. Columns (1) and (4) have results with the same controls as before in the regression for the first generation for father's and mother's exposure respectively, while Columns (2) and (5) add the additional second generation controls (year of birth dummies, birth order dummies, and family size). For in-situ radiation, we find statistically significant negative effects of exposure of first generation men in months 3 and 4 in-utero on IQ test scores of the second generation. For exposed women, the effects are also negative and statistically significant for month 4 but not month 3. The addition of the extra controls in Columns (2) and (5) make very little difference to the estimates. For exposure through air, the magnitudes are similar but the standard errors are higher so the effects are generally not statistically significant.

It is of some interest to contrast the effect of fallout on IQ scores of the first and second generations. To the extent that radiation exposure mostly affects cognitive function (as is suggested by the medical literature), the ratio of the two effects will approximate the intergenerational transmission coefficient for IQ. A lot is known about intergenerational correlations of IQ scores (see, for example, Black, Devereux and Salvanes (2009) for estimates for Norway), but little is known about causal intergenerational effects of increasing (or reducing) cognitive abilities in one generation. Because not all first generation men have sons in our sample, Column (3) provides first generation estimates of the effect of exposure on IQ when the sample includes only those men who also have sons in our sample. Given the imprecision of the estimates for air exposure, we focus on the estimates for in situ radiation in Table 7a. The second generation estimates are about -0.025; the first generation ones are about -0.04. Taken together, these suggest an intergenerational transmission coefficient of about 0.625. Importantly, this suggests that a large proportion of the adverse cognitive effects of radiation exposure is passed on from fathers to sons.

For a subsample of sons whose father and mother are both born between 1956 and 1966 in a municipality within 20k of a measuring station, we can observe both mother's and father's in utero exposure to nuclear fallout. Tables 7a and 7b, Columns 6a and 6b, present the results from a specification where both are included in the same regression. Importantly, we observe quite similar results—months 3 and 4 of exposure in utero for both mothers and fathers have long-run effects on the next generation. This suggests that in-utero exposure has persistent long-run effects onto the next generation.[43]

VI. Conclusion

A large literature has shown that shocks in utero can have lasting effects on children. In this paper, we study one such environmental factor – exposure to radiation—that affects members of all socioeconomic groups. Using variation in radioactive fallout that was generated by nuclear

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[43] We also examined the intergenerational transmission controlling for the education of the exposed parent to provide some insight into possible mechanisms. We find that coefficients are relatively unchanged when we include parental education, suggesting decreased education is unlikely to be the causal channel.

weapons testing in the northern hemisphere and local differences in precipitation and wind patterns in Norway, we find negative long-run effects of exposure to nuclear fallout on cognitive tests, education, and earnings at age 35. While the existing literature has suggested that there are effects of low-dose radiation on cognitive development, we are the first to show that there are other, persistent effects on children's outcomes. In addition, our data also allow us to verify the findings in the medical literature that individuals exposed to radiation during weeks 8 to 16 post conception are the most vulnerable.

Another important contribution we make is showing that there are intergenerational effects on cognitive scores for the second generation (the children of people exposed in utero). Importantly, the initial shock to IQ of men exposed to fallout in utero is passed along to their sons, and the transmission is approximately 0.6, suggesting very high persistence. As far as we are aware, this is the first causal evidence on the intergenerational transmission of IQ scores.

Given the lack of knowledge about the fallout in Norway at the time, our estimates are unaffected by avoidance behavior or by maternal stress. Interestingly, and contrary to the existing literature, we find no evidence that high income families are able to offset these negative effects.

While high doses of radiation are rare and confined to persons in the immediate vicinity of nuclear explosions or accidents, lower levels of radiation exposure are more commonplace.[44] Our findings of adverse effects on the fetus--even at radiation levels that are too low to make the

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[44] In particular, computed tomography (CT) scans are a large source of radioactivity and deliver 100 to 500 times the radiation associated with an ordinary X-ray. The radiation exposure levels of a chest X-ray, for example, are 0.1 mSv, a CT scan of the pelvic or abdomen, however, exposes an individual to about 15 mSv. As the fetus is exposed to the radiation dose during a short time interval when the mother receives a CT scan, the treatment should be more harmful than exposure to similar doses from nuclear fallout from nuclear weapon testing or a power plant accident (Brenner *et al.*, 2003). To put this into perspective, the total dose received people living near the Fukushima Daiichi Nuclear Power Station in Japan during the first four months after the reactors were damaged by a devastating tsunami was about 10mSv and the average external exposure in Norway from 1955 to 1975 was about 6mSv. Other possible sources of radiation are cosmic radiation during flights (the annual exposure of an airline crew flying New York to Tokyo polar route is about 9mSv) or also background radiation from radon gas (about 2 mSv per year).

mother sick--have important potential public policy implications. There is a wide range of possible exposure to anthropogenic releases of radioactivity today: A very recent example is the large amount of radioactivity that was discharged after damage to the cooling systems of several reactors in the Fukushima nuclear power plant in March 2011. Our results suggest that the fluctuating levels of radiation near the malfunctioning nuclear reactors may have had long-term effects on children who were in utero in Fukushima and its adjacent prefectures including Tokyo (see, e.g., Yasunari *et al*., 2011).

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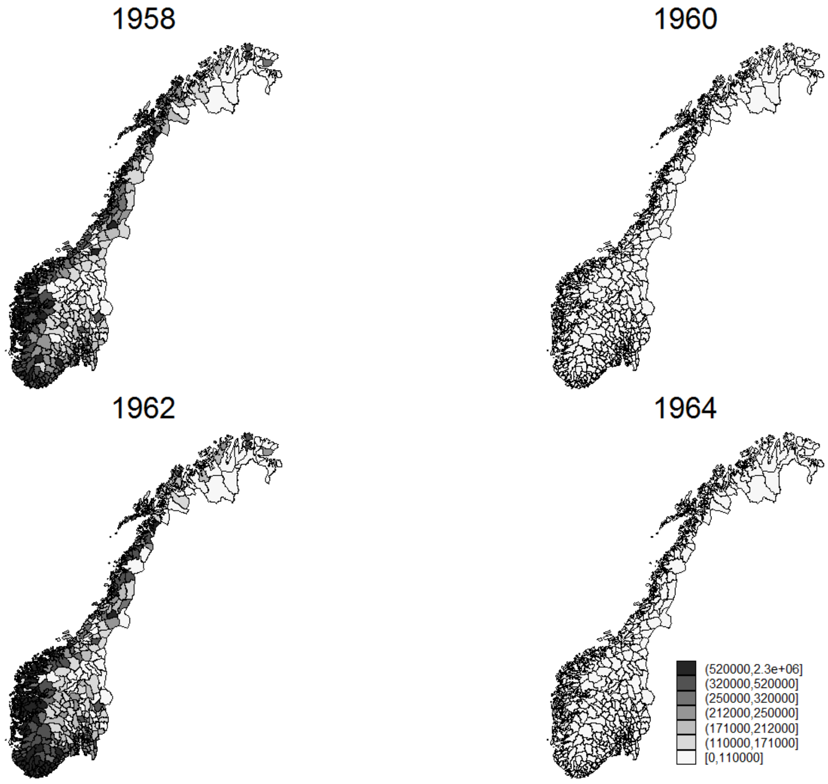
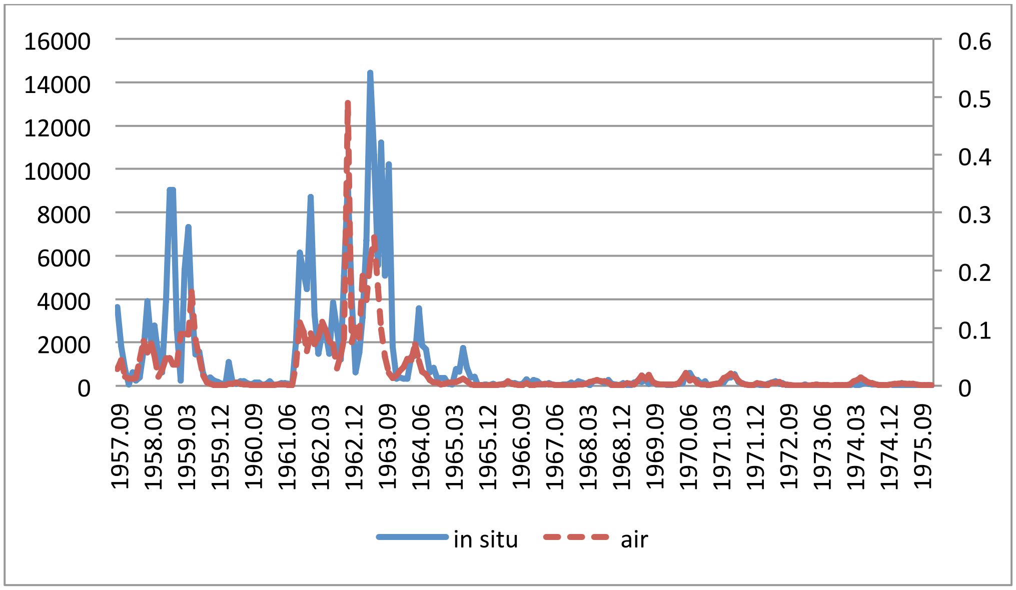
Figure 1: Total Beta Fallout in situ per Community in 1958, 1960, 1962, and 1964



