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Parental Response to Early Human Capital Shocks

Evidence from the Chernobyl Accident

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Martin Halla and Martina Zweimüller*

Parental Responses to Early Human Capital Shocks

Evidence from the Chernobyl Accident

Abstract

Little is known about the response behavior of parents whose children are exposed to an early-life shock. We interpret the prenatal exposure of the Austrian 1986 cohort to radioactive fallout from the Chernobyl accident as a negative human capital shock and examine their parents' response behavior. To identify causal effects, we can rely on exogenous variation in the exposure to radioactive fallout (over time and) between communities due to geographic differences in precipitation at the time of the accident. Our design-based approach (which accounts for culling effects) provides robust empirical evidence for compensating investment behavior. Families with low socioeconomic status reduce their family size, while families with higher status respond with reduced maternal labor supply. Our results urge caution in the interpretation of estimates of the long-term effects of early-life shocks on children. These estimates should only be interpreted as reduced-form estimates, and one has to account for parental response behavior to reach a deeper understanding on the relationship between early-life shocks and the formation of human capital. In the case of our application, we can interpret the estimates as the lower bound of the biological effect. For exposed children from higher socioeconomic backgrounds, there are no detrimental effects discernable. In contrast, exposed children from lower socioeconomic backgrounds have significantly worse human capital outcomes as young adults. This suggests that compensating investment by parents with higher socioeconomic status is relatively more effective.

JEL Classification: I18, I20, Q48, Q53, J24.

Keywords: Fetal origins, parental response, Chernobyl, radiation, health, culling, human capital, fertility, labor supply.

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1 Introduction

The importance of early-life conditions for outcomes in later life is now widely recognized among scholars in different disciplines (Barker, 1995). Economists are particularly interested in the effect of early-life events on the accumulation of human capital (Almond and Currie, 2011a). In this context, several factors complicate the isolation and interpretation of causal effects. Even in an ideal setting, that is, where one observes an exogenous early-life shock and later outcomes, estimated effects are hard to interpret. These effects may not only entail the (biological) effect of the initial shock, but also the parental response to it. As a consequence, one should to interpret theses effects as reduced-form estimates.

Until very recently, the design-based literature on early-life events completely ignored parental responses (often for data reasons) and applied a simplified interpretation of their estimates. However, given that it is *a priori* unclear whether parents will make compensating or reinforcing investments — which are potentially asymmetric along different dimensions of human capital — these reduced-form estimates cannot be even unambiguously interpreted as lower or upper bounds of the biological effect (Conti *et al.*, 2011).[1] Thus, to reach a deeper understanding on the relationship between early-life shocks and the formation of human capital, it is crucial to examine the behavior of parents whose children were exposed to the shock.

In this paper, we examine a shock during the prenatal period, which is considered as the key developmental window (Almond and Currie, 2011b), and focus on subsequent parental response behavior. In particular, we interpret the prenatal exposure of the Austrian 1986 cohort to radioactive fallout from the Chernobyl accident as a negative human capital shock. Thus, we follow Almond, Edlund and Palme (2009) (henceforth, AEP), who show that Swedish children born in 1986 that were prenatally exposed to radioactive fallout had significantly lower grades in compulsory school at the age of 16.

Our identification strategy is (like in AEP) based on the difference in rainfall levels while the radioactive plume was over Austria — which led to stark geographic variation in the levels of radioactive fallout.[2] In contrast to AEP (and papers examining other shocks), our main outcome of interest is the parental response behavior to this early-life shock and its mediating impact on children's long-term outcomes. The main result of our paper is

[1] As discussed by Almond and Mazumder (2013), there are a number of papers providing evidence on parental response behavior based on family fixed effects or more indirectly (for instance, via a comparison of OLS and fixed effects estimates). However, only a handful of papers with highly credible research designs directly examine parental response behavior. Among the latter, the papers in a development context (Adhvaryu and Nyshadham, 2012; Akresh *et al.*, 2012; Venkataramani, 2012) find clear evidence for reinforcing responses. The only paper analyzing data from a developed country finds no effects (Bharadwaj *et al.*, forthcoming).

[2] Austria ranks among those countries that received the most radioactive fallout. Differences in rainfall immediately after the accident caused substantial geographic variation in ground deposition of Caesium-137 fallout (half-life of 30 years) with maximum values of nearly 200 kilobecquerels per square meter. Only Russia, Ukraine, Belarus, and some parts of Scandinavia had fallout values higher than 200 kilobecquerels per square meter; see Figure 3.5. in IAEA (2006).

that parents responded to this early-life shock with compensating investment behavior. Families with low socioeconomic status reduced their family size (i. e., lower completed fertility), while families with higher socioeconomic status responded with reduced maternal labor supply. Both effects indicate that affected children needed more attention, and parents adapted their behavior, such that they can devote more time to their children and make necessary compensating investment. The timing of the labor supply effect is especially intriguing, since mothers of exposed children reduced their labor supply shortly after their children entered school. This pattern is consistent with the reduced cognitive abilities of exposed children as put forward by AEP.

We proceed in several analytical steps to establish our main result. We start by re-examining the effect of prenatal exposure to radioactive fallout on children's health at birth; AEP did not detect any health damage. In contrast, we find robust evidence that the in utero exposure to radioactive fallout from the Chernobyl accident in Austria increased the incidence of early fetal death. As a consequence, the surviving children exhibit better health outcomes at birth. This result illustrates the more general phenomenon that in the presence of an effect of the early-life shock on mortality, a naïve comparison of long-term outcomes of exposed and (unselected) non-exposed children gives downward biased estimates. This tension between so-called *culling* and *scarring* effects is widely acknowledged among epidemiologist, but has so far been largely ignored in the economic literature on early-life shocks. The ignorance of this *culling effect* is especially aggravating if the sample selection entails a social gradient, as in the case of radioactive exposure, where fetal deaths are highly concentrated in families with low socioeconomic status. We suggest a straight-forward methodology — which exploits the random assignment of the early-life shock and the fact that we can quantify the degree of the culling effect — to disentangle the culling and the scarring effect. After accounting for the sample selection due to culling, we observe a negative scarring effect on the health of the surviving children. Culling effects seem to be more important in the case of early exposure (first trimester) for short-run health outcomes, and of little significance in the case of long-run human capital outcomes.

In the second step, we present the main results of our paper. We document the parental response to the early-life shock along the dimensions of family size and maternal labor supply over a period of twenty years. We find clear evidence for compensating parental responses. This main result has two important implications for the literature on early-life events. First and foremost, it implies that the estimated effects in this literature have to be interpreted as reduced-form estimates. Second, it highlights that the commonly used estimation strategy of family-fixed effects is inherently flawed, since older otherwise unaffected siblings may also be affected by the parental response.

In the third step, we analyze the long-term effect on children. The estimates give us the overall impact of the accident — the sum of the biological effect and the parental

response. Given that we know that parents try to compensate for the early-life shock, we can interpret our estimates as a lower bound of the biological effect. In contrast to AEP, we can already observe the exposed cohort on the labor market. We find that exposed children from low socioeconomic backgrounds have — despite their parents' compensating response — significantly worse labor market outcomes as young adults. In the case of exposed children from higher socioeconomic backgrounds, we do not find any robust effects.

Finally, in a fourth step, we quantify the intra-household spillover effects and compare older siblings of exposed and non-exposed children. We find that siblings of exposed children from low socioeconomic backgrounds have better human capital outcomes. Positive externalities of the compensating parental response (i. e., reduced family size) seem to outweigh any negative effects of the redistribution of private goods.

Our findings have important ramifications for the economic literature beyond the studies on the effects of early-life events on the accumulation of human capital. For instance, our analysis of parental response behavior is also helpful to understand intra-household resource allocation more generally. Our evidence on the fertility response shows that parents are aware of the trade-off between the quantity and the quality of children (Becker, 1960; Becker and Lewis, 1973; Willis, 1973; Becker and Tomes, 1976). Or, consider the literature on environmental justice — studying the disproportionately high exposure of the low-income population to environmental hazards and the resulting impact on their health and economic well-being. This literature typically faces the econometric challenge that exposure to environmental hazards is correlated with a host of confounding factors (Banzhaf and Walsh, 2008) that if unaccounted for may lead to biased estimates. Our research design provides the unique opportunity to observe a randomly assigned environmental hazard free of any Tiebout sorting on endogenous socioeconomic characteristics. Our findings reveal different dimensions of treatment effect heterogeneity. Children from families with low socioeconomic status are more vulnerable to early-life shocks, both in terms of short-run health outcomes, as well as in terms of long-run labor market outcomes. This result is consistent with two complementary explanations. First, these children may suffer more since they have on average a lower birth endowment. Second, the effectiveness of later compensatory behavior may increase along the socioeconomic distribution. Each of these explanations suggests that in case of conventional environmental hazards (such as air pollution as a byproduct of the production of a marketable good), the average treatment effect on the treated should be higher than the average treatment effect. Finally, our estimates of the effect of prenatal radioactive exposure on health outcomes contributes to a long-standing discussion in the medical literature. Whether radioactive fallout from the Chernobyl accident in 1986 had detrimental effects on individuals living in Western European countries or not is still a controversial question.[3]

[3]The clean identification strategy employed by AEP and in our paper distinguishes both from earlier

Our results also hold important implications for public policymakers. In terms of social policy, our results reinforce the call for public support to disadvantaged families that assures a sufficient level of early childhood investment. More specifically, our results also speak to the ongoing debates on nuclear power. An informed discussion about the efficiency of nuclear power requires knowledge about the full cost of nuclear and radiation accidents. At least, after the accident in the Fukushima Daiichi Nuclear Power Plant in March 2011 and the ongoing contamination of the environment, there are serious doubts that even an advanced economy can master nuclear safety. The benefits of nuclear power due to comparable low emissions have to be contrasted not only with the private and social cost involved in normal operations but also with the expected total cost of a nuclear accident. Our estimation results provide evidence that accidents in nuclear power plants have large and long-lasting negative externalities (due to radioactive fallout) even for individuals living about 1,000 miles away and translate into reduced fertility and lower economic productivity of at least two generations.

The remainder of the paper is organized as follows. Section 2 describes the Chernobyl accident and the resulting radioactive contamination in the western part of the former Soviet Union and in Europe. Section 3 presents our identification strategy, the econometric specification, and the data used. Section 4 discusses our estimation results. Finally, Section 5 concludes the paper.

2 Contamination of the environment due to the Chernobyl accident

On April 26, 1986 at 1:23 A.M., an accident occurred during a systems test at the Chernobyl nuclear power plant in Ukraine (officially, the Ukrainian Soviet Socialist Republic) that caused the worst nuclear power plant accident in history (until then). An explosion and fire released large quantities of radioactive contamination into the atmosphere that was not stopped until May 6, 1986.[4] As a result, a plume of highly radioactive fallout spread over an extensive geographical area and drifted in the following days over large parts of the western part of the former Soviet Union and of Europe.[5] The radioactive

Chernobyl studies (summarized in Web Appendix A). The effects of in utero exposure to radioactive fallout caused by nuclear weapon testing have been analyzed by Black *et al.* (2013). Based on a design-based approach, the authors identify a negative effect of this comparable lower dose of radioactivity on long-term human capital outcomes (see below) and a quantitatively small effect on height at age 18.

[4]This incidence was not immediately announced by the authorities of the Soviet Union, but has been detected after radiation levels set off alarms at a nuclear power plant in Sweden located over one thousand kilometers away from Chernobyl. The world learned officially about the accident (two days later) on April 28, 1986 through a 20 second announcement by the state television broadcaster in the Soviet Union.

[5]The following link provides a computerized graphic reconstruction of the path of the first 14 days of the radioactive plume, tracking the release of Caesium-137, created by the *Institut de Radioprotection et Sûreté Nucléaire*: http://www.irsn.fr/FR/popup/Pages/tchernobyl_animation_nuage2.aspx.

particles were subsequently removed from the atmosphere solely due to gravitation (*dry deposition*) or by any form of precipitation (*wet deposition*). Given that wet disposition is by far a more efficient deposition mechanism (compared to dry deposition), the level of radioactive material deposited on soil and other surfaces (so-called *ground deposition*) was predominantly determined by the presence or absence of precipitation during the passage of the plume (Clark and Smith, 1988).

Radionuclides can enter the human body through inhalation, ingestion, and absorption through the skin. IAEA (2006, Chapter 5) describes four main pathways by which humans were exposed to the radioactive material released by the accident: (i) external dose from cloud passage, (ii) internal dose from inhalation of the cloud and resuspended material, (iii) external dose from ground deposition, and (iv) internal dose from the consumption of contaminated food and water. The latter two exposure pathways are considered the most important. Thus, humans were exposed to high levels of radiation if they were located in areas with high levels of ground deposition and/or if they consumed large quantities of contaminated food and water. While it is not observable who consumed large quantities of contaminated edibles, the external dose from ground deposition should be highly correlated with the observable local level of ground deposition at individuals' place of residence. From a researcher's point of view, the Chernobyl disaster provides an ideal natural experiment to study the consequences of exposure to radioactive ground deposition, since it seems safe to assume that the spatial distribution of precipitation during the passage of the plume was exogenous.[6]

The implementation of this research design is facilitated by the wide availability of data on local levels of radioactive ground deposition. In the aftermath of the accident, the level of ground deposition of Caesium-137 (henceforth ^{137}Cs) and other radionuclides was measured comprehensively on the soil surface in most European countries (European Commission, 1998). In the mapping of the deposition, the focus was on ^{137}Cs, because it is easy to measure (*ex post*), and because of its radiological significance. It turned out that the three countries (based on current borders) most heavily affected are Belarus, the Russian Federation, and Ukraine. However, Austria, Sweden, and Finland also contain some heavily contaminated areas (see, for instance, Figure 3.5. in IAEA (2006)).

3 Research design

In this section, we first present the Austrian radiation data that we use to determine the individual level of exposure to radioactive fallout. We then discuss the periods of prenatal exposure between which we distinguish in our analysis and explain how we translate our

[6] To be precise, our estimates may not only capture the effect of the exposure to radioactive ground deposition, but partly also the effect of the internal dose from the consumption of contaminated food and water, to the extent which this is correlated with the external dose from ground deposition. It is hard to assess how large this correlation is, since it depends on the structure of the food supply chain.

research design into a regression framework. We then distinguish between the radiation and non-radiation effects of the Chernobyl accident. When we introduce our outcome variables, we also provide information on our data sources.

3.1 Spatial distribution of radioactive fallout

In Austria, radioactive fallout (due to Chernobyl) was measured at 1,881 sites, which provides on average one measurement per 45 square kilometers (Bossew *et al.*, 1996, 2001). Radioactive fallout is measured as ground deposition of ^{137}Cs (with a half-life of 30 years) and ^{134}Cs (with a half-life of 2 years) in kilobecquerels per square meter (kBq/m^2).[7] We aggregate these measurements to the community level and focus on the average level of ground deposition of ^{137}Cs.[8] This provides us with data for 924 (out of 2,331) communities, where each data point refers to May 1, 1986.[9] The accident happened on April 26 and the radioactive plume arrived in Austria on April 29. Figure 1 depicts the spatial distribution of contamination, where we distinguish between communities with a ground deposition of ^{137}Cs below 17 kBq/m^2, between 17 and 36 kBq/m^2, at least 37 kBq/m^2, and communities without data. UNSCEAR (2000) considers regions with a ^{137}Cs ground deposition of 37 kBq/m^2 or more as contaminated. In Austria, the average level of contamination was around 20 kBq/m^2. Communities with the lowest level of contamination recorded only 0.7 kBq/m^2, while the most contaminated areas had values of about 150 kBq/m^2. It is this wide range of (within country) variation in radioactive fallout (resulting from the very local presence or absence of precipitation during the passage of the plume) that makes the Austrian case so particularly well suited for studying the impact of the Chernobyl accident.

In order to define our treatment and control group, we distinguish between communities (and their residing population) who were exposed to different levels of radioactive fallout. We follow the criteria suggested by UNSCEAR (2000) and define the 175 commu-

[7] Immediately after the arrival of the radioactive cloud, 336 dose rate meters distributed over the territory of Austria quantified the gamma radiation (in millisievert). These measurements show a high correlation with the deposition measurements of ^{137}Cs and ^{134}Cs (Bossew *et al.*, 2001).

[8] These measurements include the global fallout from the atmospheric atomic bomb tests in the 1950s and 1960s. For a reduced number of sites, we have equivalent data on the ground deposition of ^{134}Cs. This fallout stems exclusively from the Chernobyl accident and allows to isolate (with some error) the ^{137}Cs ground deposition originating from the Chernobyl accident only. Estimations based on these alternative measurements give very comparable results. In particular, the point estimates are very similar, though the standard errors increase. The latter fact can be explained by the reduced sample size (about 65 percent of the original estimation sample) and the increased measurement error in the alternative treatment variable.