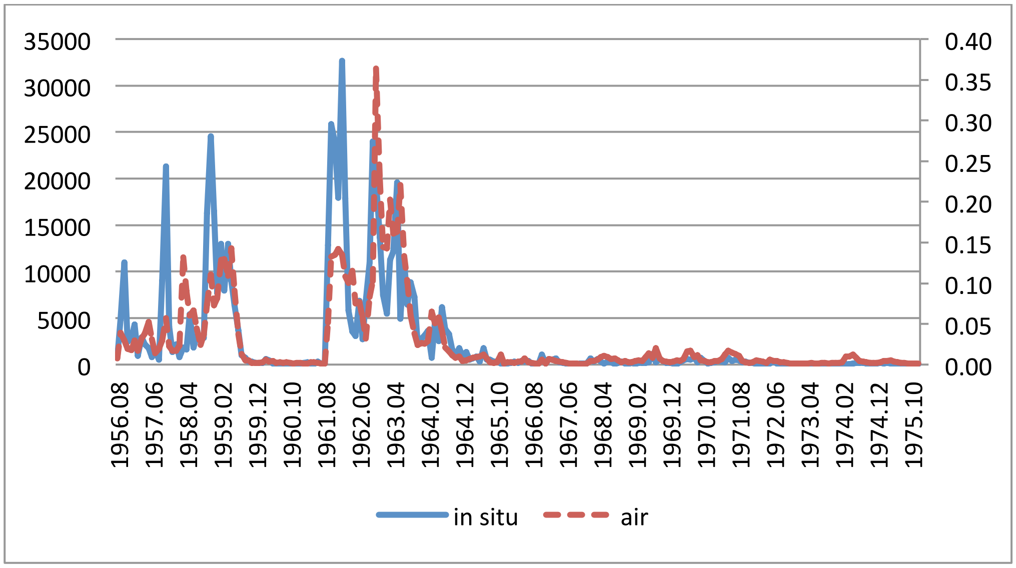
Source: Bergan (2002)

Figure 2a: Monthly Total Beta Fallout in Oslo (in situ and air).



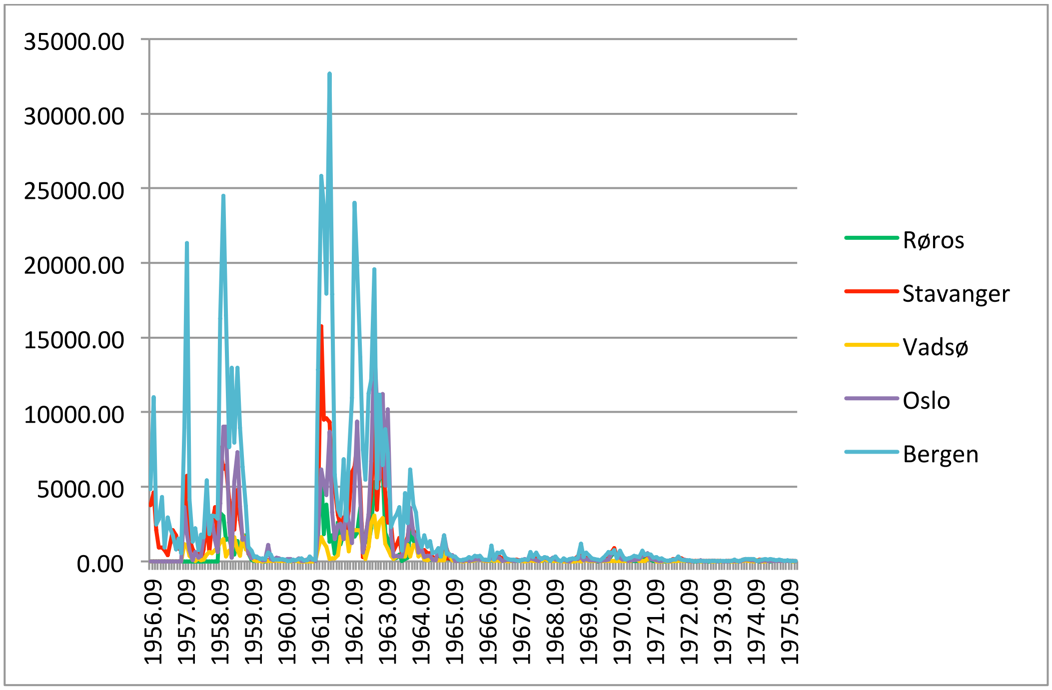
Source: Bergan (2002)

Figure 2b: Monthly Total Beta Fallout in Bergen (in situ and air).



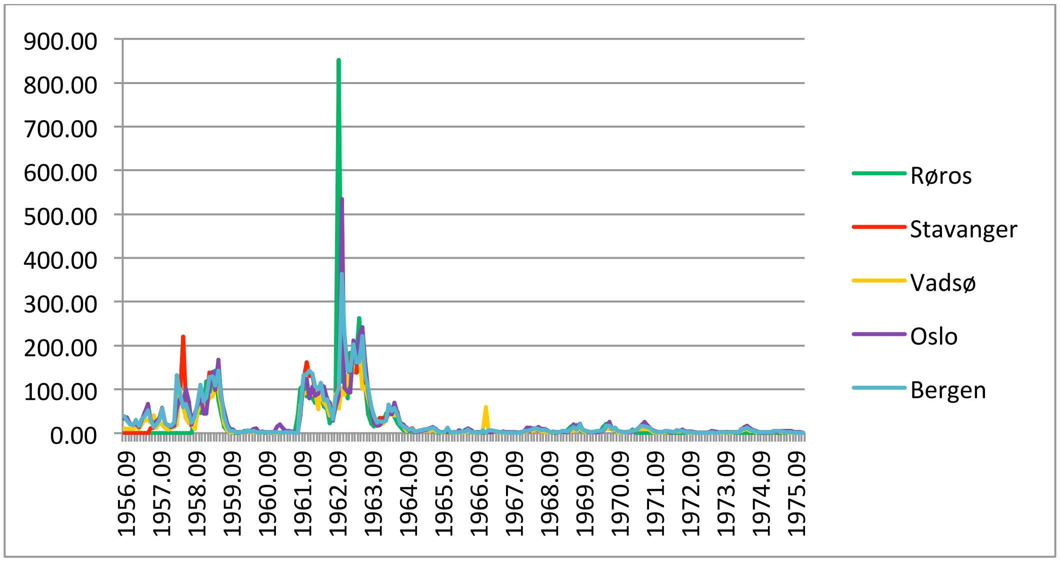
Source: Bergan (2002)

Figure 3a: Monthly Total Beta in situ fallout in 5 Norwegian cities from 1956 to 1975.



Source: Bergan (2002)

Figure 3b: Monthly Total Beta fallout in air in 5 Norwegian cities from 1956 to 1975.



Source: Bergan (2002)

Table 1a: Summary statistics

	Men (20km Sample)		Men (All)		Women (20km Sample)		Women (All)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Control variables								
Father high school degree	0.425	0.494	0.301	0.458	0.417	0.493	0.296	0.457
Mother high school degree	0.326	0.469	0.229	0.420	0.319	0.466	0.225	0.417
Unemployment rate at birth	0.010	0.009	0.013	0.009	0.010	0.009	0.013	0.009
Birth year	1961	3.121	1961	3.152	1961	3.169	1961	3.188
Radioactive fallout (months 3 and 4)								
Mean monthly. Total Beta air (Bq/m^3)	0.042	0.059			0.042	0.059		
Total month. Total Beta ground (kBq/m^2)	2.532	3.789			2.537	3.810		
Outcome variables								
IQ at age 18 (scale: 1-9)	5.264	1.995	5.011	1.999				
Height at age 18 in cm	179.7	6.376	179.4	6.387				
Years of education	12.34	2.609	12.11	2.482	12.36	2.663	12.15	2.591
High school completed	0.731	0.443	0.714	0.452	0.682	0.466	0.653	0.476
Earnings at age 35 in NOK	150146	108704	140258	102672	83191	59831	78658	55350
Observations	100354		297947		102373		305347	

Table 1b: Summary Statistics, Second Generation Sons

	Fathers (20km Sample)		Women (20km Sample)	
	Mean	Standard deviation	Mean	Standard deviation
Control variables				
Grandfather high school degree	0.420	0.494	0.406	0.491
Grandmother high school degree	0.321	0.467	0.305	0.461
Unemployment rate at birth of father	0.010	0.009	0.010	0.009
Birth year of father	1961	2.871	1961	2.879
Birth year	1985	3.191	1984	3.710
Number of siblings	1.684	0.996	1.663	0.976
Father or mothers exposure to radioactive fallout (months 3 and 4)				
Mean monthly. Total Beta air (Bq/m^3)	0.043	0.059	0.042	0.055
Total month. Total Beta ground (kBq/m^2)	2.937	3.743	2.882	3.353
Father's IQ				
IQ at age 18 (scale: 1-9)	5.760	1.809		
Outcome variable				
IQ at age 18 (scale: 1-9)	5.014	1.682	5.054	1.690
Observations	24281		36947	

Table 2: Effect of Fallout by Month on Men's IQ - Total Beta Fallout in situ and in the air

	in situ				air			
	Baseline	Municipality-Specific Trends	Fully Saturated	Sibling Fixed Effects	Baseline	Municipality-Specific Trends	Fully Saturated	Sibling Fixed Effects
3 month prior to	0.003	0.003	0.001	0.002	-0.015	-0.013	-0.014	-0.014
pregnancy	(0.006)	(0.015)	(0.005)	(0.006)	(0.019)	(0.019)	(0.011)	(0.008)
2 month prior to	-0.012	-0.011	-0.010	0.001	-0.027	-0.035	-0.014	-0.025
pregnancy	(0.008)	(0.006)	(0.009)	(0.006)	(0.014)	(0.024)	(0.016)	(0.020)
1 month prior to	-0.015	-0.014	-0.014	-0.016	-0.063	-0.060	-0.052	-0.055
pregnancy	(0.016)	(0.008)	(0.016)	(0.008)	(0.052)	(0.062)	(0.031)	(0.046)
Pregnancy month 1	-0.018	-0.016	-0.021	-0.012	-0.038	-0.040	-0.055	-0.050
	(0.010)	(0.009)	(0.012)	(0.010)	(0.028)	(0.038)	(0.042)	(0.030)
Pregnancy month 2	-0.020	-0.018	-0.016	-0.030	-0.078	-0.063	-0.074	-0.061
	(0.011)	(0.010)	(0.010)	(0.018)	(0.046)	(0.033)	(0.044)	(0.035)
Pregnancy month 3	-0.039**	-0.038**	-0.054**	-0.044**	-0.127**	-0.142**	-0.142**	-0.109**
	(0.009)	(0.008)	(0.015)	(0.010)	(0.052)	(0.069)	(0.061)	(0.050)
Pregnancy month 4	-0.043**	-0.041**	-0.058**	-0.035**	-0.093*	-0.112**	-0.125**	-0.102*
	(0.011)	(0.010)	(0.016)	(0.011)	(0.047)	(0.058)	(0.050)	(0.051)
Pregnancy month 5	0.005	0.008	-0.014*	-0.010*	-0.046	-0.052	-0.021*	-0.051
	(0.005)	(0.005)	(0.007)	(0.005)	(0.027)	(0.038)	(0.029)	(0.031)
Pregnancy month 6	0.010	0.012	0.011	0.014	-0.083	-0.076	-0.063	-0.055
	(0.006)	(0.006)	(0.008)	(0.008)	(0.064)	(0.040)	(0.098)	(0.032)
Pregnancy month 7	0.013	0.007	0.015	0.001	-0.050	-0.053	0.063	0.070
	(0.015)	(0.005)	(0.006)	(0.009)	(0.067)	(0.036)	(0.048)	(0.041)
Pregnancy month 8	-0.014	-0.010	-0.014	-0.002	-0.043	-0.051	-0.042	-0.046
	(0.009)	(0.008)	(0.011)	(0.009)	(0.031)	(0.032)	(0.040)	(0.051)
Pregnancy month 9	-0.007	-0.003	-0.003	-0.002	-0.019	-0.017	-0.026	-0.029
	(0.007)	(0.027)	(0.008)	(0.002)	(0.013)	(0.019)	(0.019)	(0.023)
Month of birth	0.005	0.012	0.008	0.003	-0.057	0.061	0.052	0.032
	(0.004)	(0.007)	(0.005)	(0.003)	(0.030)	(0.041)	(0.031)	(0.022)
After pregnancy 1	0.007	-0.001	-0.004	-0.015	0.037	0.035	0.027	0.023
	(0.006)	(0.007)	(0.007)	(0.009)	(0.029)	(0.027)	(0.016)	(0.020)
After pregnancy 2	-0.012	-0.006	-0.009	-0.000	-0.035	0.030	-0.042	0.031
	(0.007)	(0.007)	(0.007)	(0.006)	(0.038)	(0.017)	(0.031)	(0.022)
After pregnancy 3	-0.009	-0.003	-0.005	-0.007	-0.021	-0.027	-0.020	-0.022
	(0.006)	(0.006)	(0.008)	(0.009)	(0.078)	(0.019)	(0.018)	(0.019)
Observations	89892	89892	89892	54164	94649	94649	94649	83509

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3. Total beta in situ refers to ground deposition measured in kBq/m^2. The fallout measures are standardized to mean zero and standard deviation 1. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 3a: Total Beta Fallout (in situ) by Month