[9] Table B.1 in Web Appendix B compares, birth outcomes of children born and conceived before Chernobyl in the communities with and without data on ^{137}Cs ground deposition. No quantitatively important differences can be found. Aggregating the Caesium data to a higher administrative level (the county level) increases the geographic coverage at the expense of introducing measurement error. Based on 109 counties (including 99 percent of communities), we have checked the robustness of our main results for birth outcomes. The county-level results (available upon request) are very similar to the results presented in Table 5.

nities in our sample with a ^{137}Cs ground deposition of 37 kBq/m^2 or more as treatment group 1 ($T1$). We specify two further treatment groups with higher levels of contamination. To the 130 communities with a ^{137}Cs ground deposition of 42 kBq/m^2 or more, we refer as treatment group 2 ($T2$), and to the 93 communities with a ^{137}Cs ground deposition of 47 kBq/m^2 or more, we refer as treatment group 3 ($T3$). As a control group (C), we use in each case, the 427 communities with a ^{137}Cs ground deposition of 16 kBq/m^2 or less. Communities with medium levels of ^{137}Cs ground deposition (i. e., between 17 and 36/41/46 kBq/m^2) are excluded from the analysis.[10] Table 1 summarizes this grouping of communities and provides the population-weighted average of ^{137}Cs ground deposition for each group.

Given that the level of radioactive fallout was predominantly determined by the level of precipitation during the passage of the plume, we observe a correlation between ground deposition and the *general* level of precipitation. Since precipitation intensity is mainly determined by high altitude, we find higher levels of ground deposition in high-altitude areas. The average altitude of control communities is about 433 meters above sea-level, while those of $T1$ communities amounts to approximately 602 meters above sea-level. Since the population composition differs between low- and high-lands, we find some pre-treatment differences in average socioeconomic characteristics of non-exposed and exposed communities. Notably, in terms of birth outcomes such as sex of child, premature birth, or low birth weight we do not see any statistical significant differences. (See, for instance, Panel (a) of Figure 3). In any case, our difference-in-differences estimation framework (to be explained below) will clear any time-constant differences.[11]

3.2 Periods of prenatal exposure

It is conjectured that radiation exposure is especially critical at a prenatal stage.[12] While a human embryo or fetus is protected in the uterus, and the radiation exposure to a fetus should be lower than the dose to its mother, an embryo or fetus is particularly sensitive to ionizing radiation. The most important determinant of potential health effects is radiation dose and gestational age (ICPR, 2003). Exposure to radiation in the pre-implantation

[10] Our main results for birth outcomes (for the three treatment groups defined above) are quantitatively and qualitatively similar (to those presented in Table 5) when including communities with medium levels of contamination. The point estimates for communities exposed to medium levels are lower and not significant throughout. We have also used a continuous measure of exposure to ^{137}Cs ground deposition. Again, these results are robust. Note that these results are available upon request.

[11] Our results for birth outcomes are robust to the inclusion of indicators for maternal age, labor market status, foreign nationality, religious denomination, and marital status (and detailed maternal education).

[12] The empirical evidence on the effects of prenatal exposure on child health is either based on case studies of children born to women who had been treated with high doses of medical radiation while pregnant (De Santis *et al.*, 2005) or on children who have been prenatally close to the hypocenter of the atomic bomb explosions in Hiroshima and Nagasaki (Otake and Schull, 1998; Yamazaki and Schull, 1990). The only two exceptions we are aware of are the aforementioned papers: AEP and Black *et al.* (2013).

period has very likely lethal effects. During the period of major organogenesis (weeks 2–7 postconception), most human organs are formed and the embryo is sensitive to malformations and growth retardation. Negative effects on the brain development are most likely in weeks 8–15 (and to a lesser degree in weeks 16–25) postconception. Beyond about 26 weeks, the fetus is believed to be "relatively radio-resistant" (i. e., equally sensitive to radiation as a newborn).

AEP (who are mainly concerned with cognitive outcome) focus on children of gestational age 8–25 weeks at the time of the accident.[13] We use a larger window and include all conceptions between August 1, 1984 and July 31, 1987 in our estimation sample. Including conceptions from this time span allows us to control for seasonal effects at the monthly level. As depicted by Figure 2, we distinguish between four different birth cohorts. Birth cohort 0 (BC_0) includes all children who were conceived before August 1, 1985 and born before the Chernobyl accident.[14] Further, we distinguish between two birth cohorts who were exposed to Chernobyl in utero. Birth cohort I (BC_I) comprises children who were conceived between August 1, 1985 and January 31, 1986. These children have been in utero for more than 3 months at the time of the accident (second and third trimesters) and should be relatively resistant to radioactive exposure due to their gestational age. Children belonging to birth cohort II (BC_{II}) were conceived between February 1, 1986 and April 30, 1986. They have been in utero for less than 3 months at the time of the accident (first trimester) and should still be very vulnerable. For simplicity, we refer to children from BC_I and BC_{II} as the 1986 birth cohort. Finally, children from birth cohort III (BC_{III}) were conceived and born after the accident (between May 1, 1986 and July 31, 1987). While this prenatally non-exposed cohort is *per se* not interesting, its inclusion allows us to fully account for seasonal and year effects.

Our broader specification allows us to check the effect of in utero exposure at different gestational age and to identify potential non-radiation effects triggered by an early parental response behavior that is causally related to the Chernobyl accident, but not caused by radiation. For instance, since BC_{II} has been in utero for less than 3 months at the time of the accident, an induced abortion would have still been possible. In contrast, children from BC_I have not been at risk to be aborted.

Naturally, we do not observe the exact day of conception in our data. Based on the stated gestation length measured in commenced weeks (gl) and the birth day (bd), we compute the conception day (cd) as follows $cd = bd - 7 * (gl - 0.5)$. That means, we assume that a pregnancy with a stated gestation length of 38 weeks has lasted 38.5 weeks or 269.5 days. In order to minimize errors in group assignment, we exclude conceptions

[13] In line with AEP, we find that an exposure at an earlier gestational age has the most detrimental effects. In particular, we find that an exposure before week 8 is particularly critical for fetal mortality. AEP define this group as non-treated. As we will show below, this provides a plausible explanation why AEP do not find any health effects of Chernobyl.

[14] Post-term births (i. e., with gestational length of 40 weeks or more) may be born after the accident.

7 days before and after each cutoff date. Moreover, we exclude births by very young and very old mothers and focus on children born to mothers between the ages of 20 and 40. We do not exclude multiple births (about 2 percent of children), but, when analyzing parental response behavior, we include only one observation per birth. We also exclude some children because of potential intra-household spillover effects (see below). After applying those sample selection criteria, our most extensive sample includes 95,103 children (see Table 1). The number of observations depends on the treatment group definition that we use. In case of $T1$, we observe 22,496 exposed children and 72,607 non-exposed children and exclude 37,335 children from communities with medium levels of ^{137} Cs ground deposition.

3.3 Intra-household spillover effects

In the presence of intra-household spillover effects, there is also a potential effect on otherwise unaffected siblings of exposed children. The first (and more obvious case) is where a child was prenatally exposed and his younger sibling was unaffected; that is, a child from BC_I or BC_{II} residing in an exposed community, who has a younger sibling belonging to BC_{III}. The spillover effect potentially applies to any outcome of the younger sibling and such cases are potentially problematic in the whole analysis. The second case is where a child was prenatally exposed and his older sibling was unaffected; that is, a child from BC_I or BC_{II} residing in an exposed community, who has an older sibling belonging to BC_0. In these cases the spillover effect applies to any outcome measured after the child's birth. That means that observations can be used without any harm in the analysis of prenatal culling and health at birth. However, they are potentially problematic in the analysis of long-term outcomes. In the analysis of parental response outcomes, the inclusion of these observations should lead to a downward bias in radiation effects (this applies to compensatory and reinforcing investment), since affected and unaffected siblings share the same parental response in terms of family size and maternal labor supply. In the case of children's long term outcomes, the sign of the bias is unclear (see Section 4.5). To preserve a clean research design, we exclude these potential problematic observations from our analysis.[15] Moreover, we abstain from using specifications with family fixed effects (as adopted by AEP and Black *et al.* (2013)), since these are conceptually flawed in the case of any parental response causing spillover effects.

3.4 Econometric specification

Our research design translates into the following regression framework, which is performed for each definition of the treatment group $T\#$ ($T1$, $T2$, and $T3$):

[15] Our results do not change substantially due to this sample modification. This can be explained by the comparable low number of such siblings in our sample.

$$Outcome_{i,c} = \alpha + \rho_1 BC_I + \rho_2 BC_{II} + \tau_1 BC_I \times T\#_{i,c} + \tau_2 BC_{II} \times T\#_{i,c}$$
$$+\eta T\#_{i,c} + \beta_1 BC_{III} + \beta_2 BC_{III} \times T\#_{i,c} + \mathbf{X}_{i,c} + \gamma_y + \delta_m + \theta_c + \epsilon_{i,c}. \quad (1)$$

In this equation, i denotes individual and c denotes community. This *difference-in-differences* (DiD) estimation framework includes binary variables BC_I, BC_{II}, and BC_{III} to distinguish between children from three birth cohorts as defined above, a binary variable indicating the treatment status of each child's community of residence at birth ($T\#_{i,c}$), and an interaction term between each birth cohort indicator and the treatment status variable. Further, we control for conception year fixed-effects (γ_y), conception month fixed-effects (δ_m), and community fixed-effects (θ_c). Depending on the specific outcome we control for further covariates $\mathbf{X}_{i,c}$. (The treatment indicator $T\#_{i,c}$ is dropped because of perfect collinearity with the community fixed-effects θ_c.) With one exception (live births), all outcomes are measured on an individual-level. Depending on whether we analyze a child outcome or parental behavior, the index i refers to either the child or its parent(s).

The parameters τ_1 and τ_2 provide the estimated prenatal radiation effects (i. e., the true causal effect of radioactive fallout) for BC_I and BC_{II}. We refer to these effects as *radiation effects*, which are the parameters of primary interest. The identification of these parameters relies on variation in the exposure to radioactive fallout (over time and) between communities due to geographic differences in precipitation after the accident. To be precise, given that we estimate these effects with a DiD procedure, all we have to assume is that exposed and non-exposed children would have followed a parallel trend in the respective outcome, in the counterfactual situation without the Chernobyl accident. This assumption seems quite plausible.

Given that the local level of ground deposition was not known at the time of the accident, all parents (or even potential parents) may have been stressed and anxious in the aftermath of the accident and may have changed their behavior immediately in response to the accident irrespective of their treatment status.[16] Put differently, one might distinguish between two treatments: everyone was treated with the Chernobyl accident (first treatment), but only a sub-population was in addition exposed to significant levels

[16] We have scanned three major national newspapers (*Die Presse*, *Neue Kronen Zeitung*, and *Oberösterreichische Nachrichten*) in the period from April 29 through June 18, 1986 for all articles relating to the Chernobyl accident. In general, the coverage was very confusing and inconsistent. For instance, while the population was informed about radioactivity in milk and dairy products and was requested to carefully wash vegetables and fruits, an expert from the Institute of Atomic and Subatomic Physics at the Vienna University of Technology considered the level of radioactive fallout erroneously as low as the level of radioactive fallout caused by nuclear weapon testing in the 1960s and did not expect any health effects on the Austrian population (Die Presse, May 17, 1986). Most importantly, we did not find any systematic information on local levels of radioactive contamination. There are some scattered statements referring to federal states.

of ground deposition (second treatment). The parental response to the first treatment may have affected different dimensions, such as maternal diet (of pregnant women), the decision to have a child, and even the likelihood of having an induced abortion. This means that this early parental response behavior may have generated scarring and/or culling effects. Given that these effects are causally related to the accident, but constitute a distinct channel which should not be mixed up with the biological effects of radiation, we refer to them as *non-radiation effects*.

Non-radiation effects for BC_I and BC_{II} are captured by the parameters ρ_1 and ρ_2, if early parental response did not vary with the exposure to radioactive fallout. While the validity of this assumption is not as clear as the identifying assumption of the radiation effects, it can be justified by the fact that the actual level of *local* radioactive fallout was verifiably not known at the time of the accident. Therefore, we think it is reasonable to assume that early parental response behavior is not systematically correlated with the actual level of radiation exposure (as measured in retrospect).

The method of estimation is least squares and robust standard errors — allowing for clustering by community and heteroskedasticity of unknown form — are calculated throughout. Given that we find a strong social gradient in the effects of prenatal exposure to radiation, we present a discussion based on a separate estimation analysis for children from low and higher socioeconomic backgrounds. In particular, we use the available information on mother's educational attainment at the time of birth to distinguish between low socioeconomic backgrounds (i. e., mother has compulsory schooling or less) and higher socioeconomic backgrounds (i. e., mother has any degree higher than compulsory schooling). According to this definition, about 26 percent of children have a low socioeconomic background.

3.5 Outcome variables

We examine health and human capital outcomes available in administrative data sources that allow us to infer on the effects of the early-life shock on children at a prenatal stage, at the time of birth, during adolescence, and early adulthood. Parental response behavior is evaluated in terms of fertility and maternal labor supply in the post-treatment period. Table 2 provides an overview of all (potential) outcomes with information on measurement and data source.

For the estimation of prenatal culling effects, we use the *Austrian Birth Register*. This includes the universe of all live births and stillbirths in Austria with individual-level information on socioeconomic characteristics and birth outcomes. These data allows us to quantify the incidence of live births on a community-level (by socioeconomic groups) and to conduct an individual-level analysis of the likelihood of a stillbirth. For the estimation of postnatal culling effects, we link the *Austrian Birth Register* with the *Austrian Death*

Register, which enables us to estimate the likelihood of infant mortality on an individual level. The analysis of short-run effects examines health at birth and focuses on different health indicators such as the gestation length, birth weight, and Apgar scores, which are documented in the *Austrian Birth Register*. To evaluate long-term effects, we focus on human capital formation and labor market outcomes in early adulthood (up to the age of 23). In particular, we obtain individual-level information on employment, broad occupation, apprenticeship training, and wages in the *Austrian Social Security Database*. To evaluate parental postnatal investment behavior, we use family size (based on completed fertility) and maternal labor supply.

4 Estimation results

In this section, we first highlight the crucial tension between culling and scarring effects that has to be considered in the interpretation of empirical estimates of the effect of the Chernobyl accident, in order to *not* underestimate the true impact. We quantify the importance of culling effects and suggest a simple sample correction method. Following this, we analyze the effect of Chernobyl on children's health at birth and reconcile our results with those of AEP. Then, we present our main results on the parental response behavior and discuss non-radiation effects. In the next step, we analyze the long-run effects on children's human capital outcomes. Finally, we test for any intra-household spillover effects by examining long-term outcomes of otherwise unaffected siblings.

4.1 Culling effects

The possible effects of prenatal radiation exposure include increased risk for medical conditions later in life (such as cancer), and immediate effects, such as malformations or even fetal death (ICPR, 2003). Thus, radioactive exposure experienced in utero may do more than "scar" exposed children. It may increase mortality at different stages of development. This so-called culling effect may lead to a potentially selected sample of survivors at any point in time after the initial shock, where selection is endogenous to the same shock as the scarring effect. This imposes two empirical challenges for our analysis of the parental response to this early-life shock and its impact on children's long-term outcomes. First, we need to estimate the extent of culling. Second, we need an empirical strategy to disentangle the scarring and culling effects.

4.1.1 Quantification of culling effects

The *Centers for Disease Control and Prevention (CDC)* concludes that the risk of fetal death increases with radiation dose and decreases with gestational age.[17] Mortality risk

[17] In contrast, carcinogenic risks are assumed to be constant throughout pregnancy.

is especially high in the first weeks after conception, since an embryo is made up of only a few cells. Damage to one cell (the progenitor of many other cells) may cause embryo death, and the blastocyst will fail to implant in the uterus. Beyond about 26 weeks, the fetus is believed to be "relatively radio-resistant".

Prenatal culling In order to calculate the extent of prenatal culling, one would have to compare the number of conceptions with the number of live births. Clearly, we cannot observe the number of conceptions. We also do not have information on the incidence of miscarriages (medically termed *spontaneous abortions*). Very early miscarriages (so-called early pregnancy losses) happen in many cases before a woman may even know she is pregnant, and therefore, without clinical recognition. Later miscarriages, which occur after the sixth week since the woman's last menstrual period (so-called *clinical spontaneous abortion*) are not universally documented in Austria. As in most countries, Austria begins its comprehensive documentation of fetal mortality with stillbirths. A stillbirth is defined as the birth of a child of at least 35 centimeter of length, without vital signs (body temperature, heart rate, blood pressure, respiratory rate).[18] Smaller fetus are categorized as miscarriages, and therefore, not documented. Finally, live births are very well documented in the *Austrian Birth Register*, which comprises individual-level data on the parents and the new-born. Information on induced abortions is not available. Although, abortion has been legal in Austria since 1975, no official statistics exist.

In order to infer on the effects of Chernobyl on prenatal culling, we propose three complementary strategies. First, we examine the incidence of live births on a community level. A lower estimated number of live births in exposed communities would provide evidence for prenatal culling. Second, we follow Sanders and Stoecker (2011) and use the sex-ratio of live births as a metric of fetal death. This methodology is based on an evolutionary theory advocated by Trivers and Willard (1973). The so-called *Trivers-Willard Hypothesis* states that the population sex ratio responds to parental conditions through prenatal selection. It predicts that mothers in good conditions are expected to have more sons, while mothers in poor conditions should have more daughters.[19] The precise prenatal mechanism how mothers (or their reproductive system) "favor" either female or male offspring, depending on their condition, is still debated (Navara, 2010). The adjustment

[18] The definition of stillbirths (in particular, the differentiation to miscarriages) varies somewhat across countries (Heisler, 2012). In Austria, the stated definition was valid throughout our sample period (until 1994). Since 1995, a stillbirth is defined as the birth of a child of at least 500 grams weight without vital signs.

[19] This prediction can be rationalized by a biological mechanism that tries to maximize the reproductive success of the offspring. Given that offspring health is correlated with parental health and that differences in offspring health will persist into adulthood, the main assumption is that the relationship between offspring health and mating success is less pronounced for women (compared to men). Put differently, since males can in principle have children with multiple women, healthy males could secure several mates, while males in poor health secure none. In contrast, in the case of females, mating with healthy men is also possible for females in poor health.

of the sex ratio may either take place at the primary or the secondary level. While a lower primary sex ratio is the result of a lower proportion of male offsprings at fertilization, a lower secondary sex ratio results from a lower likelihood of implantation of the blastocyst or a higher likelihood of male fetal loss. There are two empirical observations, which are in line with the Trivers-Willard Hypothesis. First, male fetus are more fragile than female fetus (Kraemer, 2000). Second, there exist robust empirical evidence that women in poor health (or under less favorable conditions) are less likely to have male offsprings (see, for instance, Almond and Edlund, 2007; Catalano *et al.*, 2005; Catalano and Bruckner, 2006; Hansen *et al.*, 1999). In our empirical analysis, we associate a decreased probability of male births with an increase in miscarriages (including early pregnancy losses).

Our third strategy is to examine the probability of a stillbirth based on the sample of all births (i. e., sum of stillbirths and live births). Table 3 summarizes the estimated effects on prenatal culling for BC_{II}, which was in the first trimester post conception at the time of the accident.

Families with low socioeconomic status The first panel shows the estimation results for the incidence of live births based on monthly community-level data. The dependent variable is equal to the number of live births per $1,000$ female inhabitants aged between 15 and 39 in the respective educational attainment group divided by the respective sample mean. We find a statistically significant negative effect, which provides first evidence on prenatal culling. The effect amounts to 8.6–11.2 percent fewer live births in exposed communities and is significant for all three definitions of exposure to radiation. This reduction in live births should be accompanied by an increase in the incidence of miscarriages or stillbirths (or both). Put differently, either some children are stillbirths (which are documented) or they die at an earlier stage of the pregnancy.

The second panel summarizes the estimated effects on the likelihood of a stillbirth based on individual-level data. We do not find any statistically significant effects. This suggests that radioactive exposure should lead to a higher incidence of miscarriages. While we cannot directly observe miscarriages, we can use the sex of the child as a proxy variable. As the results summarized in the third panel show, we indeed find a statistically significant negative effect on the likelihood of a male birth in exposed communities. Exposure to radiation in the first trimester post conception reduces the likelihood of a male birth by 4.3–8.8 percentage points. The size and significance of this effect increases with the level of radioactive exposure. Following the literature and interpreting this as evidence for miscarriages, this finding is consistent with the negative effect on live births (and the zero effect on stillbirths).

In order to assess the quantitative importance of the effect of radiation exposure on prenatal culling, it is useful to consider the baseline rate of conceptions that are lost spontaneously (aborted). The incidence of spontaneous abortion is widely believed to be

about 40 percent of all pregnancies (Macklon *et al.*, 2002).[20] This means that the effect of prenatal radiation exposure of roughly 10 additional percentage points equates to an odds ratio of $[(0.4 \times 1.1) \times 0.6] \setminus [(1 - 0.4 \times 1.1) \times 0.4] = 1.18$. In comparison, women who smoked more than 10 cigarettes per day during the first trimester have an estimated increased risk of spontaneous abortion with an odds ratio of 1.40 (Chatenoud *et al.*, 1998).

Families with higher socioeconomic status For exposed mothers with higher socioeconomic status we find — with the exception of one coefficient — point estimates in line with less live births and more miscarriages. However, the effects are not statistically significant at conventional levels. This suggest that there is a significant social gradient in the effect of prenatal exposure to radiation on culling. This finding is consistent with two explanations. First, it is well-documented that mothers with low socioeconomic status tend to have less favorable pregnancy outcomes (Kramer, 1987; Currie and Moretti, 2003). This means that the unborn children of these mothers are also weaker at any prenatal stage, and any negative shock should have more detrimental effects. Second, our finding is in principle consistent with research highlighting an educational gradient in the reaction to emerging health risk information. For instance, Aizer and Stroud (2010) show that highly educated women immediately reduced smoking in response to the *1964 Surgeon General Report on Smoking and Health*, while the low educated did not. Anderberg *et al.* (2011) find evidence for a social gradient in the response to the measles, mumps, and rubella (MMR) controversy in the UK. In the case of the Chernobyl accident, this would imply that mothers with higher socioeconomic status — residing in exposed, as well as in non-exposed communities, without knowing their actual treatment status — took measures that successfully reduced their exposure to radiation. Given that it seems hardly feasible to reduce exposure to radiation (one would have to stay inside over a longer period of time and manage to avoid contaminated food and water), we consider the first explanation as more plausible.

Exposure at higher gestational age For children from low socioeconomic backgrounds belonging to BC_I, which were already in their second or third trimester, we find less significant effects. Estimation output is provided in Table C.1.1 in Web Appendix C.1. The point estimates on live births are somewhat lower but the standard errors are unchanged. The effects on stillbirths are even smaller (and essentially zero). We do not find any evidence on the incidence of fetal death. These results are consistent with the existing evidence on the heterogeneous impact of radioactive exposure over the gestation period. In the case of children from higher socioeconomic backgrounds, the effects for BC_I are smaller as compared to those for BC_{II}; that is, they provide even less evidence for prenatal culling.

[20] Macklon *et al.* (2002) suggest a rate of 30 percent early pregnancy losses and a rate of 10 percent clinical miscarriages ($30 + 10 = 40$ percent). Furthermore, 30 percent of conceptus fail to implant, resulting in 30 live births per 100 conceptions.

In sum this set of results provides robust evidence that prenatal radiation exposure (to ^{137}Cs ground deposition of 37 kBq/m^2 or higher) during the first trimester post conception significantly increased prenatal culling among mothers with low socioeconomic status. Our analysis also reveals that male embryos and fetus are more vulnerable to radiation compared to female ones, and prenatal radiation exposure has the potential to distort the sex ratio at birth.

Postnatal culling To test for any effects of radioactive exposure on postnatal culling, we examine infant survival at different points in time after birth: after twenty-four hours, after seven days, after one month, and after one year. The main estimation results for BC_{II} are summarized in Table 4. Overall, we find little evidence for culling after birth. In the case of exposed mothers with low socioeconomic status, we do not observe any statistically significant effects. This suggests that exposed children (who survived the prenatal culling stage) were in no different physical condition as compared to non-exposed children, or were at least sufficiently healthy to survive the first year. Among children from exposed families with higher socioeconomic status, we observe some significantly positive effects on survival in communities with the highest radioactive exposure. The effects are significant up to one month after birth. One year after birth, no significant differences exist. This suggests that prenatal culling led to a slightly positively selected sample of live births in this particular group.

Exposure at higher gestational age In the case of children from low socioeconomic backgrounds, the effects for BC_I are equal to those for BC_{II} (i. e., no evidence for postnatal culling). In the case of children from higher socioeconomic backgrounds, we find some differences. In fact, post-natal culling is the only outcome, where we find more pronounced effects for children from BC_I (as compared to BC_{II}). We find reduced infant survival in BC_I (where effects are driven by mortality within the first week after birth). Estimation output is provided in Table C.1.2 in Web Appendix C.1. Prenatal exposure to radioactive fallout at a higher gestational age might have not been harmful enough to cause fetal death, but may have caused harm, which lead to death shortly after birth.

4.1.2 Cancelling out culling effects

To motivate our empirical strategy, which allows us to disentangle the culling and scarring effects, we formalize the tension between these two effects. While it is framed with respect to fetal mortality — which empirically turned out to be the most relevant stage — the same arguments apply to mortality at any point in time after the initial shock.

We start by assuming that each fetus i has some potential endowment b_i, which is distributed in the population with a cumulative distribution function $F(b)$ and density function $f(b)$. Fetus with an endowment below or equal to the cutoff z will not be born alive. Radioactive exposure in utero may have two effects: First, it may reduce the odds

of survival conditional on the birth endowment (*culling*), and second, it may shift the distribution of birth endowments to the left (*scarring*). Let us first consider the culling effect only; radioactive exposure shifts the survival cutoff from z to $z + r$, such that a fetus is born alive only if

$$b_i > z + r. \tag{2}$$

The fetal mortality rate m^T in exposed communities T is then given by

$$m^T = F(z + r). \tag{3}$$

In addition, radioactive exposure may also reduce the fetus' birth endowment by some fraction τ of r, which shifts the distribution of birth endowments to the left. (We may want to call τ, the scarring-parameter.) Given that this fraction is permanently lost, radioactive exposure may also have long lasting effects on the survivors.[21] Thus, for survivors, we have

$$\tilde{b}_i = b_i - \tau r. \tag{4}$$

The average birth endowment of the survivors in exposed communities is then given by

$$\bar{b}^T = \underbrace{\frac{\int_{z+r}^{\infty} b \cdot f(b) db}{1 - F(z + r)}}_{\text{Culling}} - \underbrace{\tau r}_{\text{Scarring}}. \tag{5}$$

The first term is increasing in the level of radioactive exposure (i. e., the average birth endowment increases), while the second term is negative and increases in absolute terms with higher levels of radioactive exposure. This tension between the culling (positive effect on birth endowment) and scarring effects (negative effect on birth endowment) has been long recognized in epidemiology.

Since the distribution of b_i, the value of z, and the scarring parameter τ are unknown, we generally cannot disentangle the culling and scarring effects without further assumptions. However, due to random assignment into treatment, we can assume that the untruncated distribution of birth endowments is equal in exposed and non-exposed communities. Panel (a) of Figure 3 shows the empirical cumulative distribution of gestation length for mothers with low socioeconomic status in BC_0 providing evidence that substantiates this assumption. The untruncated distribution — i. e. the average birth

[21] For simplicity and following Bozzoli *et al.* (2009), we assume that only the birth endowment of a survivor is reduced by τr. In the case that all fetus' birth endowments are reduced ,the mortality rate is given by

$$\hat{m}^T = F(z + r + \tau r),$$

because then, a fetus only survives if the reduced birth endowment $b_i - \tau r$ is above the survival cutoff $z + r$, implying

$$b_i > z + r + \tau r.$$

endowment of children born in non-exposed communities — is then given by

$$\bar{b}^C = \frac{\int_z^\infty b \cdot f(b)db}{1 - F(z)}. \tag{6}$$

We suggest a sample correction method to disentangle the culling and scarring effects. Given that assignment into treatment was random, we can implement a simple method, which adjusts the sample of non-exposed children such that it is comparable to the "culled" sample of exposed children. The distribution of the birth endowment in the sample of non-exposed children is a mixture of two distributions: (i) the distribution for children who would survive irrespective of their treatment status (children with $b_i > z + r$), and (ii) the distribution for children who survive only in the absence of the treatment (children with $z < b_i \leq z + r$). We basically manually cull the control group by removing those children who would not have survived if they had been exposed to the Chernobyl accident.[22]

Therefore, we exploit our knowledge about the extent and nature of the culling effects caused by the Chernobyl accident. We have estimated the extent of prenatal culling to be about 10 percent among exposed mothers with low socioeconomic status. This is the difference in the fetal mortality rate between the treated m^T and control regions m^C, which we denote by $\Delta m \equiv m^T - m^C$. Since the fetal mortality rate in control regions C is defined as $m^C = F(z)$, it follows that

$$\Delta m = F(z + r) - F(z). \tag{7}$$

Regarding the nature of the culling process, we have to decide *which* 10 percent of the control group have to be excluded. It seems plausible that culling tends to eliminate those in poor health (i. e., survivors of Chernobyl should generally be positively selected). To implement our sample correction method, we use the gestation length as a proxy for the strength of the fetus (its birth endowment) and exclude the lowest decile of the control group. Given that the assignment into treatment was random, this simple sample correction method should give us two comparable samples of treated and control units, net of culling effects. Estimation based on the two culled samples — where one was culled by the treatment, and the other by our sample correction method — should allow us to isolate any scarring effects.

Panel (b) of Figure 3 shows the observed distribution of gestation length for mothers with low socioeconomic status from BC_{II} by treatment status. The graph illustrates that the percentage of premature births is lower in the treatment group as compared to in the control group. This indicates that culling tends to eliminate children with low birth endowment. After manually culling the control group, the distribution of gestation

[22] Our procedure is comparable to the one suggested by Lee (2008). However, we use the culled sample to analyze further outcome variables and are only interested in the upper bound estimate (and not the lower bound estimate).

length shifts to the right, as depicted by Panel (c) of Figure 3. The comparison of the two culled samples in Panel (d) of Figure 3 shows that the distribution of gestation length in the treatment group now dominates the distribution in the culled control group. This provides first evidence for a negative scarring effect on birth outcomes. In the case of mothers with higher socioeconomic status, we do not apply a sample correction, since we did not observe any significant culling effects for this group.

4.2 Children's health at birth

To evaluate the impact of Chernobyl on health at birth, we summarize the estimation results based on individual level data for the commonly used outcomes, gestation length, birth weight, and Apgar scores in Table 5. Gestational length is classified as premature if it is below 37 weeks. Weight at birth is typically considered as low if it is below 2500 grams.[23] The Apgar score quickly and summarily assesses after one, five, and ten minutes the health of newborn babies based on five criteria (appearance, pulse, grimace, activity, and respiration) and ranges from zero ("good") to ten ("bad"). For each outcome, we present estimated coefficients based on the observed sample (first row) and the corrected sample (second row). In the former case, the estimates capture the sum of the culling and scarring effects, while in the latter case, only the scarring effects should remain.

Families with low socioeconomic status The signs of all estimates based on the observed sample suggest a strong positive culling effect that overcompensates any negative scarring effects. In the case of the outcome premature birth, the overall effect is statistically significant across specifications, where the point estimates marginally increase with the level of radioactive exposure. Children born alive are estimated to be about 3 percentage points less likely to be a preterm birth. Given an average incidence of preterm births of about 5.6 percent, the estimated effect is substantial and supports the notion that live births are a selected group of healthier newborns. This is in line with our estimation results on prenatal culling discussed above.

The estimation results after our sample correction reveal statistically significant scarring effects. In the case of premature births, this is *de facto* a mechanical result, since we have manually "culled" the lower tail of the gestational age distribution. The estimated scarring effects amount to about 3 percentage points. However, in the case of the other outcomes, we observe negative scarring effects. In the case of birth weight, the estimated effects are significant and suggest an increased likelihood of low birth weight between 2.3 and 3.1 percentage points, depending on the level of radioactive exposure. The estimated scarring effects for the Apgar score are, as expected, negative but remain statistically insignificant.

[23] Both a premature gestation length and a low birth weight are related to higher likelihood of infant mortality, but may also have long-lasting effects on health, education, and labor market outcomes (see, for instance, Black *et al.*, 2007).

As another indicator for health at birth, we use the duration of maternity leave. The statutory maternity leave is eight weeks before the delivery and usually eight weeks after the delivery. Under certain conditions, this duration may be extended; the sample average of the before and after spell are approximately nine weeks. If a premature birth reduces the pre-birth spell, the post-birth spell is extended such that the total maternity leave duration adds up to sixteen weeks. Moreover, the post-birth spell can be extended if health complications arise (i. e., the health of the mother or child would be endangered). Thus, an extended post-birth spell may reflect a mechanical effect due to low gestational age and/or post-birth health conditions. In line with the result above, we observe that the surviving treated population has shorter post-birth spells; these children are less likely to be premature births and/or of better health. Again, after we apply our sample correction method, these effects vanish.[24]

Families with higher socioeconomic status In the case of children from mothers with higher socioeconomic status, we did not apply the sample correction method, since we found very little evidence for prenatal culling. The analysis of health at birth (consequently based on the observed samples), however, partly suggests evidence for positive culling effects. While estimated effects on the likelihood of premature birth and the Apgar scores are insignificant and essentially zero, we find a reduced likelihood of low birth weight and a small negative effect on the post-birth maternity leave spell.

Exposure at higher gestational age In the case of children from BC_I, we find basically no evidence of radioactive exposure on health at birth (see Table C.1.3 in Web Appendix C.1). This applies to children irrespective of their socioeconomic backgrounds and is in line with our results on prenatal culling. The estimated coefficients for premature birth, low birth weight, and Apgar scores are all statistically insignificant and essentially zero. The only exceptions are some negative effects on the Apgar scores of treated children from higher socioeconomic backgrounds.