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
3 month prior to pregnancy	0.003	0.026	0.008	-0.001	0.001	0.005	-0.002	0.006
	(0.006)	(0.025)	(0.011)	(0.002)	(0.003)	(0.009)	(0.002)	(0.005)
2 month prior to pregnancy	-0.012	-0.003	0.016	0.002	-0.003	-0.029	-0.003	-0.007
	(0.008)	(0.025)	(0.010)	(0.002)	(0.003)	(0.012)	(0.002)	(0.005)
1 month prior to pregnancy	-0.015	-0.010	0.028	0.003	0.002	0.014	0.001	0.002
	(0.016)	(0.030)	(0.020)	(0.002)	(0.003)	(0.016)	(0.002)	(0.005)
Pregnancy month 1	-0.018	0.064	-0.006	0.001	-0.000	-0.005	0.005	0.003
	(0.010)	(0.035)	(0.012)	(0.001)	(0.005)	(0.011)	(0.003)	(0.004)
Pregnancy month 2	-0.020	-0.056	-0.017	-0.003	-0.000	0.052	-0.006**	0.005
	(0.011)	(0.030)	(0.015)	(0.002)	(0.007)	(0.030)	(0.002)	(0.005)
Pregnancy month 3	-0.039**	-0.068	-0.075**	-0.002	-0.007*	-0.100**	-0.009*	-0.006
	(0.009)	(0.036)	(0.020)	(0.002)	(0.003)	(0.033)	(0.005)	(0.004)
Pregnancy month 4	-0.043**	-0.093**	-0.082**	-0.008**	-0.006	-0.107**	-0.011**	-0.011*
	(0.011)	(0.020)	(0.022)	(0.003)	(0.004)	(0.033)	(0.003)	(0.006)
Pregnancy month 5	0.005	0.018	-0.062**	0.002	-0.005	0.022	-0.003	0.006
	(0.005)	(0.026)	(0.017)	(0.002)	(0.005)	(0.019)	(0.002)	(0.006)
Pregnancy month 6	0.010	0.092	-0.001	-0.002	0.002	0.000	0.004	0.002
	(0.006)	(0.051)	(0.008)	(0.002)	(0.008)	(0.012)	(0.002)	(0.004)
Pregnancy month 7	0.013	-0.020	0.027	0.005	0.001	-0.000	-0.004	-0.010
	(0.015)	(0.031)	(0.017)	(0.003)	(0.005)	(0.012)	(0.004)	(0.005)
Pregnancy month 8	-0.014	-0.053*	-0.003	-0.004	-0.007	-0.030	0.006	0.016
	(0.009)	(0.024)	(0.014)	(0.003)	(0.004)	(0.019)	(0.004)	(0.015)
Pregnancy month 9	-0.007	-0.018	-0.003	-0.003	0.001	0.018	0.002	-0.004
	(0.007)	(0.038)	(0.015)	(0.003)	(0.003)	(0.010)	(0.002)	(0.004)
Month of birth	0.005	-0.021	0.003	0.006	-0.006	-0.005	-0.003	-0.011
	(0.004)	(0.033)	(0.013)	(0.004)	(0.003)	(0.014)	(0.002)	(0.007)
After pregnancy 1	0.007	0.051	0.006	-0.002	0.006	-0.019	-0.001	-0.017
	(0.006)	(0.030)	(0.013)	(0.002)	(0.005)	(0.012)	(0.002)	(0.015)
After pregnancy 2	-0.012	0.021	-0.012	-0.000	0.006	-0.023	-0.003	-0.002
	(0.007)	(0.023)	(0.010)	(0.002)	(0.004)	(0.013)	(0.002)	(0.005)
After pregnancy 3	-0.009	0.033	-0.014	-0.005*	0.001	-0.001	-0.002	-0.012
	(0.006)	(0.023)	(0.011)	(0.003)	(0.003)	(0.015)	(0.002)	(0.007)
Observations	89892	89892	94827	95280	88024	95781	96288	83509

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in situ refers to ground deposition measured in kBq/m^2. The fallout measures are standardized to mean zero and standard deviation 1. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 3b: Total Beta Fallout (Air) by Month

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
3 month prior to	-0.015	0.031	-0.039	-0.004	-0.005	-0.007	0.000	0.003
pregnancy	(0.019)	(0.057)	(0.022)	(0.002)	(0.003)	(0.011)	(0.002)	(0.003)
2 month prior to	-0.027	-0.055	-0.015	0.001	0.003	0.003	-0.001	-0.007
pregnancy	(0.014)	(0.037)	(0.021)	(0.003)	(0.003)	(0.012)	(0.002)	(0.006)
1 month prior to	-0.063	0.004	-0.034	-0.008	0.004	0.000	-0.000	0.003
pregnancy	(0.052)	(0.043)	(0.025)	(0.002)	(0.005)	(0.012)	(0.002)	(0.006)
Pregnancy month 1	-0.038	0.006	-0.020	-0.004	-0.004	-0.009	-0.002	0.004
	(0.028)	(0.046)	(0.012)	(0.003)	(0.004)	(0.015)	(0.003)	(0.008)
Pregnancy month 2	-0.078	-0.077*	-0.033	-0.001	0.006	-0.029	-0.006*	-0.006
	(0.046)	(0.037)	(0.015)	(0.003)	(0.006)	(0.017)	(0.002)	(0.006)
Pregnancy month 3	-0.127**	-0.011	-0.190**	-0.017**	-0.006	-0.118**	-0.011**	-0.008
	(0.052)	(0.034)	(0.035)	(0.002)	(0.004)	(0.032)	(0.004)	(0.005)
Pregnancy month 4	-0.093*	-0.029	-0.172**	-0.014**	-0.008*	-0.135**	-0.010**	-0.010*
	(0.047)	(0.039)	(0.035)	(0.003)	(0.004)	(0.033)	(0.003)	(0.005)
Pregnancy month 5	-0.046	-0.004	-0.011	0.000	0.004	-0.015	-0.001	-0.004
	(0.027)	(0.004)	(0.021)	(0.003)	(0.003)	(0.018)	(0.003)	(0.006)
Pregnancy month 6	-0.083	0.079	-0.041	-0.007	0.001	-0.023	-0.003	-0.006
	(0.064)	(0.045)	(0.024)	(0.004)	(0.004)	(0.013)	(0.002)	(0.005)
Pregnancy month 7	-0.050	-0.042	-0.015	0.002	0.001	-0.030*	-0.003	-0.001
	(0.067)	(0.029)	(0.013)	(0.002)	(0.006)	(0.011)	(0.003)	(0.007)
Pregnancy month 8	-0.043	-0.059	0.004	-0.003	0.007	0.010	-0.002	-0.001
	(0.031)	(0.036)	(0.016)	(0.002)	(0.006)	(0.014)	(0.003)	(0.006)
Pregnancy month 9	-0.019	0.005	-0.019	-0.005	0.003	-0.006	-0.004	-0.002
	(0.013)	(0.036)	(0.014)	(0.003)	(0.004)	(0.018)	(0.00)	(0.006)
Month of birth	-0.057	-0.003	0.005	-0.002	0.010	-0.003	-0.001	-0.007
	(0.030)	(0.043)	(0.014)	(0.003)	(0.006)	(0.015)	(0.002)	(0.005)
After pregnancy 1	0.037	-0.012	0.002	0.001	0.002	-0.018	-0.002	-0.011
	(0.029)	(0.059)	(0.014)	(0.002)	(0.004)	(0.013)	(0.002)	(0.007)
After pregnancy 2	-0.035	-0.018	-0.033	-0.001	-0.000	-0.026	-0.005	0.010
	(0.038)	(0.039)	(0.019)	(0.003)	(0.006)	(0.014)	(0.003)	(0.006)
After pregnancy 3	-0.021	-0.060	-0.017	-0.001	0.006	-0.019	-0.006	-0.005
	(0.078)	(0.038)	(0.013)	(0.002)	(0.004)	(0.012)	(0.004)	(0.006)
Observations	94649	94649	93275	93723	86544	94018	94511	81984

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3. The fallout measures are standardized to mean zero and standard deviation 1. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 4a: Log Total Beta Fallout (in situ) by Month