4.2.1 Reconciliation with the no health effects result by AEP

There are at least three potential explanations why we find health effects of the Chernobyl accident (in terms of culling and scarring), while AEP do not identify any effects in their Swedish data. First, the level of ^{137}Cs ground deposition the average inhabitant was exposed to was considerably higher in Austria as compared to Sweden. AEP report a mean level of contamination of about 6 kBq/m^2 for Sweden and a mean level of about 44 kBq/m^2 in areas with the highest exposure. In contrast, the average Austrian was exposed to a ^{137}Cs level of about 20 kBq/m^2, and the mean level of contamination in areas with the highest exposure ranges from 49 to 59 kBq/m^2 depending on our treatment group.[25]

[24] We do not the use the pre-birth spell duration, since the interpretation of the results is complicated — the mechanical effect and the health effect have opposite signs.

[25] Although both countries rank among those countries with the highest contamination levels in Western Europe, the relative size of the contaminated area is 10.3 percent in Austria as compared to 2.7

Second, a comparison of the infant mortality rates suggests that the average Austrian child (unborn or newborn) had a significantly lower level of birth endowment at that time.[26] This means that the negative early-life shock should have more detrimental effects for the average Austrian child as compared to the average Swedish child.

Third, AEP exclude the birth cohort with a gestational age below eight weeks. It is possible that the prenatal culling is particularily driven by this cohort who was exposed to radiation at a very early stage. For comparison, we present results based on an empirical model in the spirit of AEP in Table 6. We estimate two specifications. In the first specification, the treatment group consists of children who have been in utero between 2 and 6 months (about 8–25 weeks) at the time of the accident. This specification uses the same definition of treatment status regarding timing as AEP. In the second specification, we also include children who have been in utero between 0 and 2 months (about 0–7 weeks) at the time of the accident. Results based on the first specification are qualitatively similar to those found by AEP. There is no significant effect (neither positive nor negative) on health outcomes measured at birth. In line with that, there is no evidence for a distortion of the sex ratio, and in terms of live births, only one out of three estimated coefficients is significant. In sum, we do not find much evidence for prenatal culling.

In contrast, based on the second specification (i. e., for children with a gestational age between 0 and 6 months), we do find evidence for prenatal culling in terms of a significantly negative effect on live births and the probability of a male birth. However, the estimated effects are weaker as compared to those for BC_{II}, which includes only children at gestational age between 0 and 3 months (see Table 3 and Table 5). Moreover, we do not find any positive effects on health outcomes at birth — which would indicate prenatal culling — for children who have been in utero between 0 and 6 months at the time of the accident. Therefore, it seems that prenatal culling is actually driven by the birth cohort with a gestational age between 0 and 3 months (our BC_{II}).[27]

4.3 Parental response

In this section, we analyze the parental response to their child's early-life shock. We do not impose any assumption on whether the parents become aware of their child being prenatally exposed to high levels of radioactive fallout. Our implicit assumption is that

percent in Sweden (Source: Own calculations based on UNSCEAR (2000, Table 5, p. 520)). Moreover, the population density is substantially higher in Austria (92 inhabitants per km^2) than in Sweden (19 inhabitants per km^2). Therefore, the average Austrian was exposed to a higher ^{137}Cs level than the average Swede.

[26]The average infant mortality rate based on annual figures from the period from 1980 through 1985 was 12.2 in Austria and only 6.8 in Sweden (Source: Own calculations based on data from the *The World Bank*). A higher infant mortality rate reflects (among others) a low birth weight and a short gestational age among live births.

[27]In line with our analysis, AEP report in an earlier version (Almond *et al.*, 2007), a negative effect of Chernobyl on cohort size and the probability of a male birth for children with a gestational age between 0 and 7 weeks.

parents observe the physiological and/or cognitive deficiencies of their child and might react to these.

To quantify parental response behavior, we examine families' post-treatment fertility and maternal labor market outcomes.[28] We presume that both, a lower family size and a reduced maternal labor supply, enable more (time) investment in the child's human capital. Thus, we will associate either of these parental response behaviors with compensating investment in the treated child. In contrast, an increased family size and higher maternal engagement on the labor market will be interpreted as reinforcing investment. Table 7 summarizes the estimations results on post-treatment fertility. Each entry represents the results from a separate regression, where the dependent variable is equal to the number of children born to BC_{II} mothers in the respective year after treatment. Given that the mothers in our sample are between 40 and 63 years of age twenty years after the treatment, the estimated coefficient in the last row can be interpreted as the effect on completed fertility. Table 8 summarizes the estimations results on maternal labor market participation. The dependent variable is equal to one if the mother is in the labor force in the respective year after birth. Each entry represents the coefficient for exposed BC_{II} mothers interacted with years since the birth of the child.

In the case of families with low socioeconomic status, estimates we perform the estimation of both outcomes based on the observed samples and after applying our sample correction method. The estimates are somewhat larger in absolute terms based on the corrected sample. Culling effects seem to be of second-order importance in the case of long-term outcomes. Still, we focus here on the results based on the corrected sample (see Table 7 and Table 8) and relegate the estimation output based on the observed samples to Web Appendix C.2 (see Table C.2.1 and Table C.2.2).

Families with low socioeconomic status Exposed families with low socioeconomic status have significantly less children at any point in time after treatment (see Table 7). The size of the effect increases in absolute terms with the level of radioactive exposure and over time. Twenty years after the birth of the pivotal child, the effect amounts to minus 0.12 to minus 0.18 children. This is equivalent to a reduction in completed family size of about 17–26 percent. A closer inspection of how the estimated effects evolve over time (i. e., first differences in the estimates) reveals that the reduction is predominantly due to less births in the second, fifth, eight, and eleventh years after treatment.

Starting from about four years after birth of the pivotal child, exposed women are more likely to be active on the labor market (see Table 8). However, the estimated effects

[28] Due to an imperfect match between administrative data sources, we lose 4 percent of the sample (compared to the analysis of children's health at birth) for our analysis of maternal labor market outcomes. We do not find a significant relationship between in utero exposure to radiation and a binary variable that indicates whether we observe maternal labor market outcomes. Moreover, the results on children's health at birth do not change when we exclude children with missing information on maternal labor market outcomes. For our analysis of post-treatment fertility, we can use the full sample.

are not statistically significant for each single year. There is a pattern with a peak in the fifth and twelfth year after treatment with an estimated effect of about eight percentage points. We suggest *not* to interpret this labor market response as reinforcing investment, but as a direct consequence of the reduced family size. This interpretation is supported by the timing of these two responses. First, the initial and most pronounced fertility reaction (in the second year) predates the labor market adjustment. Second, the pattern of the labor market response (i. e., the peaks in the fifth and twelfth years) coincides with the timing of the subsequent peaks in the fertility response.

Families with higher socioeconomic status In the case of exposed mothers with higher socioeconomic status, we do not observe any effects on fertility (see Table 7). The estimates are all statistically not significantly different from zero and the coefficients are quite close to zero. This means that there is evidence neither for any impact in terms of the timing of further births nor regarding completed family size.

In contrast, we find evidence that exposed mothers reduce their labor force participation temporarily (see Table 8). The timing of this effect is especially intriguing, since it coincides with the pivotal child's enrollment in primary school. The effect emerges in the seventh year, peaks in the eighth year, and dissipates over time. After the tenth year, the estimates are basically all zero. Notably, the estimated coefficients for the years 1 to 14 are jointly statistically significant. At the peak, the effect is between minus 4.0 and minus 6.9 percentage points, depending on the level of radioactive exposure. This pattern is consistent with reduced cognitive abilities of exposed children as put forward by AEP. While it is not observable to us, when treated parents realize that their children have cognitive problems, a drastic intervention during primary school (enrollment) seems plausible. Due to the specific feature of *early tracking* in the Austrian education system, grades in even primary school have far-reaching consequences for later educational choice.[29] Therefore, involved parents will take different measures to solve any learning differences at this stage. Given the basic content of the curriculum, professional tutoring is less uncommon for pupils of this age and typically, parents teach their children after school to overcome any learning difficulties.

To summarize the main results of these analyses, we find for both socioeconomic groups statistically significant evidence for compensatory investment in the treated child. Families with low socioeconomic status reduce their fertility (trading child quality for quantity), while families with higher socioeconomic status respond with reduced maternal labor supply. Both effects indicate that affected children need more attention, and parents adapt their behavior, such that they can devote more time to their children and make

[29] As we will discuss in more detail below, in Austria, students are allocated two different educational track already in grade five (i. e., at the age of 10). Allocation to the *low track* or the *high track* are based on grades in the third and fourth grades. Only graduates from the *high track* have access to university education.

necessary compensating investment.[30]

How do these results compare to other findings in the literature? The existing design-based literature on the parental response to child endowments is rather scarce (see footnote 1), especially with respect to developed countries. Bharadwaj *et al.* (forthcoming) exploit a discontinuity in a neonatal health care treatment for children with very low birth weight and find no evidence for parental response behavior in their Norwegian (and Chilean) data. In another context, Frijters *et al.* (2009) use left-handedness to instrument for poor early child development and find a negative effect on maternal labor supply, suggesting that parents make compensating investments.

Exposure at higher gestational age For families from BC_I, we find a similar pattern for the fertility response behavior (see Table C.1.4). Again, there is no significant reaction by families with higher socioeconomic status. For families with low socioeconomic status we find a reduction in fertility, but, the estimated effects are almost half in size and not statistically significant at conventional levels. The effect on maternal labor force participation is summarized in Table C.1.5). For families with low socioeconomic status, we do not observe any significant effects on maternal labor force participation. This is consistent with the insignificant fertility response. For families with higher socioeconomic status, we observe a positive effect on maternal labor force participation in several years after child birth. The effect is between 1.8 and 4.8 percentage points and of varying significance, depending on the level of radioactive exposure. There are two possible explanations for this finding. First, it may reflect a reinforcing parental behavior in response to a negative scarring effect. We found some evidence that these children had a lower Apgar score at birth (see Table C.1.3). Alternatively, given that we find some evidence for postnatal culling in this group (see Table C.1.2), these children may be somewhat positively selected. A higher labor force participation may then simply reflect the fact that these children have higher cognitive endowments, and less parental tutoring is needed. Given that we also do not find much evidence for scarring effects for these children in our analysis of labor market outcomes (see below), we consider the second explanation as more plausible.

4.3.1 Non-radiation effects

The local level of ground deposition was not known at the time of the accident. Therefore, parents (or even potential parents) in exposed and non-exposed communities may have been stressed and anxious in the aftermath of the accident. This may have changed their behavior immediately after the accident and caused what we termed *non-radiation effects* with potential scarring and culling consequences for children. In case of live births and fetal death, only culling effects are possible.

Most likely, women who were already aware about their pregnancy were extremely

[30] We have also examined the length of parental leave spells: no difference between exposed and non-exposed families is discernible.

stressed and anxious. This stress *per se* may have had detrimental effects on the embryo or fetus, or even led to miscarriage.[31] A very direct culling effect is given by an adaption in abortion behavior: pregnant women may have decided to have an induced abortion.[32] Less drastically, expecting mothers could have tried to reduce exposure to radiation. While it is general unlikely that such an avoidance behavior (e. g., change of diet) is effective in reducing exposure to radiation, it could have nevertheless affected the child in some way.

The scope of early parental response behavior differs across birth cohorts. Parents of a child belonging to BC_I had the smallest scope for action. An induced abortion was not possible anymore, since the pregnancy had advanced past the first trimester (the legal time limit). However, their unborn child could have been exposed to maternal stress or a modified maternal diet during the last two trimesters of pregnancy.[33] In comparison, parents of a child belonging to BC_{II} could have reacted quite drastically and have an abortion.

The parameters ρ_1 and ρ_2 give the estimated non-radiation effects. Table 9 summarizes the effects for prenatal culling and health at birth. In the case of prenatal culling outcomes, the parameter ρ_1 gives the estimated non-radiation effects (for BC_I) that work through miscarriages. Among the mothers with higher socioeconomic status, we find some evidence for an increased number of miscarriages. While the effect is not statistically significant at conventional levels in the case of live births, we find a skewed sex ratio. In line with the Trivers-Willard Hypothesis, there is significant negative effect on the likelihood of male birth. The effect is almost identical across different levels of exposure.[34] This does not affect the outcomes gestational age and birth weight at the critical margins (i. e., premature birth or low birth weight). The parameter ρ_2 gives the estimated non-radiation effects (for BC_{II}) due to miscarriages and induced abortions. No significant effects are found. By imposing the assumption that the non-radiation effects on miscarriages are equal for BC_I and BC_{II}, it is possible to interpret the difference between ρ_1 and ρ_2 as the effect of induced abortions. Given that miscarriages are generally far more common

[31] Experimental evidence on the negative effects of in utero exposure to maternal stress on offspring outcomes is only available in animal studies (Kaiser and Sachser, 2005). For humans, a number of observational studies report a negative effect of maternal stress (measured by cortisol levels). Nepomnaschy *et al.* (2006) find evidence for increased fetal death. Aizer *et al.* (2009) report negative effects on educational attainment, the probability of a severe chronic health condition, and verbal IQ at age of seven. Similar results are obtained for birth weight by design-based papers using earthquakes (Torche, 2011) and terrorist attacks (Camacho, 2008; Mansour and Rees, 2012). Currie and Rossin-Slater (2012), exploiting hurricane exposure, find some evidence for complications of labor and delivery, but no effect on birth weight and gestation.

[32] In fact, there is some evidence indicating a temporary increase in the number of induced abortions in Greece, Italy, and Sweden (see Web Appendix A).

[33] There is some evidence for a high responsiveness of birth weight to nutritional changes in the third trimester of pregnancy (Painter *et al.*, 2005).

[34] While in the case of radiation effects, one would expect variation in the estimated effects according to the degree of exposure to radioactive fallout, in the case of non-radiation effects, a uniform response across regions can be expected given that individuals had not been made aware of the local level of ground deposition.

in the first trimester than in the second or third trimester, we interpret the abortion effect with caution. Still, we find statistically significant evidence (not tabulated) that induced abortions have decreased the fetal death rate between 3.8–4.3 percentage points (depending on the level of radiation).

Among mothers with low socioeconomic status, we do not find any significant non-radiation effects. This suggests that early parental response behavior was only prevalent (or at least discernible) among families with higher socioeconomic status.

4.4 Children's human capital outcomes

We now assess the long-term effects on exposed children. Since we observe that parents try to compensate for the early-life shock, we can interpret the estimates in this section as a lower bound of the biological effect. We examine human capital outcomes between the age of 15 and 23.[35] Due to a widespread dual education system and low rates of university graduates, the vast majority of the Austrian population is already in the work force at this age (either as an apprentice or as a regular employee). Table 10 shows that this applies in particular for children from low socioeconomic backgrounds.

To motivate our estimation strategy, we outline the average Austrian student's transition from school to work. This is driven by two distinguishing features of the Austrian education system: *early tracking* and the widespread dual education system. Students are allocated already in grade five to two different educational tracks. The lower secondary schools (*low track*) comprise grades 5 to 8, provide basic general education and prepare students for vocational education either within an intermediate vocational school or within the dual education system. The higher general schools (*high track*) comprise a first stage (grades 5 to 8) and a second stage (grades 9 to 12), provide advanced general education and conclude with a university entrance exam.[36]

Low track career path The majority of the students (about 72 percent) are allocated to the *low track*. This share is higher among children from parents with low socioeconomic status (87 percent) than among those from parents with higher socioeconomic status (66 percent).[37] Approximately 82 percent of students from the low track enter the work force

[35] This analysis is based on a sub-sample (as compared to the analysis of children's health at birth). We are able to link only 70 percent of the children in the *Austrian Birth Register* with the ASSD. Fortunately, whether we observe a child's human capital is not related to in utero exposure. Moreover, the results on children's health at birth are robust to the exclusion of these 30 percent of children.

[36] A further institutional detail of the Austrian education system impedes an analysis of test scores. Tests in either track are decentralized. This means that they are prepared and graded by the respective teacher. This rules out a meaningful comparison of test scores across schools. Test scores from the *Programme for International Student Assessment* (PISA) and *Trends in International Mathematics and Science Study* (TIMSS) would be comparable across time and space; however, neither study covers the treated birth cohort. The only feasible data are cognitive test scores collected by the Austrian military. (All male Austrian citizens are subject to compulsory military service and have to enlist and muster for different examination within one year after attaining their 17th birthday.) This data is, however, until now, not available to researchers.

[37] These figures are our own calculations based on retrospective data from Knittler (2011) and refer to

at around 15 years of age, ideally via the dual education system or as an unskilled worker. The dual education system combines apprenticeship in a firm and (vocational) education at a vocational school. Not all students who want to enter the dual education system, manage to find an employer. They either register unemployed or find a job as an unskilled worker. The remaining 18 percent continue with an intermediate vocational school and enter the workforce at around 17 years of age.

Higher track career path Only about 30 percent of all students are allocated to the *high track*. Among children from low socioeconomic backgrounds, this share is only 14 percent, while among children from higher socioeconomic backgrounds, it amounts to 34 percent. Students from the high track enter the workforce either after graduation from a higher general school (at around 18 years of age), a higher vocational school (at around 19 years of age), or a university.