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
3 month prior to pregnancy	0.008	-0.014	-0.012	0.000	0.001	0.016	0.005	-0.001
	(0.010)	(0.041)	(0.014)	(0.003)	(0.004)	(0.011)	(0.003)	(0.003)
2 month prior to pregnancy	-0.020	-0.061*	0.038	0.008	0.002	-0.017	-0.002	-0.004
	(0.011)	(0.027)	(0.020)	(0.006)	(0.005)	(0.012)	(0.002)	(0.004)
1 month prior to pregnancy	-0.021	0.001	-0.025	0.002	-0.000	-0.006	-0.011	-0.019*
	(0.019)	(0.044)	(0.022)	(0.005)	(0.003)	(0.015)	(0.012)	(0.009)
Pregnancy month 1	-0.001	-0.008	0.011	-0.013	0.006	0.017	0.015	-0.004
	(0.011)	(0.040)	(0.014)	(0.008)	(0.005)	(0.014)	(0.009)	(0.006)
Pregnancy month 2	0.013	-0.013	0.050	0.013	-0.001	0.032	0.001	0.001
	(0.012)	(0.032)	(0.038)	(0.013)	(0.004)	(0.022)	(0.003)	(0.007)
Pregnancy month 3	-0.033**	-0.012	-0.141**	-0.023**	-0.018**	-0.150**	-0.025**	-0.008
	(0.019)	(0.035)	(0.054)	(0.008)	(0.005)	(0.029)	(0.009)	(0.004)
Pregnancy month 4	-0.042**	-0.022	-0.140**	-0.028**	-0.014	-0.152**	-0.029**	-0.0180**
	(0.020)	(0.037)	(0.053)	(0.006)	(0.008)	(0.022)	(0.008)	(0.005)
Pregnancy month 5	0.021	0.015	-0.056*	0.012	-0.016*	0.029	0.015	0.010
	(0.018)	(0.028)	(0.029)	(0.007)	(0.008)	(0.018)	(0.013)	(0.006)
Pregnancy month 6	0.014	0.022	0.008	0.000	0.007	-0.011	-0.004	-0.006
	(0.016)	(0.036)	(0.024)	(0.003)	(0.005)	(0.014)	(0.003)	(0.007)
Pregnancy month 7	-0.019	-0.066	-0.014	0.014	-0.003	-0.016	-0.013	0.002
	(0.011)	(0.035)	(0.033)	(0.012)	(0.006)	(0.022)	(0.008)	(0.007)
Pregnancy month 8	-0.007	0.025	-0.007	0.000	-0.001	-0.010	0.002	-0.000
	(0.010)	(0.033)	(0.010)	(0.002)	(0.003)	(0.015)	(0.002)	(0.008)
Pregnancy month 9	-0.009	0.050	-0.025	-0.006	0.001	-0.013	0.003	-0.002
	(0.009)	(0.038)	(0.036)	(0.008)	(0.005)	(0.012)	(0.003)	(0.005)
Month of birth	0.000	-0.030	-0.003	0.001	-0.002	-0.008	-0.005	-0.011
	(0.006)	(0.035)	(0.018)	(0.005)	(0.004)	(0.012)	(0.003)	(0.009)
After pregnancy 1	-0.017	0.006	-0.016	-0.002	0.001	-0.021	-0.005	-0.002
	(0.010)	(0.027)	(0.023)	(0.002)	(0.002)	(0.013)	(0.003)	(0.007)
After pregnancy 2	-0.011	-0.043	-0.004	0.001	0.008	-0.031*	-0.001	-0.003
	(0.011)	(0.033)	(0.011)	(0.002)	(0.004)	(0.012)	(0.002)	(0.005)
After pregnancy 3	-0.020	0.008	-0.418**	-0.004	0.001	0.018	0.001	-0.000
	(0.011)	(0.040)	(0.014)	(0.004)	(0.004)	(0.017)	(0.002)	(0.005)
Observations	82706	86767	94827	87670	80856	87015	87457	76011

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 4b: Log Total Beta Fallout (Air) by Month

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
3 month prior to pregnancy	0.0059	0.0897	-0.0446	-0.0049	-0.0079	-0.0464	-0.0033	0.0052
	(0.0336)	(0.0699)	(0.0339)	(0.0033)	(0.0051)	(0.0276)	(0.0036)	(0.0113)
2 month prior to pregnancy	-0.0145	-0.1483*	-0.0210	0.0035	-0.0013	0.0144	0.0027	-0.0008
	(0.0350)	(0.0646)	(0.0317)	(0.0035)	(0.0049)	(0.0173)	(0.0039)	(0.0091)
1 month prior to pregnancy	-0.0475	-0.0654	-0.0092	-0.0116	0.0045	-0.0319	0.0022	-0.0063
	(0.0238)	(0.0667)	(0.0279)	(0.0066)	(0.0058)	(0.0185)	(0.0034)	(0.0093)
Pregnancy month 1	-0.0328	0.0307	-0.0286	-0.0057	0.0051	0.0122	-0.0025	0.0023
	(0.0210)	(0.0709)	(0.0325)	(0.0038)	(0.0065)	(0.0285)	(0.0041)	(0.0086)
Pregnancy month 2	0.0702	-0.0573	0.0214	0.0120	0.0109	0.0452	0.0035	-0.0063
	(0.0436)	(0.0797)	(0.0488)	(0.0070)	(0.0057)	(0.0280)	(0.0047)	(0.0121)
Pregnancy month 3	-0.2302**	-0.0390	-0.2693**	-0.0566**	-0.0220**	-0.3885**	-0.0540**	-0.0250*
	(0.0343)	(0.0697)	(0.0733)	(0.0148)	(0.0046)	(0.0590)	(0.0065)	(0.0122)
Pregnancy month 4	-0.2963**	-0.0951	-0.3348**	-0.0425**	-0.0111	-0.4301**	-0.0553**	-0.0114
	(0.0488)	(0.0616)	(0.0616)	(0.0139)	(0.0060)	(0.0454)	(0.0071)	(0.0098)
Pregnancy month 5	0.0740	0.0292	-0.0985	0.0094	-0.0022	-0.0909*	-0.0135*	0.0090
	(0.0429)	(0.0496)	(0.0594)	(0.0054)	(0.0049)	(0.0446)	(0.0066)	(0.0067)
Pregnancy month 6	-0.0280	0.0912	-0.0168	-0.0052	0.0094	-0.0278	-0.0044	-0.0033
	(0.0210)	(0.0545)	(0.0201)	(0.0039)	(0.0050)	(0.0244)	(0.0042)	(0.0056)
Pregnancy month 7	-0.0013	-0.1095*	-0.0323	-0.0037	0.0128	-0.0429	-0.0009	-0.0071
	(0.0174)	(0.0483)	(0.0410)	(0.0031)	(0.0083)	(0.0265)	(0.0066)	(0.0090)
Pregnancy month 8	-0.0342	0.0326	-0.0353	-0.0100	0.0034	0.0058	0.0044	0.0035
	(0.0191)	(0.0544)	(0.0250)	(0.0052)	(0.0056)	(0.0248)	(0.0040)	(0.0135)
Pregnancy month 9	-0.0290	-0.0545	-0.0226	-0.0034	-0.0042	-0.0468	-0.0140*	-0.0101
	(0.0182)	(0.0363)	(0.0210)	(0.0026)	(0.0045)	(0.0248)	(0.0055)	(0.0109)
Month of birth	0.0411	0.0075	-0.0465*	-0.0075*	0.0065	-0.0137	-0.0043	-0.0002
	(0.0240)	(0.0661)	(0.0215)	(0.0033)	(0.0080)	(0.0155)	(0.0040)	(0.0092)
After pregnancy 1	-0.0102	-0.0886	-0.0120	-0.0031	0.0041	-0.0248	-0.0020	0.0083
	(0.0283)	(0.0455)	(0.0234)	(0.0033)	(0.0050)	(0.0399)	(0.0056)	(0.0081)
After pregnancy 2	-0.0426	-0.0144	-0.0368	-0.0046	0.0070	-0.0488	-0.0083	0.0019
	(0.0183)	(0.0748)	(0.0297)	(0.0060)	(0.0087)	(0.0252)	(0.0052)	(0.0098)
After pregnancy 3	0.0195	-0.0122	0.0068	0.0064	0.0074	-0.0443	-0.0027	-0.0098
	(0.0173)	(0.0539)	(0.0215)	(0.0039)	(0.0096)	(0.0246)	(0.0038)	(0.0107)
Observations	74796	78367	78848	79216	72948	77597	77985	67864

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 5: Controlling for Both Fallout Types

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
Total Beta in situ	-0.037**	0.018	-0.098**	-0.005**	-0.007*	-0.140**	-0.012**	-0.022**
	(0.012)	(0.028)	(0.025)	(0.002)	(0.003)	(0.039)	(0.004)	(0.005)
Total Beta in Air	-0.151**	-0.061	-0.367**	-0.028**	-0.009	-0.337**	-0.031**	-0.024**
	(0.041)	(0.045)	(0.079)	(0.006)	(0.007)	(0.093)	(0.009)	(0.009)
Observations	88446	92793	93275	93723	86544	95781	96288	83509

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3 during months 3 and 4 in utero (the average value over the two months). Total beta in situ refers to ground deposition measured in kBq/m^2 during months 3 and 4 in utero (the average value over the two months). The fallout measures are standardized to mean zero and standard deviation 1. Each set of estimates (column) comes from a separate regression with controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level.

Table 6: Quintile of Fallout, in situ and in air

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
Total Beta in situ								
Quintile 2	-0.112	0.012	-0.187	-0.015	-0.022	-0.122	-0.022	-0.019
	(0.059)	(0.110)	(0.106)	(0.009)	(0.019)	(0.125)	(0.012)	(0.015)
Quintile 3	-0.116	-0.065	-0.422**	-0.029**	-0.028	-0.271	-0.039	-0.023
	(0.059)	(0.150)	(0.132)	(0.011)	(0.015)	(0.239)	(0.020)	(0.030)
Quintile 4	-0.264**	-0.163	-0.560**	-0.034**	-0.046*	-0.610**	-0.054**	-0.073**
	(0.059)	(0.194)	(0.125)	(0.011)	(0.018)	(0.215)	(0.020)	(0.028)
Quintile 5	-0.373**	-0.06	-0.992**	-0.069**	-0.053*	-1.005**	-0.081**	-0.091**
	(0.045)	(0.210)	(0.096)	(0.011)	(0.021)	(0.201)	(0.021)	(0.036)
Total Beta in air								
Quintile 2	-0.09	-0.101	-0.192	-0.021	-0.024	-0.145	-0.039	-0.033
	(0.046)	(0.136)	(0.118)	(0.013)	(0.014)	(0.119)	(0.029)	(0.020)
Quintile 3	-0.16	-0.296	-0.469**	-0.043*	-0.048	-0.308	-0.043*	-0.046
	(0.090)	(0.178)	(0.218)	(0.021)	(0.028)	(0.239)	(0.021)	(0.025)
Quintile 4	-0.279**	-0.446	-0.636**	-0.067**	-0.069*	-0.780**	-0.077**	-0.058*
	(0.116)	(0.243)	(0.308)	(0.027)	(0.030)	(0.310)	(0.028)	(0.029)
Quintile 5	-0.504**	-0.678*	-1.097**	-0.109**	-0.083*	-1.176**	-0.111**	-0.101**
	(0.164)	(0.302)	(0.423)	(0.030)	(0.037)	(0.439)	(0.039)	(0.034)
Observations	94649	99367	99850	100332	92778	101783	102343	88633

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3 during months 3 and 4 in utero (the average value over the two months). Total beta in situ refers to ground deposition measured in kBq/m^2 during months 3 and 4 in utero (the average value over the two months). The fallout measures are standardized to mean zero and standard deviation 1. Each set of quintile estimates comes from a separate regression with controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level.** implies significant at the 1% level. * implies significant at 5% level.

Table 7a: Effect of Fallout (in situ) by Month on the Second Generation, male offspring

	Father Exposed			Mother Exposed		Father and Mother Exposed	
	Son’s IQ	Son’s IQ	Father’s IQ	Son’s IQ	Son’s IQ	Son’s IQ	
	(1)	(2)	(3)	(4)	(5)	Father’s Exposure (6a)	Mother’s Exposure (6b)
3 month prior to pregnancy	-0.002	0.001	0.010	-0.012	-0.017	-0.002	-0.001
	(0.022)	(0.023)	(0.023)	(0.017)	(0.017)	(0.026)	(0.003)
2 month prior to pregnancy	0.016	0.015	-0.005	0.001	0.000	0.016	0.001
	(0.022)	(0.021)	(0.022)	(0.021)	(0.021)	(0.020)	(0.003)
1 month prior to pregnancy	0.018	0.027	0.021*	-0.015	-0.012	0.031	-0.001
	(0.019)	(0.020)	(0.009)	(0.019)	(0.019)	(0.023)	(0.004)
Pregnancy month 1	0.015	0.007	-0.045	0.025	0.021	0.009	0.015
	(0.018)	(0.018)	(0.029)	(0.013)	(0.013)	(0.021)	(0.050)
Pregnancy month 2	0.004	0.006	0.009	0.005	0.005	0.001	0.027
	(0.030)	(0.030)	(0.025)	(0.008)	(0.008)	(0.033)	(0.052)
Pregnancy month 3	-0.024**	-0.028**	-0.042*	-0.023	-0.024	-0.018*	-0.013*
	(0.007)	(0.008)	(0.018)	(0.017)	(0.016)	(0.007)	(0.005)
Pregnancy month 4	-0.027*	-0.030*	-0.043	-0.030*	-0.030*	-0.022*	-0.013
	(0.013)	(0.013)	(0.026)	(0.013)	(0.013)	(0.011)	(0.009)
Pregnancy month 5	-0.039	-0.029	0.012	-0.017	-0.013	-0.031	-0.011
	(0.021)	(0.022)	(0.025)	(0.015)	(0.015)	(0.024)	(0.026)
Pregnancy month 6	0.043*	0.038	0.019	0.000	-0.000	0.044	-0.000
	(0.021)	(0.023)	(0.023)	(0.011)	(0.011)	(0.028)	(0.005)
Pregnancy month 7	0.015	0.014	0.046	-0.027	-0.029	-0.016	-0.006
	(0.020)	(0.022)	(0.026)	(0.021)	(0.021)	(0.028)	(0.012)
Pregnancy month 8	0.027	0.034	-0.005	0.038*	0.037*	0.032	-0.001*
	(0.023)	(0.022)	(0.023)	(0.017)	(0.016)	(0.019)	(0.000)
Pregnancy month 9	-0.033	-0.031	-0.027	-0.012	-0.010	-0.028	-0.011
	(0.024)	(0.023)	(0.023)	(0.014)	(0.013)	(0.022)	(0.007)
Month of birth	-0.012	-0.006	0.011	-0.013	-0.014	-0.034	-0.015
	(0.019)	(0.020)	(0.025)	(0.016)	(0.016)	(0.016)	(0.017)
After pregnancy 1	-0.001	0.001	0.001	0.029	0.031	0.022	0.033
	(0.020)	(0.019)	(0.026)	(0.027)	(0.028)	(0.020)	(0.023)
After pregnancy 2	0.008	0.008	0.004	0.032**	0.033**	0.022	0.014
	(0.020)	(0.019)	(0.014)	(0.008)	(0.008)	(0.022)	(0.008)
After pregnancy 3	0.014	0.011	0.001	0.003	0.004	0.004	0.004
	(0.015)	(0.014)	(0.026)	(0.012)	(0.012)	(0.014)	(0.011)
Post 1960 Controls		X			X		
Observations	24281	24281	19079	36947	36947	20773	

The sample includes parents born between 1956 and 1966 in municipalities within a radius of 20km of the test stations. All regressions are weighted so each parent gets equal weight. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth, controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level.** implies significant at the 1% level. * implies significant at 5% level. (1) and (4): only pre 1960 controls included, (2) and (5): also includes controls for the second generation, (3): Comparative estimates for first generation men who have at least one son in the sample, (6a/6b): includes only pre 1960 controls for both mothers and fathers.