While our data, derived from the ASSD, do not include any information on educational attainment, it comprises detailed information on all workers in Austria regarding their labor market status in employment (including basic employer information), unemployment, and various other qualifications on a daily basis. In particular, we can distinguish between an apprenticeship training, different types of regular employment, and unemployment (each measured on the first day of the quarter that includes their birthday). Table 11 summarizes our main estimation result, where the dependent variable is equal to one if the child is in the labor force at a certain age.[38] Each entry represents the coefficient for exposed children BC_{II} interacted with their age. In Table 12, we further estimate the impact on the likelihood of being an apprentice at ages 16, 17, and 18, as well as, the effect on the overall labor income earned between the age of 15 through 23.

Families with low socioeconomic status For this group, we have again compared the estimates based on the observed and corrected samples. As in the case of parental response behavior, the sample correction has little impact. This means that there are no culling effects present in the long run. They seem to have vanished since birth. In fact, in the case of children's labor market outcomes, the point estimates are almost identical. Therefore, we report here the estimates based on the corrected sample and relegate the estimation output for the observed sample to Web Appendix C.2 (see Table C.1.6 and Table C.1.7).

Put simply, due to high intergenerational educational persistence in Austria (OECD, 2010), there are two realistic successful career paths for children from low socioeconomic backgrounds. They start an apprenticeship training at the age of 15, graduate and are employed from there on. Alternatively, they graduate from an intermediate vocational school and start working at the age of 17. Those who do not graduate and become

the sum of graduates and drop-outs from the low track.

[38] Labor force participation includes any form of dependent employment (blue-collar, white-collar, civil servant), self-employment, employment as farmer, apprenticeship training, freelance service contract ("Freier Dienstvertrag/Werkvertrag"), subsidized employment, sick leave, and unemployment except marginal employment.

(employed or unemployed) unskilled workers are the low performers.

Our estimation results highlight two robust effects. First, treated children are less likely to be an apprentice. The effect is strongest at the age of 17 and amounts to approximately minus 8 percentage points (see Table 12). Second, exposed children are less likely to be employed throughout the whole time period under consideration (see Table 11). While not each coefficient is individually significant, they are consistently negative and jointly significant. The effect is on average minus 7 percentage points. In sum, these two results suggest that treated children are less likely to finish an apprenticeship, and (due to a lack of vocational career options), they are less likely to be employed thereafter.[39] This means that exposed children from low socioeconomic backgrounds have worse educational and labor market outcomes and have (at least until the age of 23 years) accumulated less human capital. We conclude that for this group prenatal exposure to radiation has — despite compensating behavior of their parents — substantial long-term scarring effects. Based on wage regressions (42 kBq), the estimated loss in annual before-tax income amounts to 8,665 Euro or 53.0 percent. A quantification of the corresponding loss in the counterfactual situation where parents of exposed children would have not adjusted family size (as a response to the treatment) is hard, since this compensating investment is endogenous.

Families with higher socioeconomic status For children from higher socioeconomic backgrounds, we find little evidence for effects on their labor market outcomes. At the age of 16, they are somewhat more likely to be in the labor force (about four to five percentage points). A comparison between Table 11 and 12 shows that this effect is driven by an increased likelihood of being an apprentice. Since this is a below-average career path for this group, the effect should be interpreted as a negative scarring effect. At higher ages, labor market participation is not statistically significantly different between exposed and non-exposed children; the same holds for the likelihood of being an apprentice and the total earned labor income. The majority of the point estimates (especially those at higher ages) are also quite close to zero. This suggests that even if some negative scarring effects are present in adolescence, they seem to vanish over time. Of course, it is unclear whether exposed children would have worse outcomes in the case where parents would have not compensated for the shock.

These results conform with existing evidence on the impact of in utero exposure to

[39] Strictly speaking, our estimation results are also consistent with an interpretation where exposed children are more likely to graduate from the high track and proceed to college, and are for this reason less likely to be employed. Theoretically, this could be the result of very effective parental response behavior,We which overcompensates the effect of the early-life shock. This interpretation, however, seems farfetched. Only 14 percent of children from low socioeconomic backgrounds complete the high track — this would imply an effect of almost 60 percent. Still, to provide supportive evidence for our interpretation, we have estimated the effect on the so-called *marginal employment*. This type of employment contract is for jobs with a low number of working hours, low pay (up to just over USD 284 per month in 2002) and covers only accident insurance. This type of employment is very common among college students who work while enrolled. We do not find any significant effects on the likelihood of marginal employment.

radioactivity on long-term human capital outcomes. AEP find that Swedish children in low-educated families (who were prenatally exposed to radioactive fallout of the Chernobyl accident) had significantly lower grades in compulsory school at the age of 16. In contrast, for children in highly-educated families, they identify no comparable effect. Black *et al.* (2013) show with their Norwegian data that in utero exposure to radioactive fallout caused by nuclear weapons testing reduced IQ scores, educational attainment, and earnings. Some of these effects are more pronounced for individuals from low socioeconomic backgrounds.

The social gradient in the long-term effects on treated children can be explained by a comparable more-effective compensating investment made by families with higher socioeconomic status. It seems plausible that families from low socioeconomic backgrounds are more restricted in their compensatory investment; for instance, binding financial constraints may not allow an adjustment of maternal labor supply or changes along other non-observable dimensions (such as private tutoring or social job-finding networks).

Exposure at higher gestational age For children from BC_I, we do not find robust evidence for any long-term effects on human capital outcomes (see Tables C.1.6 and C.1.7). The vast majority of the estimates have a negative sign (this applies to children from all socioeconomic backgrounds), though, the estimates are mostly statistically insignificant. In sum, these results corroborate the conjecture that prenatal exposure to radiation is less critical at a higher gestational age.

4.5 Siblings' human capital outcomes

Last, we ascertain whether the compensating parental response has spillover effects onto otherwise unaffected siblings. *A priori*, it is unclear whether the compensatory investments come at their cost or to their benefit. On the one hand, siblings may have suffered if parents reallocate resources (i. e., private goods) from them to the exposed child. We do not have information on this dimension. On the other hand, they may have benefited from an increased supply of local public goods, such as via reduced family size and/or the lower maternal labor supply as we have identified above. Thus, the net effect can be positive or negative.

Since post-treatment fertility is endogenous, we can cleanly identify this overall spillover effect based only on older siblings. This means that we use the families who had at least one child before the pivotal child. Our most extensive sample (using treatment group definition 1) comprises 52,461 older siblings, of which 26 percent had an exposed sibling and 74 percent had a non-exposed sibling. An equivalent estimation analysis as in the previous section is summarized in Tables 13 and 14. We find a positive effect on labor force participation for children from either socioeconomic background. In the case of children from low socioeconomic backgrounds, we do not see a different likelihood of apprenticeship training; however, we find positive effects on labor force participation in

their early 20s. Untabulated results show that this is driven by employment (predominantly in white-collar jobs) and not by unemployment. In sum, these siblings seem to have benefited from the reduced family size. This is confirmed by some positive effects on their annual before-tax income.

For children from higher socioeconomic backgrounds, we observe positive effects on labor force participation around 16 and in their early 20s. The early effects are driven by a higher likelihood of apprenticeship training. The effects in their early 20s are more pronounced (and statistically significant) if we use employment as an outcome (not shown in table). More detailed regressions reveal that the effects are driven by blue-collar jobs. We find no effect on the wage sum; this is in line with a zero sum of more employment in lower-paying blue collar jobs. Given that apprenticeship training and a blue-collar job do not represent a desirable career path for this group of siblings, we interpret the overall effect as negative. This suggest that in families with higher socioeconomic status the negative effect of the reallocation of private goods dominates the positive externalities of the compensating behavior. One may speculate that the positive spillover effects are larger in the case of reduced family size as compared to reduced maternal labor supply.

5 Conclusions

The literature on the long-term effects of early childhood conditions on human capital accumulation has devoted little attention to parental response behavior. In this paper, we study the case of prenatal exposure in the Austrian 1986 cohort to radioactive fallout from the Chernobyl accident and examine how parents of exposed children respond to this early-life shock. Identification is based on exogenous geographic variation in the exposure to radioactive fallout due to differences in precipitation at the time of the accident. Based on different administrative data sources, we find robust evidence for compensating parental investment that differs in type and effectiveness across families' socioeconomic backgrounds.

Our results urge caution in the interpretation of estimates of the long-term effects of early-life shocks on children. They demonstrate that these estimates can only be interpreted as reduced-form estimates, and not as the biological effect of the shock, since parental investment behavior is an empirically relevant phenomenon. To reach a deeper understanding on the relationship between early-life shocks and the formation of human capital, it is indispensable to account for parental response behavior.

In the case of Chernobyl, we find that parents try to compensate for the early-life shock. Families with low socioeconomic status reduce their family size, and families with higher socioeconomic status reduce maternal labor supply temporarily. This observation allows us to interpret the estimated long-term effects on children as a lower bound of the biological effect. Exposed children from low socio-economic backgrounds still have worse outcomes

in young adulthood, whereas for children from higher socioeconomic backgrounds, we do not find any detrimental long-term effects. Notably, we find spillover effects on otherwise unaffected older siblings for each group.

These results should also be of interest to policy-makers. The most straightforward policy implication of our result is another strong argument for providing disadvantaged families with the necessary economic and social resources that allow early childhood investment. It is widely documented that (i) children from low socioeconomic backgrounds typically grow up in less-favorable environments and (ii) there is also some evidence that early conditions matter more for children from this group. Our results shed light on the underlying mechanism. They suggest that all parents — irrespective of their socioeconomic status — adjust their behavior to invest in their children according to their specific needs. However, parental response behavior of families with higher socioeconomic status seems more effective. Families with low socioeconomic status are most likely to be more restricted in their compensatory investment along pecuniary and non-pecuniary dimensions.

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6 Tables and figures

Figure 1: Average Caesium-137 ground deposition in Austria on May 1, 1986

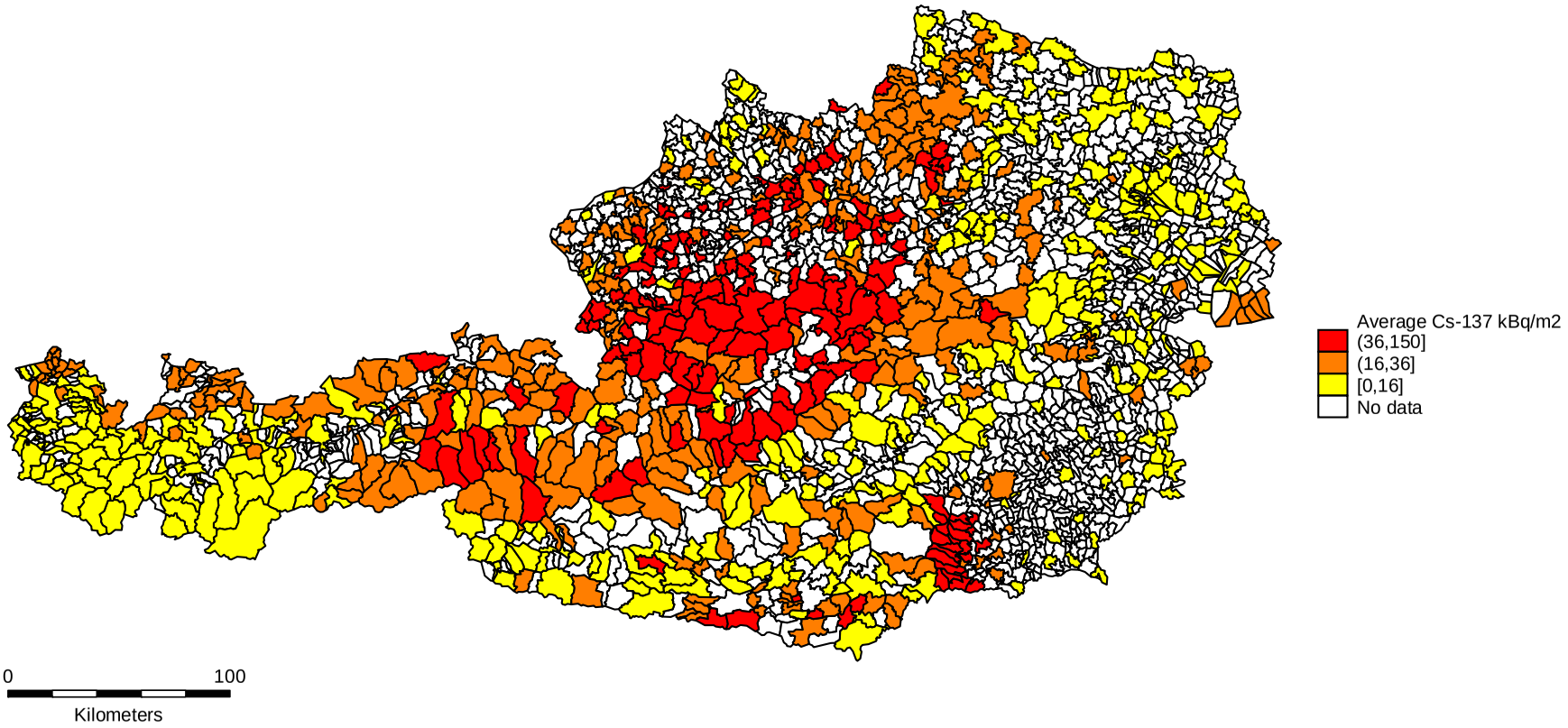


Table 1: Definition of treatment and control groups

Group	Acronym	Average level of ^{137}Cs ground deposition (in kBq/m^2)	No. of communities	Mean ^{137}Cs	Std.Dev. ^{137}Cs	No. of children
Control group	C	less than 17	427	8.1	(4.6)	72,607
Treatment group 1	$T1$	37 ore more	175	49.1	(12.5)	22,496
Treatment group 2	$T2$	42 ore more	130	54.4	(12.3)	14,812
Treatment group 3	$T3$	47 ore more	93	59.2	(12.5)	9,986
Excluded[a]		between 17 and 36	322	27.3	(5.5)	37,335
		between 17 and 41	367	29.3	(6.6)	45,019
		between 17 and 46	404	30.7	(7.8)	49,845

[a] The cutoff-value, the number of communities and the population-weighted mean of ^{137}Cs ground deposition depend on the respective treatment group.

Figure 2: Birth cohorts included in the estimation samples

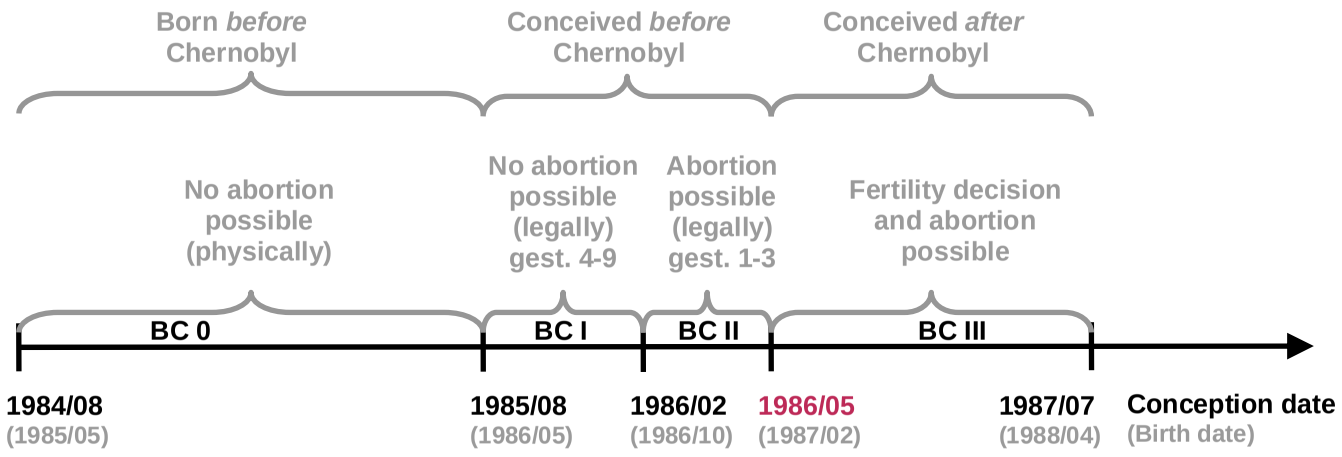


Table 2: Outcome variables

Outcome	**Level of available data**	**Measurements**	**Data source**
Live births	Community	Absolute number per 1,000 female inhabitants aged 15-39 in 1981 in the respective education group	*Austrian Birth Register*
Stillbirth	Individual	Binary variable	*Austrian Birth Register*
Spontaneous abortion	Not observable	Proxied by sex-ratio (binary variable that indicates whether child's sex is male)	*Austrian Birth Register*
Health at birth	Individual	Gestation length, weight, Apgar scores	*Austrian Birth Register*
Maternity leave	Individual	length in days	*Austrian Social Security Database*
Infant mortality	Individual	Binary variables that indicate whether child is still alive after 24 hours/7 days/1 month/1 year	*Austrian Birth & Death Register*
Parental leave	Individual	Length in days, take-up	*Austrian Social Security Database*
Labor market outcomes	Individual	For mother and child: apprenticeship training, employment, wages	*Austrian Social Security Database*
Post-treatment fertility	Individual	Number of children	*Austrian Birth Register/ Austrian Social Security Database*

Table 3: Radiation effects on prenatal culling

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Live birth								
Live birth rate[a]	3.031	−0.086**	−0.112**	−0.106*	8.918	−0.061	0.054	−0.025
		(0.043)	(0.049)	(0.058)		(0.126)	(0.153)	(0.178)
Stillbirth								
Prob(Stillbirth)[b]	0.005	0.004	0.009	0.009	0.004	−0.001	0.000	−0.002
		(0.005)	(0.007)	(0.008)		(0.002)	(0.002)	(0.002)
Fetal death								
Proxy: *Prob*(male)[c]	0.510	−0.043	−0.075*	−0.088**	0.514	−0.015	−0.005	−0.016
		(0.036)	(0.039)	(0.040)		(0.019)	(0.022)	(0.027)

This table summarizes estimation results based on community-level data (first row) and individual-level data (second and third row) from the *Austrian Birth Register* and the *Austrian Death Register* covering births conceived between 08/1984 and 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from the BC_{II}. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to the number of live births per 1,000 female inhabitants aged between 15 and 39 years of age in 1981 (in the respective education group) divided by the respective sample mean. [b] The dependent variable is equal to one if the child is a stillbirth and zero if the child is a live birth. [c] The dependent variable is equal to one if the child is male, and zero otherwise.

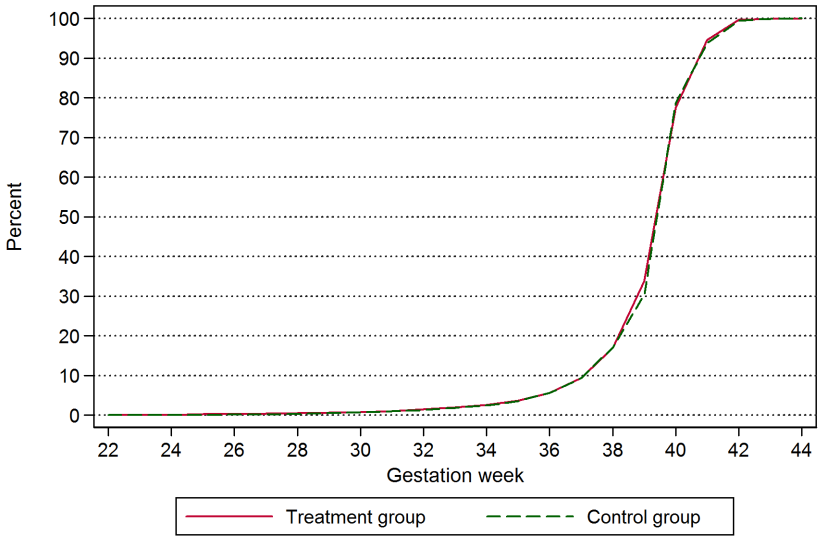
Table 4: Radiation effects for postnatal culling

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Alive after 24 hours	0.993	−0.008	−0.013	−0.017	0.995	0.002	0.001	0.003*
		(0.007)	(0.009)	(0.011)		(0.002)	(0.003)	(0.002)
Alive after 7 days	0.990	−0.007	−0.013	−0.011	0.992	0.002	0.003	0.005**
		(0.008)	(0.010)	(0.011)		(0.003)	(0.003)	(0.002)
Alive after 1 month	0.988	−0.006	−0.011	−0.010	0.991	0.002	0.004	0.006**
		(0.008)	(0.010)	(0.011)		(0.003)	(0.003)	(0.002)
Alive after 1 year	0.983	0.004	−0.004	−0.003	0.988	0.001	0.005	0.006
		(0.009)	(0.011)	(0.013)		(0.004)	(0.004)	(0.004)

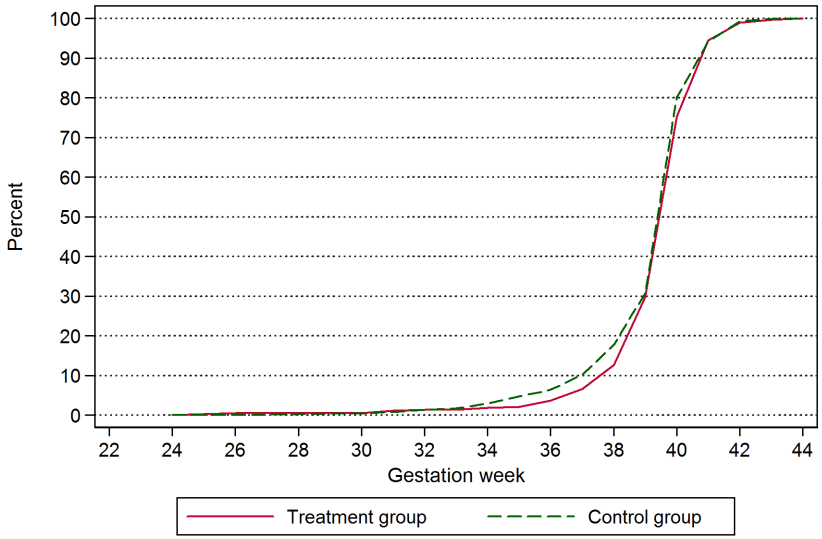
This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Death Register* covering births conceived between 08/1984 and07/1987. The dependent variable is equal to one if the child is still alive after the respective time period after birth. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from the BC_{II}. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Figure 3: Cumulative distribution of gestation length for mothers with low socioeconomic backgrounds

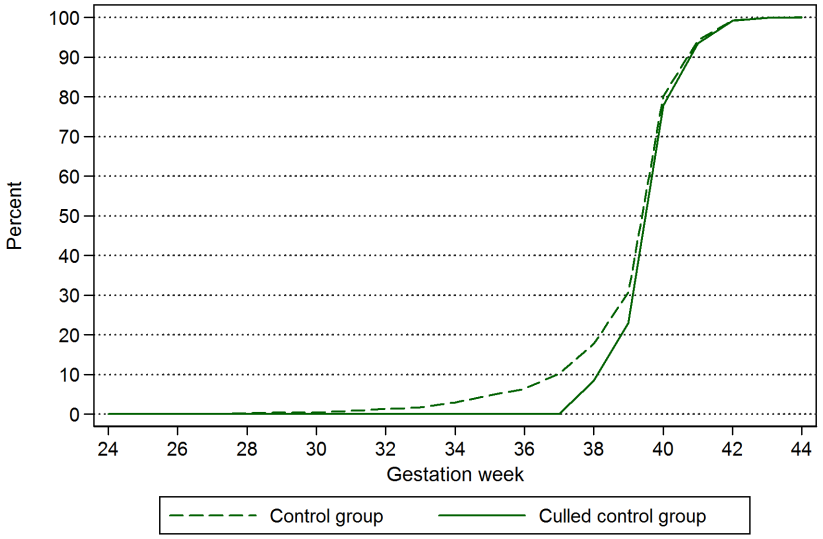
(a) BC 0 — treatment group vs. control group



(b) BC II — treatment group vs. control group



(c) BC II — control group vs. culled control group



(d) BC II — treatment group vs. culled control group

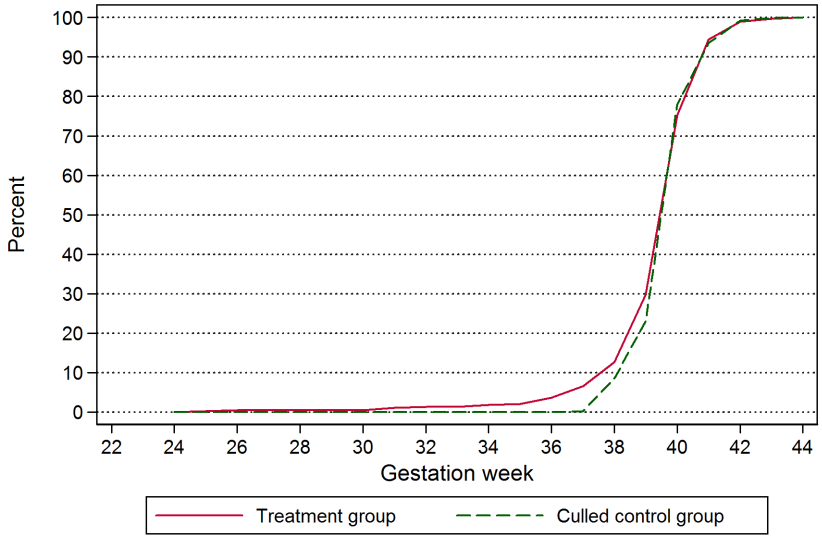


Table 5: Radiation effects (culling & scarring) on health at birth

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Premature birth[a]								
Culling & scarring	0.056	−0.029**	−0.029**	−0.032**	0.047	−0.008	−0.009	−0.011
		(0.011)	(0.013)	(0.014)		(0.008)	(0.009)	(0.010)
Scarring	0.053	0.035***	0.035***	0.032***				
		(0.009)	(0.010)	(0.012)				
Low birth weight[b]								
Culling & scarring	0.067	−0.014	−0.012	−0.020	0.054	−0.025***	−0.032***	−0.028***
		(0.013)	(0.015)	(0.017)		(0.007)	(0.008)	(0.009)
Scarring	0.065	0.028**	0.031**	0.023				
		(0.012)	(0.014)	(0.016)				
Apgar score[c]								
Culling & scarring	9.870	0.025	0.005	−0.018	9.897	0.019	0.023	0.021
		(0.047)	(0.053)	(0.069)		(0.018)	(0.022)	(0.028)
Scarring	9.873	−0.022	−0.042	−0.065				
		(0.044)	(0.051)	(0.067)				
Maternity leave (post)[d]								
Culling & scarring	62.79	−1.807**	−1.543	−1.570	62.59	−0.807**	−0.801	−0.917*
		(0.860)	(1.059)	(1.199)		(0.400)	(0.519)	(0.537)
Scarring	62.71	−0.256	0.007	−0.016				
		(0.831)	(1.037)	(1.181)				

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from the BC_{II}. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the gestation period is below 37 weeks, and zero otherwise. [b] The dependent variable is equal to one if the birth weight is lower than 2,500 grams, and zero otherwise. [c] The dependent variable is equal to the Apgar score after ten minutes. [d] The dependent variable is equal to the number of days on maternity leave after birth of the pivotal child. Further control variable: binary indicator for multiple birth.

Table 6: Reconciliation with the no health effects result by AEP

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Live birth[a]								
2-6 months post conception	3.031	−0.062	−0.108**	−0.106	8.918	−0.067	−0.060	−0.095
		(0.047)	(0.054)	(0.070)		(0.090)	(0.101)	(0.117)
0-6 months post conception	3.031	−0.070*	−0.103**	−0.101*	8.918	−0.073	−0.021	−0.069
		(0.036)	(0.042)	(0.053)		(0.077)	(0.090)	(0.102)
Fetal death: Prob(male)[b]								
2-6 months post conception	0.511	−0.014	−0.022	−0.043	0.513	0.007	0.012	0.003
		(0.022)	(0.027)	(0.033)		(0.014)	(0.017)	(0.022)
0-6 months post conception	0.511	−0.031	−0.051**	−0.063***	0.514	−0.000	0.003	−0.005
		(0.019)	(0.021)	(0.024)		(0.011)	(0.015)	(0.020)
Premature birth[c]								
2-6 months post conception	0.057	0.012	−0.001	0.003	0.047	0.003	−0.001	−0.005
		(0.012)	(0.012)	(0.014)		(0.006)	(0.007)	(0.008)
0-6 months post conception	0.057	−0.005	−0.015	−0.015	0.047	−0.002	−0.003	−0.009
		(0.009)	(0.009)	(0.011)		(0.005)	(0.006)	(0.007)
Low birth weight[d]								
2-6 months post conception	0.067	0.007	−0.004	−0.001	0.054	−0.002	−0.001	0.002
		(0.013)	(0.014)	(0.016)		(0.006)	(0.008)	(0.009)
0-6 months post conception	0.067	−0.002	−0.009	−0.014	0.054	−0.010*	−0.012*	−0.011
		(0.010)	(0.011)	(0.014)		(0.005)	(0.006)	(0.008)
Apgar score[e]								
2-6 months post conception	9.869	0.037	0.034	0.026	9.896	−0.011	−0.017	−0.014
		(0.027)	(0.031)	(0.035)		(0.016)	(0.020)	(0.025)
0-6 months post conception	9.869	0.035	0.032	0.015	9.897	0.002	−0.001	0.001
		(0.027)	(0.032)	(0.037)		(0.013)	(0.016)	(0.021)

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for the cohort between 2 and 6 months post conception at the time of the accident (*AEP cohort*) and the cohort between 0 and 6 months post conception. These cohorts was conceived between 11/1985 and 02/1986 (04/1986). (We drop conceptions one week before and after each cutoff date.) Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to the number of live births per 1,000 female inhabitants aged between 15 and 39 years of age in 1981 (in the respective education group) divided by the respective sample mean. [b] The dependent variable is equal to one if the child is male, and zero otherwise. [c] The dependent variable is equal to one if the gestation period is below 37 weeks, and zero otherwise. [d] The dependent variable is equal to one if the birth weight is lower than 2,500 grams, and zero otherwise. [e] The dependent variable is equal to the Apgar score after ten minutes.

Table 7: Radiation effects (scarring) on fertility

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
1 yr after	0.009	0.010*	0.008	0.005	0.006	−0.001	−0.001	0.004
		(0.007)	(0.008)	(0.009)		(0.003)	(0.004)	(0.005)
2 yrs after	0.110	−0.031	−0.058***	−0.065**	0.113	−0.007	−0.004	−0.003
		(0.029)	(0.022)	(0.025)		(0.010)	(0.014)	(0.017)
3 yrs after	0.210	−0.010	−0.019	−0.026	0.233	0.004	−0.005	−0.004
		(0.031)	(0.032)	(0.036)		(0.016)	(0.018)	(0.021)
4 yrs after	0.296	−0.035	−0.051	−0.067	0.329	0.023	0.007	−0.001
		(0.034)	(0.036)	(0.042)		(0.019)	(0.020)	(0.024)
5 yrs after	0.368	−0.051	−0.071	−0.103**	0.401	0.018	−0.007	−0.019
		(0.038)	(0.044)	(0.051)		(0.021)	(0.021)	(0.026)
6 yrs after	0.429	−0.077*	−0.099**	−0.112**	0.460	0.027	−0.007	−0.017
		(0.043)	(0.048)	(0.054)		(0.026)	(0.024)	(0.029)
7 yrs after	0.485	−0.090*	−0.104**	−0.123**	0.510	0.040*	0.016	0.010
		(0.046)	(0.053)	(0.058)		(0.024)	(0.027)	(0.033)
8 yrs after	0.528	−0.099**	−0.119**	−0.162***	0.544	0.035	−0.003	−0.007
		(0.049)	(0.054)	(0.061)		(0.028)	(0.028)	(0.035)
9 yrs after	0.565	−0.085*	−0.110*	−0.149**	0.572	0.032	−0.005	−0.011
		(0.051)	(0.058)	(0.064)		(0.027)	(0.028)	(0.034)
10 yrs after	0.595	−0.087	−0.111*	−0.150**	0.597	0.027	−0.016	−0.013
		(0.056)	(0.063)	(0.071)		(0.030)	(0.030)	(0.038)
11 yrs after	0.619	−0.103*	−0.132**	−0.167**	0.619	0.026	−0.016	−0.014
		(0.056)	(0.062)	(0.070)		(0.032)	(0.031)	(0.038)
12 yrs after	0.639	−0.106*	−0.137**	−0.172**	0.632	0.020	−0.022	−0.027
		(0.056)	(0.063)	(0.070)		(0.032)	(0.030)	(0.038)
13 yrs after	0.655	−0.099*	−0.125*	−0.156**	0.643	0.018	−0.027	−0.034
		(0.058)	(0.066)	(0.076)		(0.035)	(0.031)	(0.039)
14 yrs after	0.668	−0.104*	−0.138**	−0.168**	0.652	0.019	−0.026	−0.032
		(0.059)	(0.066)	(0.077)		(0.035)	(0.032)	(0.041)
15 yrs after	0.677	−0.117**	−0.148**	−0.178**	0.660	0.023	−0.024	−0.036
		(0.059)	(0.067)	(0.078)		(0.035)	(0.032)	(0.041)
16 yrs after	0.685	−0.118*	−0.155**	−0.181**	0.665	0.022	−0.026	−0.036
		(0.060)	(0.067)	(0.078)		(0.036)	(0.033)	(0.042)
17 yrs after	0.692	−0.118*	−0.155**	−0.176**	0.669	0.025	−0.021	−0.029
		(0.062)	(0.069)	(0.081)		(0.037)	(0.034)	(0.043)
18 yrs after	0.697	−0.120*	−0.157**	−0.177**	0.672	0.030	−0.017	−0.028
		(0.062)	(0.069)	(0.081)		(0.037)	(0.034)	(0.043)
19 yrs after	0.701	−0.120*	−0.160**	−0.180**	0.675	0.032	−0.018	−0.028
		(0.062)	(0.069)	(0.081)		(0.037)	(0.034)	(0.043)
20 yrs after	0.703	−0.123**	−0.162**	−0.179**	0.676	0.030	−0.020	−0.030
		(0.062)	(0.070)	(0.082)		(0.037)	(0.034)	(0.043)
Obs.		24,554	22,824	21,635		68,544	62,742	59,206