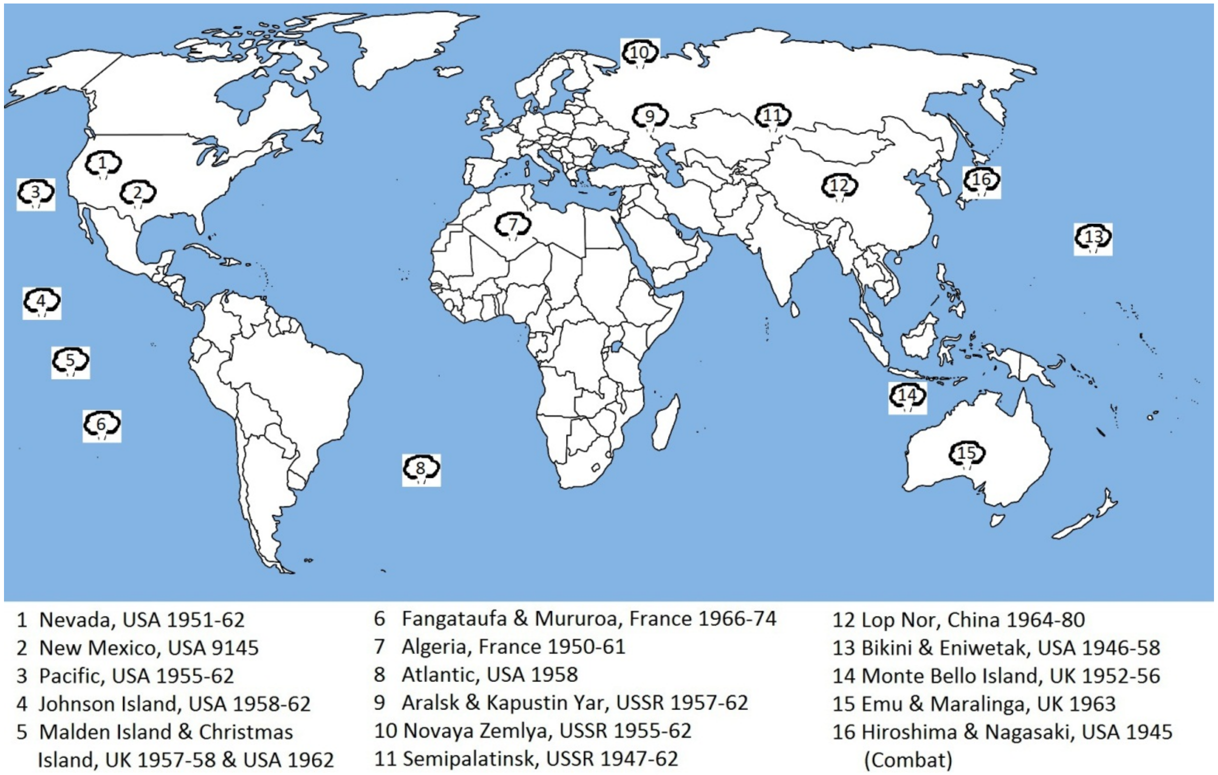
Table 7b: Effect of Fallout (in air) by Month on the Second Generation, male offspring

	Father Exposed			Mother Exposed		Father and Mother Exposed	
	Son’s IQ	Son’s IQ	Father’s IQ	Son’s IQ	Son’s IQ	Son’s IQ	
	(1)	(2)	(3)	(4)	(5)	Father’s Exposure (6a)	Mother’s Exposure (6b)
3 month prior to pregnancy	-0.030	-0.022	0.006	-0.028	-0.031	0.034	-0.022
	(0.030)	(0.034)	(0.040)	(0.020)	(0.020)	(0.035)	(0.031)
2 month prior to pregnancy	-0.000	0.002	-0.012	0.007	0.009	0.031	-0.025
	(0.025)	(0.027)	(0.031)	(0.020)	(0.020)	(0.027)	(0.026)
1 month prior to pregnancy	0.014	0.020	0.009	0.015	0.021	-0.006	0.010
	(0.033)	(0.033)	(0.019)	(0.019)	(0.019)	(0.034)	(0.014)
Pregnancy month 1	-0.014	-0.015	-0.011	-0.034	-0.029	0.026	-0.009
	(0.039)	(0.037)	(0.024)	(0.022)	(0.023)	(0.029)	(0.015)
Pregnancy month 2	0.014*	0.014*	-0.008	-0.031	-0.030	0.013	-0.030
	(0.006)	(0.005)	(0.026)	(0.025)	(0.025)	(0.007)	(0.023)
Pregnancy month 3	-0.030	-0.036	-0.045	-0.027**	-0.028**	-0.043	-0.032*
	(0.027)	(0.027)	(0.025)	(0.010)	(0.010)	(0.022)	(0.015)
Pregnancy month 4	-0.077	-0.077	-0.042	-0.026	-0.026	-0.081*	-0.031
	(0.041)	(0.041)	(0.040)	(0.017)	(0.017)	(0.039)	(0.017)
Pregnancy month 5	0.009	0.013	-0.030	0.023	0.026	-0.061	-0.015
	(0.037)	(0.034)	(0.034)	(0.024)	(0.023)	(0.036)	(0.026)
Pregnancy month 6	-0.013	-0.007	0.005	0.024	0.027	0.009	0.018
	(0.053)	(0.051)	(0.027)	(0.030)	(0.029)	(0.026)	(0.025)
Pregnancy month 7	0.008	0.009	-0.020	0.006	0.006	-0.003	-0.006
	(0.031)	(0.029)	(0.027)	(0.019)	(0.017)	(0.025)	(0.021)
Pregnancy month 8	0.026	0.027	0.007	0.008	0.008	0.013	-0.006
	(0.028)	(0.026)	(0.021)	(0.021)	(0.020)	(0.034)	(0.032)
Pregnancy month 9	0.016	0.010	0.015	-0.007	-0.001	0.018	-0.019
	(0.028)	(0.030)	(0.028)	(0.023)	(0.022)	(0.022)	(0.022)
Month of birth	0.054	0.053	-0.004	0.001	0.004	0.036	-0.024
	(0.038)	(0.037)	(0.021)	(0.023)	(0.023)	(0.039)	(0.027)
After pregnancy 1	-0.010	-0.009	0.028	0.012	0.012	-0.019	0.008
	(0.029)	(0.030)	(0.028)	(0.031)	(0.030)	(0.041)	(0.014)
After pregnancy 2	0.015	0.015	-0.005	-0.024	-0.019	0.007	-0.033
	(0.035)	(0.033)	(0.025)	(0.024)	(0.024)	(0.038)	(0.026)
After pregnancy 3	0.013	0.012	-0.008	0.007	0.009	0.034	0.017
	(0.028)	(0.028)	(0.026)	(0.023)	(0.023)	(0.041)	(0.013)
Post 1960 Controls		X			X		
Observations	23378	23378	18412	35745	35745	11919	

The sample includes parents born between 1956 and 1966 in municipalities within a radius of 20km of the test stations. All regressions are weighted so each parent gets equal weight. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth, controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level.** implies significant at the 1% level. * implies significant at 5% level. (1) and (4): only pre 1960 controls included, (2) and (5): also includes controls for the second generation, (3): Comparative estimates for first generation men who have at least one son in the sample, (6a/6b): includes only pre 1960 controls for both mothers and fathers.