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering families with births conceived between 08/1984 and 07/1987. The dependent variable is equal to the number of children born to the mother the respective number of years after the birth of the pivotal child. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from the BC_{II}. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. (The results are robust to including indicators for maternal age.) Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table 8: Radiation effects (scarring) on maternal labor force participation

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
1 yr after	0.086	−0.006	−0.001	0.011	0.106	−0.001	−0.011	−0.015
		(0.019)	(0.022)	(0.025)		(0.012)	(0.014)	(0.016)
2 yrs after	0.355	0.002	0.014	0.000	0.386	−0.039**	−0.030	−0.028
		(0.032)	(0.034)	(0.043)		(0.017)	(0.022)	(0.025)
3 yrs after	0.372	0.011	0.009	−0.003	0.411	−0.021	−0.010	−0.003
		(0.028)	(0.033)	(0.040)		(0.017)	(0.021)	(0.025)
4 yrs after	0.400	0.026	0.036	0.041	0.449	−0.011	−0.026	−0.023
		(0.034)	(0.039)	(0.049)		(0.018)	(0.020)	(0.026)
5 yrs after	0.449	0.078**	0.087**	0.083*	0.489	−0.018	0.006	0.026
		(0.038)	(0.039)	(0.048)		(0.020)	(0.020)	(0.025)
6 yrs after	0.470	0.067*	0.085**	0.071*	0.516	−0.018	0.010	0.017
		(0.040)	(0.036)	(0.042)		(0.019)	(0.020)	(0.025)
7 yrs after	0.487	0.060*	0.064*	0.051	0.536	−0.040***	−0.040**	−0.044*
		(0.036)	(0.038)	(0.044)		(0.015)	(0.018)	(0.023)
8 yrs after	0.508	0.027	0.035	0.041	0.560	−0.039**	−0.054***	−0.069***
		(0.035)	(0.035)	(0.042)		(0.018)	(0.020)	(0.023)
9 yrs after	0.531	0.020	0.030	0.050	0.590	−0.018	−0.031	−0.035
		(0.035)	(0.034)	(0.038)		(0.017)	(0.021)	(0.025)
10 yrs after	0.557	−0.003	0.011	0.010	0.619	−0.014	−0.007	−0.016
		(0.038)	(0.039)	(0.047)		(0.018)	(0.025)	(0.029)
11 yrs after	0.581	0.046	0.062	0.051	0.645	−0.007	0.002	−0.009
		(0.035)	(0.040)	(0.050)		(0.018)	(0.023)	(0.027)
12 yrs after	0.602	0.078**	0.101***	0.087*	0.669	−0.001	−0.004	−0.006
		(0.038)	(0.039)	(0.045)		(0.016)	(0.021)	(0.025)
13 yrs after	0.620	0.049	0.069*	0.068	0.690	−0.003	−0.010	−0.022
		(0.032)	(0.038)	(0.044)		(0.017)	(0.022)	(0.026)
14 yrs after	0.635	0.026	0.048	0.046	0.710	−0.002	0.001	0.003
		(0.030)	(0.036)	(0.040)		(0.016)	(0.020)	(0.024)
15 yrs after	0.653	0.033	0.053	0.062	0.733	0.001	0.001	−0.000
		(0.030)	(0.036)	(0.042)		(0.016)	(0.021)	(0.024)
16 yrs after	0.666	0.016	0.025	0.033	0.750	−0.000	−0.003	−0.011
		(0.028)	(0.034)	(0.038)		(0.016)	(0.021)	(0.025)
17 yrs after	0.671	0.041	0.035	0.038	0.761	0.014	0.016	0.016
		(0.029)	(0.037)	(0.044)		(0.014)	(0.019)	(0.021)
18 yrs after	0.671	0.056*	0.066*	0.069	0.766	0.010	0.013	0.011
		(0.031)	(0.037)	(0.045)		(0.013)	(0.017)	(0.020)
19 yrs after	0.669	0.066**	0.074*	0.078*	0.768	−0.005	0.002	0.001
		(0.031)	(0.038)	(0.046)		(0.014)	(0.018)	(0.020)
20 yrs after	0.663	0.060**	0.054*	0.066*	0.769	0.004	0.006	0.001
		(0.027)	(0.033)	(0.039)		(0.014)	(0.018)	(0.021)
Obs.		719,541	668,484	632,803		2,053,657	1,879,809	1,773,200
No. mothers		23,211	21,564	20,413		66,247	60,639	57,200

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the mother is in the labor force in the respective number of years after childbirth. Each entry represents the coefficient for treated units from the BC_{II} interacted with years since the birth of the child (ranging from −9 years before to 21 years after birth). This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table 9: Non-radiation effects (culling & scarring) on prenatal culling and health at birth

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Live birth[a]								
BC I	3.031	0.034	0.035	0.036	8.918	−0.102	−0.085	−0.110
		(0.033)	(0.034)	(0.035)		(0.077)	(0.079)	(0.081)
BC II		0.035	0.035	0.034		0.058	0.080	0.031
		(0.058)	(0.060)	(0.062)		(0.130)	(0.135)	(0.138)
Fetal death: Prob(male)[b]								
BC I	0.510	0.006	0.006	0.017	0.514	−0.021*	−0.025**	−0.023*
		(0.018)	(0.018)	(0.018)		(0.012)	(0.012)	(0.012)
BC II		0.031	0.035	0.049		0.022	0.013	0.016
		(0.034)	(0.035)	(0.036)		(0.024)	(0.024)	(0.024)
Premature birth[c]								
BC I	0.056	0.002	0.004	0.004	0.047	−0.006	−0.006	−0.005
		(0.010)	(0.011)	(0.011)		(0.007)	(0.007)	(0.007)
BC II		0.001	−0.001	0.001		−0.009	−0.007	−0.004
		(0.016)	(0.017)	(0.017)		(0.009)	(0.009)	(0.009)
Low birth weight[d]								
BC I	0.067	−0.005	−0.004	−0.002	0.054	0.005	0.006	0.005
		(0.011)	(0.011)	(0.011)		(0.006)	(0.006)	(0.006)
BC II		−0.020	−0.028	−0.021		−0.002	0.001	0.001
		(0.019)	(0.019)	(0.020)		(0.008)	(0.009)	(0.009)
Apgar score[e]								
BC I	9.870	0.010	0.003	−0.001	9.897	−0.001	−0.003	0.001
		(0.023)	(0.024)	(0.024)		(0.013)	(0.014)	(0.014)
BC II		−0.008	−0.002	−0.014		0.016	0.010	0.012
		(0.039)	(0.040)	(0.040)		(0.021)	(0.021)	(0.022)

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. The dependent variable is indicated in boldface; the estimated non-radiation effects on treated units from birth cohorts I and II are displayed below. BC_I was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. BC_{II} was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to the number of live births per 1,000 female inhabitants aged between 15 and 39 years of age in 1981 (in the respective education group) divided by the respective sample mean. [b] The dependent variable is equal to one if the child is male, and zero otherwise. [c] The dependent variable is equal to one if the gestation period is below 37 weeks, and zero otherwise. [d] The dependent variable is equal to one if the birth weight is lower than 2,500 grams, and zero otherwise. [e] The dependent variable is equal to the Apgar score after ten minutes.

Table 10: Percent share in workforce by age and socioeconomic status of family

Age of child	All families	Low SES	Higher SES
15	59.51	76.28	52.47
17	71.88	86.45	65.77
18/19	89.12	95.55	86.43

Own calculations based on Knittler (2011); see footnote 37.

Table 11: Children's long-term outcomes: Radiation effects (scarring) on labor force participation

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Age 15	0.057	−0.016	−0.028**	−0.028**	0.025	−0.002	−0.007	−0.007
		(0.011)	(0.011)	(0.013)		(0.005)	(0.006)	(0.007)
Age 16	0.475	−0.069**	−0.079*	−0.082*	0.241	0.040	0.041*	0.056*
		(0.033)	(0.041)	(0.046)		(0.028)	(0.024)	(0.030)
Age 17	0.591	−0.063*	−0.099**	−0.097**	0.309	0.027	0.039	0.042
		(0.037)	(0.040)	(0.044)		(0.028)	(0.024)	(0.031)
Age 18	0.613	−0.063	−0.087**	−0.077*	0.325	0.023	0.030	0.037
		(0.042)	(0.041)	(0.046)		(0.025)	(0.025)	(0.034)
Age 19	0.585	−0.053	−0.073*	−0.050	0.319	−0.001	0.000	0.000
		(0.037)	(0.039)	(0.043)		(0.021)	(0.023)	(0.029)
Age 20	0.581	−0.095**	−0.131***	−0.106**	0.358	0.000	−0.013	0.013
		(0.038)	(0.040)	(0.044)		(0.021)	(0.024)	(0.031)
Age 21	0.671	−0.019	−0.030	−0.014	0.458	0.012	0.027	0.032
		(0.035)	(0.041)	(0.047)		(0.026)	(0.026)	(0.027)
Age 22	0.711	−0.066*	−0.086**	−0.096**	0.513	0.007	0.009	0.015
		(0.035)	(0.041)	(0.048)		(0.024)	(0.027)	(0.026)
Age 23	0.727	−0.050	−0.059	−0.080*	0.552	0.008	−0.001	0.017
		(0.033)	(0.037)	(0.044)		(0.021)	(0.027)	(0.031)
Obs.		143,370	133,119	125,766		452,160	413,316	389,538

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the child is in the labor force at the respective age. Each entry represents the coefficient for treated units from the BC_{II} interacted with age. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table 12: Children's long-term outcomes: Radiation effects (scarring) on apprenticeship training & labor income

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Apprenticeship training[a]								
Age 16	0.378	−0.039	−0.035	−0.050	0.191	0.043	0.047*	0.062**
		(0.033)	(0.040)	(0.044)		(0.029)	(0.024)	(0.029)
Age 17	0.487	−0.076**	−0.076*	−0.088**	0.248	−0.003	0.014	0.024
		(0.034)	(0.040)	(0.044)		(0.030)	(0.023)	(0.028)
Age 18	0.489	−0.033	−0.033	−0.021	0.257	0.013	0.027	0.032
		(0.037)	(0.042)	(0.046)		(0.028)	(0.024)	(0.033)
Obs.		143,370	133,119	125,766		452,160	413,316	389,538
Income								
Age 15-23 (wage sum)[b]	9.534	−0.509	−0.722**	−0.913**	7.729	−0.052	−0.110	0.005
		(0.321)	(0.324)	(0.387)		(0.205)	(0.253)	(0.261)
Age 15-23 (total wage sum)[c]	9.702	−0.534*	−0.755**	−0.947**	7.588	−0.044	−0.099	0.034
		(0.323)	(0.325)	(0.388)		(0.210)	(0.258)	(0.263)
Obs.		15,930	14,791	13,974		50,240	45,924	43,282

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. Each entry represents the coefficient for treated units from the BC_{II} (interacted with age 15-23). This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the child is in apprenticeship training at the respective age. [b] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in the main job. [c] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in all jobs.

Table 13: Siblings' long-term outcomes: Radiation effects (scarring) on labor force participation

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Age 15	0.052	0.011	0.011	−0.005	0.024	0.004	0.006	0.014
		(0.017)	(0.019)	(0.022)		(0.010)	(0.012)	(0.017)
Age 16	0.479	−0.021	−0.018	0.002	0.243	0.050**	0.075***	0.094***
		(0.038)	(0.045)	(0.051)		(0.024)	(0.029)	(0.032)
Age 17	0.608	−0.003	−0.002	0.047	0.330	0.050*	0.070**	0.079**
		(0.042)	(0.049)	(0.055)		(0.029)	(0.031)	(0.034)
Age 18	0.659	−0.010	0.008	0.035	0.372	0.044	0.065**	0.068*
		(0.037)	(0.040)	(0.048)		(0.032)	(0.030)	(0.036)
Age 19	0.629	0.004	0.006	−0.011	0.376	0.016	0.007	0.018
		(0.037)	(0.042)	(0.050)		(0.026)	(0.030)	(0.031)
Age 20	0.616	−0.030	−0.036	−0.016	0.412	0.040	0.056*	0.032
		(0.039)	(0.042)	(0.049)		(0.028)	(0.034)	(0.034)
Age 21	0.696	0.019	0.017	−0.023	0.501	0.049**	0.050**	0.033
		(0.035)	(0.042)	(0.051)		(0.022)	(0.025)	(0.031)
Age 22	0.728	0.061*	0.065	0.082*	0.553	0.034	0.040	0.025
		(0.035)	(0.041)	(0.047)		(0.022)	(0.027)	(0.033)
Age 23	0.738	0.062**	0.063*	0.078*	0.593	0.029	0.035	0.045
		(0.031)	(0.036)	(0.040)		(0.022)	(0.025)	(0.034)
Age 24	0.739	0.049	0.044	0.091**	0.626	0.025	0.038	0.048
		(0.032)	(0.036)	(0.040)		(0.023)	(0.024)	(0.030)
Age 25	0.742	0.038	0.061	0.095**	0.660	0.025	0.034	0.037
		(0.035)	(0.038)	(0.043)		(0.026)	(0.029)	(0.026)
Obs.		187,011	174,878	164,857		389,147	355,234	330,330

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering old siblings of children conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the older sibling is in the labor force at the respective age. Each entry represents the coefficient for siblings of treated units from the BC_{II} interacted with age 15-25. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table 14: Siblings long-term outcomes: Radiation effects (scarring) on apprenticeship training & labor income

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Apprenticeship training[a]								
Age 16	0.384	−0.003	−0.003	0.022	0.204	0.039*	0.061**	0.085***
		(0.041)	(0.049)	(0.056)		(0.021)	(0.026)	(0.029)
Age 17	0.493	0.008	0.007	0.068	0.271	0.052*	0.074**	0.086**
		(0.043)	(0.050)	(0.057)		(0.027)	(0.031)	(0.035)
Age 18	0.500	−0.022	−0.005	0.039	0.288	0.036	0.049	0.058
		(0.039)	(0.044)	(0.052)		(0.030)	(0.032)	(0.035)
Obs.		187,011	174,878	164,857		389,147	355,234	330,330
Income								
Age 15-25 (wage sum)[b]	10.517	0.215	0.208	0.370∗	9.273	0.093	0.061	−0.001
		(0.176)	(0.180)	(0.209)		(0.210)	(0.239)	(0.287)
Age 15-25 (total wage sum)[c]	10.667	0.189	0.178	0.342	9.422	0.060	0.015	−0.059
		(0.178)	(0.179)	(0.208)		(0.209)	(0.240)	(0.292)
Obs.		17,001	15,898	14,987		35,377	32,294	30,030

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering old siblings of children conceived between 08/1984 and 07/1987. Each entry represents the coefficient for siblings of treated units from the BC_{II} (interacted with age 15-25). This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the child is in apprenticeship training at the respective age. [b] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 25 in the main job. [c] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 25 in all jobs.

Web Appendix

A Existing evidence on the effects of the Chernobyl accident on reproductive outcomes

The International Commission on Radiological Protection (ICRP) considers an effective dose of 100 mSv as a threshold for effects after in utero exposure to ionizing radiation, including the induction of cancer. Whether the Chernobyl accident caused any negative health effects on individuals living in European countries is still under debate, despite the much lower radiation dose those individuals were exposed to. (See for example the recent debate in The Lancet (Holt, 2010).)

The existing evidence on the health impact of in utero exposure to the Chernobyl accident (summarized below) is mainly based on epidemiological studies analyzing time trends (across differently exposed regions[1]) in the rates of live births, stillbirths, spontaneous (and induced) abortions, infant mortality and perinatal and postnatal outcomes (e. g. pre-term birth, low birth weight, congenital malformations, incidence of specific diseases). Any (short-term) deviations from the long-term trend after the Chernobyl accident are cautiously interpreted as evidence for radiation-related health effects. However, most authors acknowledge the limited power of their studies to detect small effects and emphasize that causal inference is hardly possible based on ecological studies. In light of these limitations, most reviews of the existing evidence conclude that there is no consistent evidence of detrimental effects of the Chernobyl disaster except for an increase in thyroid cancer for individuals exposed in childhood, particularly in Belarus, Ukraine and Russia. (e. g. Little, 1993; WHO, 2006; UNSCEAR, 2000).