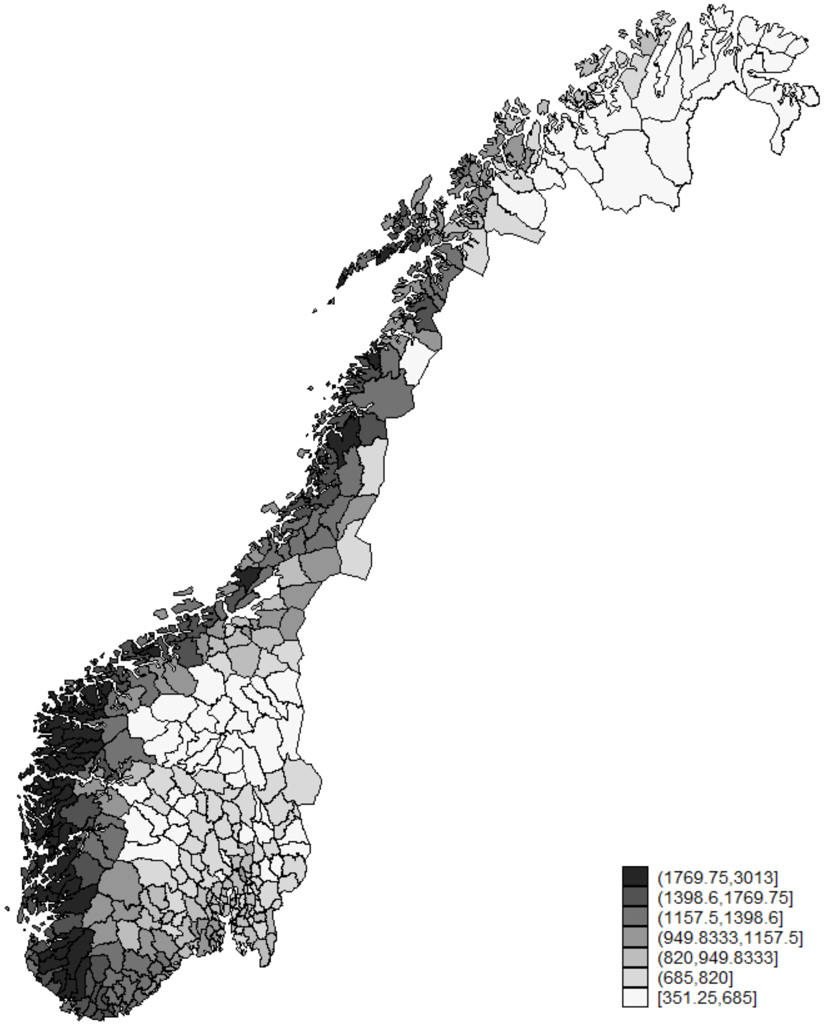
Appendix

Figure A1: Location of Atmospheric Nuclear Test Sites



Source: Bergan, 2002

Figure A2: Annual Precipitation per Municipality



Source: Norwegian Meteorological Institute

Table A1: Interaction with Season of Exposure (Summer: April - September)

	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
Total Beta in situ								
Total beta	-0.041**	0.029	-0.105**	-0.006**	-0.006	-0.131**	-0.010**	-0.019**
in situ	(0.011)	(0.030)	(0.022)	(0.002)	(0.004)	(0.024)	(0.003)	(0.004)
Summer	0.196	0.04	0.135	0.025	0.025	-0.076	0.022	0.074
	(0.117)	(0.476)	(0.104)	(0.024)	(0.048)	(0.126)	(0.021)	(0.054)
Interaction	-0.106**	-0.154*	-0.276**	-0.018**	-0.02	-0.402**	-0.044**	-0.040**
term	(0.020)	(0.072)	(0.060)	(0.005)	(0.011)	(0.047)	(0.006)	(0.014)
Total Beta in air								
Total beta	-0.113**	0.001	-0.234**	-0.018**	0.002	-0.220**	-0.019**	-0.021*
in air	(0.037)	(0.045)	(0.065)	(0.006)	(0.006)	(0.077)	(0.007)	(0.009)
Summer	0.14	0.062	-0.291	-0.039	0.026	-0.03	-0.003	-0.017
	(0.111)	(0.521)	(0.252)	(0.048)	(0.047)	(0.206)	(0.021)	(0.060)
Interaction	-0.238**	-0.283*	-0.794**	-0.055**	-0.065**	-0.814**	-0.077**	-0.043*
	(0.068)	(0.118)	(0.173)	(0.014)	(0.021)	(0.149)	(0.009)	(0.021)
Observations	94649	99367	99850	100332	92778	101783	102343	88633

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3 during months 3 and 4 in utero (the average value over the two months). Total beta in situ refers to ground deposition measured in kBq/m^2 during months 3 and 4 in utero (the average value over the two months). The fallout measures are standardized to mean zero and standard deviation 1. Each set of estimates comes from a separate regression with controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level.** implies significant at the 1% level. * implies significant at 5% level.

Table A2: Interaction with Mother's Education

	Men					Women		
	IQ	Height	Years of education	High school completed	Log earnings 35	Years of education	High school completed	Log earnings 35
Total Beta in situ	-0.050**	0.021	-0.111**	-0.008**	-0.007	-0.164**	-0.015**	-0.023**
	(0.013)	(0.031)	(0.032)	(0.002)	(0.004)	(0.040)	(0.005)	(0.005)
Mother has high school	1.019**	1.006**	1.362**	0.144**	0.106**	1.470**	0.178**	0.164**
	(0.021)	(0.036)	(0.044)	(0.005)	(0.005)	(0.025)	(0.004)	(0.008)
Interaction term	-0.01	-0.033	-0.096**	-0.003	-0.006	-0.045*	0.000	-0.001
	(0.009)	(0.057)	(0.026)	(0.003)	(0.005)	(0.022)	(0.002)	(0.004)
Total Beta air	-0.158**	-0.053	-0.371**	-0.029**	-0.008	-0.363**	-0.034**	-0.030**
	(0.042)	(0.047)	(0.084)	(0.006)	(0.007)	(0.104)	(0.010)	(0.011)
Mother has high school	1.017**	1.004**	1.355**	0.144**	0.105**	1.468**	0.177**	0.165**
	(0.022)	(0.036)	(0.049)	(0.005)	(0.005)	(0.029)	(0.004)	(0.008)
Interaction term	-0.007	-0.01	-0.079*	0.001	-0.01	-0.024	0.001	0.005
	(0.015)	(0.039)	(0.030)	(0.004)	(0.006)	(0.022)	(0.002)	(0.007)
Observations	89892	94339	94827	95280	88024	95781	96288	83509

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Total beta in air refers to air deposition measured in kBq/m^3 during months 3 and 4 in utero (the average value over the two months). Total beta in situ refers to ground deposition measured in kBq/m^2 during months 3 and 4 in utero (the average value over the two months). The fallout measures are standardized to mean zero and standard deviation 1. Each set of estimates comes from a separate regression with controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level.** implies significant at the 1% level. * implies significant at 5% level.

Table A3: Effect of Fallout by Month on Having a Son in the Second Generation Sample

	Men		Women	
	in situ	air	in situ	air
3 month prior to pregnancy	-0.003	-0.002	0.001	-0.005
	(0.002)	(0.002)	(0.002)	(0.003)
2 month prior to pregnancy	0.003	0.005*	0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.003)
1 month prior to pregnancy	-0.005*	0.003	-0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.004)
Pregnancy month 1	0.002	-0.001	-0.001	0.001
	(0.001)	(0.003)	(0.002)	(0.003)
Pregnancy month 2	-0.000	0.001	0.009*	-0.001
	(0.001)	(0.002)	(0.004)	(0.002)
Pregnancy month 3	0.000	0.005	-0.001	-0.002
	(0.001)	(0.003)	(0.002)	(0.003)
Pregnancy month 4	-0.003	0.003	0.003	0.005
	(0.002)	(0.002)	(0.002)	(0.004)
Pregnancy month 5	0.001	0.004	-0.001	0.001
	(0.002)	(0.003)	(0.002)	(0.003)
Pregnancy month 6	0.004	0.001	0.004	0.002
	(0.003)	(0.002)	(0.003)	(0.003)
Pregnancy month 7	-0.002	-0.000	0.001	0.005
	(0.002)	(0.002)	(0.002)	(0.003)
Pregnancy month 8	0.004	0.004	-0.002	0.003
	(0.003)	(0.003)	(0.002)	(0.003)
Pregnancy month 9	-0.002	0.004	0.008	0.006
	(0.002)	(0.003)	(0.005)	(0.003)
Month of birth	0.006	0.003	-0.005	0.011*
	(0.004)	(0.003)	(0.003)	(0.005)
After pregnancy 1	-0.001	0.004	0.006	0.006
	(0.002)	(0.003)	(0.004)	(0.003)
After pregnancy 2	0.003	0.002	-0.006	0.006
	(0.002)	(0.002)	(0.004)	(0.004)
After pregnancy 3	-0.003	0.003	0.003	0.006
	(0.002)	(0.002)	(0.003)	(0.003)
Observations	89892	88446	96316	94538

The sample includes persons born between 1956 and 1966 and includes municipalities within a radius of 20km of the test stations. Each column represents a separate regression that includes controls for municipality dummies and year of birth by month of birth dummies. Also included in each specification are controls for parental education, birth order, and the municipality unemployment rate. Standard errors are clustered at the municipality level. ** implies significant at the 1% level. * implies significant at 5% level