There is some evidence for an increase in the proportion of stillbirths and the early infant (or perinatal) mortality rate after the Chernobyl accident in Germany.[2] However, these results have been challenged by other studies using German data and studies for other countries (e. g. Finland, Sweden).[3] Furthermore, there is no evidence for a significant relationship between the level of fallout and the rate of spontaneous abortions, congenital malformations or other postnatal outcomes (pre-term birth, low birth weight, childhood cancer).[4] In contrast, there is some evidence for a decrease in the birth rate (independent of the fallout level) 9-11 months after the accident in Sweden, Finland, Norway and Italy and a temporary increase in the rate of induced abortions in Greece, Italy and Sweden.[5] Both effects may be attributed to the conflicting information in the media and the anxiety of pregnant women in the first month after the Chernobyl accident.

[1] However, this is not done in a difference-in-difference framework.

[2] See, Lüning *et al.* (1989); Scherb *et al.* (1999); Körblein and Küchenhoff (1997); Scherb *et al.* (2000).

[3] See, Blettner (2000); Grosche *et al.* (1997); Auvinen *et al.* (2001); Ericson and Kallen (1994).

[4] See, Auvinen *et al.* (2001); Ericson and Kallen (1994); Irgens *et al.* (1991); Haeusler *et al.* (1992); Harjulehto *et al.* (1989).

[5] See, Auvinen *et al.* (2001); Ericson and Kallen (1994); Bertollini *et al.* (1990); Irgens *et al.* (1991); Trichopoulos *et al.* (1987). Haeusler *et al.* (1992) find no effect on the counseling rate at pregnancy termination clinics in southern Austria.

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B Descriptive statistics

Table B.1: Average birth outcomes in communities with and without data on ^{137}Cs ground deposition

	Without data (N=73,086)	With data (N=103,531)	Difference
	Mean (S.D.)	Mean (S.D.)	Mean (p-value)
Male birth	51.33	51.24	0.09
	(49.98)	(49.98)	(0.71)
Gestation length (in days)	273.54	273.34	0.20
	(12.52)	(12.60)	(0.00)
Birth weight (in decagram)	328.12	326.50	1.63
	(53.12)	(53.27)	(0.00)
Premature birth (<37 weeks)	5.03	5.11	−0.08
	(21.85)	(22.02)	(0.44)
Low birth weight (<2500 g)	5.52	5.87	−0.35
	(22.84)	(23.50)	(0.00)
Apgar score (1 min. after birth)	8.79	8.72	0.07
	(1.24)	(1.23)	(0.00)
Apgar score (5 min. after birth)	9.70	9.68	0.02
	(0.80)	(0.83)	(0.00)
Apgar score (10 min. after birth)	9.90	9.90	0.01
	(0.54)	(0.56)	(0.05)

This table presents average birth outcomes for mothers in communities for which data on ^{137}Cs ground deposition is available (column 2) and communities for which we have no measure of the contamination level at the community level (column 1). The figures are based on birth cohort 0, which was conceived between 08/1984 and 08/1985 and born before the accident. In parentheses standard deviations are reported. Column 3 presents the difference along with the p-value. Estimations are based on individual-level data from the *Austrian Birth Register* before making any restrictions as explained in Section 3.2 of the paper.

C Additional estimation output

C.1 Estimation output for birth cohort I

Table C.1.1: Radiation effects on prenatal culling for birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Live birth								
Live birth rate[a]	3.031	−0.044	−0.083*	−0.093	8.918	0.036	0.083	−0.003
		(0.040)	(0.047)	(0.058)		(0.086)	(0.102)	(0.125)
Stillbirth								
Prob(Stillbirth)[b]	0.005	0.000	0.001	0.001	0.004	−0.001	0.000	−0.002
		(0.003)	(0.004)	(0.004)		(0.002)	(0.002)	(0.002)
Fetal death								
Proxy: *Prob*(male)[c]	0.510	0.008	0.010	0.009	0.514	−0.006	−0.004	0.002
		(0.022)	(0.026)	(0.033)		(0.013)	(0.017)	(0.021)

This table summarizes estimation results based on community-level data (first row) and individual-level data (second and third row) from the *Austrian Birth Register* and the *Austrian Death Register* covering births conceived between 08/1984 and 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from BC_I. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to the number of live births per 1,000 female inhabitants aged between 15 and 39 years of age in 1981 (in the respective education group) divided by the respective sample mean. [b] The dependent variable is equal to one if the child is a stillbirth and zero if the child is a live birth. [c] The dependent variable is equal to one if the child is male, and zero otherwise.

Table C.1.2: Radiation effects on postnatal culling for birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Alive after 24 hours	0.993	−0.001	−0.001	−0.004	0.995	−0.004*	−0.004	−0.007*
		(0.004)	(0.004)	(0.005)		(0.002)	(0.003)	(0.004)
Alive after 7 days	0.990	−0.001	−0.003	−0.003	0.992	−0.004	−0.005*	−0.010**
		(0.005)	(0.005)	(0.007)		(0.003)	(0.003)	(0.004)
Alive after 1 month	0.988	−0.003	−0.001	−0.003	0.991	−0.004	−0.006*	−0.009**
		(0.005)	(0.006)	(0.007)		(0.003)	(0.003)	(0.004)
Alive after 1 year	0.983	−0.004	−0.004	−0.004	0.988	−0.003	−0.006	−0.010*
		(0.006)	(0.007)	(0.008)		(0.003)	(0.004)	(0.005)

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Death Register* covering births conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the child is still alive after the respective time period after birth. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from BC_I. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table C.1.3: Radiation effects on health at birth of birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Premature birth[a]								
Culling & scarring	0.056	0.006	−0.001	−0.001	0.047	−0.005	−0.004	−0.007
		(0.011)	(0.012)	(0.014)		(0.006)	(0.007)	(0.008)
Low birth weight[b]								
Culling & scarring	0.067	0.017	0.013	0.013	0.054	−0.011	−0.007	−0.003
		(0.012)	(0.015)	(0.017)		(0.007)	(0.008)	(0.009)
Apgar score[c]								
Culling & scarring	9.870	−0.009	−0.004	−0.000	9.897	−0.026	−0.054**	−0.076**
		(0.029)	(0.032)	(0.043)		(0.019)	(0.022)	(0.028)
Maternity leave (post)[d]								
Culling & scarring	62.79	0.562	0.543	0.493	62.59	−0.121	0.013	−0.160
		(0.502)	(0.561)	(0.677)		(0.282)	(0.336)	(0.387)

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from BC_I. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the gestation period is below 37 weeks, and zero otherwise. [b] The dependent variable is equal to one if the birth weight is lower than 2,500 grams, and zero otherwise. [c] The dependent variable is equal to the Apgar score after ten minutes. [d] The dependent variable is equal to the number of days on maternity leave after birth of the pivotal child.

Table C.1.4: Radiation effects on fertility of families from birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
2 yrs after	0.110	−0.007	0.016	0.017	0.113	−0.001	−0.009	−0.008
		(0.016)	(0.017)	(0.021)		(0.007)	(0.009)	(0.011)
4 yrs after	0.296	−0.010	0.003	−0.023	0.329	0.024**	0.010	0.019
		(0.022)	(0.029)	(0.033)		(0.012)	(0.015)	(0.018)
6 yrs after	0.429	−0.041	−0.029	−0.055	0.460	0.011	−0.004	−0.005
		(0.026)	(0.033)	(0.041)		(0.015)	(0.018)	(0.021)
8 yrs after	0.528	−0.045	−0.035	−0.071	0.544	0.015	0.004	0.009
		(0.030)	(0.037)	(0.045)		(0.016)	(0.020)	(0.024)
10 yrs after	0.595	−0.031	−0.028	−0.056	0.597	0.009	−0.009	0.000
		(0.033)	(0.040)	(0.050)		(0.018)	(0.021)	(0.024)
12 yrs after	0.638	−0.046	−0.049	−0.072	0.632	0.008	−0.011	−0.005
		(0.035)	(0.044)	(0.055)		(0.020)	(0.021)	(0.024)
14 yrs after	0.667	−0.045	−0.048	−0.081	0.652	0.005	−0.013	−0.006
		(0.037)	(0.046)	(0.059)		(0.020)	(0.022)	(0.024)
16 yrs after	0.684	−0.046	−0.055	−0.082	0.665	0.001	−0.017	−0.007
		(0.038)	(0.046)	(0.058)		(0.021)	(0.023)	(0.025)
18 yrs after	0.696	−0.048	−0.059	−0.085	0.672	0.004	−0.017	−0.006
		(0.038)	(0.047)	(0.058)		(0.021)	(0.023)	(0.025)
20 yrs after	0.702	−0.054	−0.067	−0.091	0.676	0.002	−0.020	−0.010
		(0.039)	(0.048)	(0.058)		(0.021)	(0.023)	(0.025)
Obs.		24,682	22,952	21,763		68,544	62,742	59,206

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering families with births conceived between 08/1984 and 07/1987. The dependent variable is equal to the number of children born to the mother the respective number of years after the birth of the pivotal child. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from BC_I. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table C.1.5: Radiation effects on maternal labor force participation of families from birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
2 yrs after	0.355	0.024	0.031	0.009	0.386	−0.020	−0.005	0.001
		(0.022)	(0.023)	(0.028)		(0.017)	(0.017)	(0.018)
4 yrs after	0.400	0.021	0.034	0.028	0.449	−0.011	0.001	0.007
		(0.022)	(0.026)	(0.033)		(0.015)	(0.016)	(0.018)
6 yrs after	0.470	0.031	0.032	0.021	0.516	0.023	0.042***	0.048***
		(0.022)	(0.025)	(0.029)		(0.018)	(0.015)	(0.018)
8 yrs after	0.508	0.017	0.019	0.011	0.560	0.012	0.014	0.010
		(0.021)	(0.024)	(0.027)		(0.012)	(0.015)	(0.018)
10 yrs after	0.557	0.019	0.014	0.012	0.619	0.016	0.025*	0.016
		(0.020)	(0.024)	(0.030)		(0.012)	(0.014)	(0.016)
12 yrs after	0.602	0.033	0.032	0.016	0.669	0.015	0.020	0.013
		(0.025)	(0.029)	(0.037)		(0.012)	(0.015)	(0.017)
14 yrs after	0.635	0.024	0.017	−0.009	0.710	0.030***	0.025*	0.019
		(0.023)	(0.027)	(0.033)		(0.011)	(0.014)	(0.015)
16 yrs after	0.666	−0.015	−0.022	−0.032	0.750	0.008	−0.000	−0.008
		(0.022)	(0.023)	(0.027)		(0.011)	(0.014)	(0.016)
18 yrs after	0.671	−0.011	−0.014	−0.027	0.766	0.018*	0.002	−0.000
		(0.024)	(0.026)	(0.030)		(0.009)	(0.012)	(0.015)
20 yrs after	0.663	−0.010	−0.014	−0.023	0.769	0.022**	0.010	−0.001
		(0.021)	(0.024)	(0.029)		(0.010)	(0.013)	(0.015)
Obs.		719,541	668,484	632,803		2,053,657	1,879,809	1,773,200

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the mother is in the labor force in the respective number of years after childbirth. Each entry represents the coefficient for treated units from BC_I interacted with years since the birth of the child (ranging from −9 years before to 21 years after birth). This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table C.1.6: Children's long-term outcomes: Radiation effects on labor force participation from birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Age 15	0.056	−0.005	−0.003	−0.003	0.025	0.003	0.002	0.002
		(0.013)	(0.017)	(0.019)		(0.005)	(0.007)	(0.007)
Age 16	0.475	−0.033	−0.053*	−0.030	0.241	−0.027**	−0.028*	−0.046**
		(0.030)	(0.032)	(0.040)		(0.013)	(0.015)	(0.020)
Age 17	0.591	−0.040	−0.063**	−0.056*	0.310	−0.013	−0.017	−0.045**
		(0.030)	(0.029)	(0.033)		(0.014)	(0.017)	(0.019)
Age 18	0.613	−0.013	−0.014	−0.005	0.325	0.002	0.001	−0.018
		(0.025)	(0.027)	(0.031)		(0.015)	(0.019)	(0.021)
Age 19	0.585	−0.014	−0.018	−0.007	0.319	−0.004	−0.009	−0.027
		(0.024)	(0.028)	(0.032)		(0.017)	(0.020)	(0.024)
Age 20	0.581	−0.005	−0.001	0.012	0.358	−0.009	−0.021	−0.024
		(0.024)	(0.030)	(0.035)		(0.014)	(0.015)	(0.017)
Age 21	0.671	−0.017	−0.023	0.010	0.458	−0.020	−0.019	−0.028
		(0.022)	(0.026)	(0.029)		(0.015)	(0.017)	(0.019)
Age 22	0.711	0.011	0.006	0.027	0.513	−0.014	−0.007	−0.016
		(0.022)	(0.025)	(0.028)		(0.013)	(0.016)	(0.019)
Age 23	0.727	0.032	0.039*	0.039	0.552	−0.014	−0.019	−0.022
		(0.020)	(0.023)	(0.024)		(0.013)	(0.016)	(0.020)
Obs.		144,180	133,929	126,576		452,160	413,316	389,538

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. The dependent variable is equal to one if the child is in the labor force at the respective age. Each entry represents the coefficient for treated units from BC_I interacted with age. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample.

Table C.1.7: Children's long-term outcomes: Radiation effects on apprenticeship training & labor income from birth cohort I

	Low SES				Higher SES			
	Mean	37 kBq	42 kBq	47 kBq	Mean	37 kBq	42 kBq	47 kBq
Apprenticeship training[a]								
Age 16	0.378	−0.034	−0.042	−0.029	0.191	−0.003	−0.007	−0.025
		(0.028)	(0.033)	(0.043)		(0.012)	(0.014)	(0.016)
Age 17	0.487	−0.036	−0.044	−0.056	0.248	−0.001	−0.002	−0.018
		(0.030)	(0.031)	(0.036)		(0.014)	(0.016)	(0.020)
Age 18	0.489	−0.033	−0.029	−0.032	0.257	0.004	0.002	−0.012
		(0.029)	(0.030)	(0.034)		(0.014)	(0.017)	(0.021)
Obs.		144,180	133,929	126,576		452,160	413,316	389,538
Income								
Age 15-23 (wage sum)[b]	9.533	−0.040	−0.056	−0.069	7.588	−0.117	−0.111	−0.197
		(0.161)	(0.179)	(0.190)		(0.126)	(0.160)	(0.188)
Age 15-23 (total wage sum)[c]	9.702	−0.054	−0.069	−0.072	7.729	−0.112	−0.110	−0.189
		(0.160)	(0.178)	(0.188)		(0.128)	(0.162)	(0.191)
Obs.		16,020	14,881	14,064		50,240	45,924	43,282

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the *Austrian Social Security Database* covering births conceived between 08/1984 and 07/1987. Each entry represents the coefficient for treated units from BC_I interacted with age. This cohort was conceived between 08/1985 and 01/1986 and was between 4 and 9 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors (clustered at the community level) are shown in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Families with a low socioeconomic status (SES) have mothers with compulsory schooling or less. Families with a higher SES have mothers with any degree higher than compulsory schooling. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the child is in apprenticeship training at the respective age. [b] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in the main job. [c] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in all jobs.

C.2 Radiation effects (culling & scarring) for birth cohort II

Table C.2.1: Radiation effects (culling & scarring) — fertility[a]

	Low SES			
	Mean	37 kBq	42 kBq	47 kBq
2 yrs after	0.110	−0.029	−0.057***	−0.063***
		(0.029)	(0.022)	(0.025)
4 yrs after	0.296	−0.030	−0.045	−0.061
		(0.034)	(0.036)	(0.041)
6 yrs after	0.429	−0.065	−0.087*	−0.100*
		(0.042)	(0.047)	(0.054)
8 yrs after	0.528	−0.085*	−0.104*	−0.148**
		(0.048)	(0.053)	(0.060)
10 yrs after	0.595	−0.071	−0.095	−0.134*
		(0.055)	(0.062)	(0.070)
12 yrs after	0.638	−0.089	−0.120*	−0.156**
		(0.056)	(0.062)	(0.070)
14 yrs after	0.667	−0.087	−0.120*	−0.150**
		(0.058)	(0.066)	(0.076)
16 yrs after	0.684	−0.098	−0.136**	−0.161**
		(0.060)	(0.066)	(0.077)
18 yrs after	0.696	−0.100	−0.137**	−0.156*
		(0.061)	(0.068)	(0.080)
20 yrs after	0.702	−0.104*	−0.144**	−0.161**
		(0.061)	(0.069)	(0.081)
Obs.		24,682	22,952	21,763

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the*Austrian Social Security Database* in the period from 08/1984 through 07/1987. Each entry represents a separate regression, where the dependent variable is indicated in the first column, and shows the estimated coefficient for treated units from BC_{II}. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. (The results are robust to including indicators for maternal age.) Method of estimation is a least squares. Robust standard errors in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to the number of children born to the mother the respective number of years after the birth of the pivotal child.

Table C.2.2: Radiation effects (culling & scarring) — maternal labor force participation[a]

	Low SES			
	Mean	37 kBq	42 kBq	47 kBq
2 yrs after	0.355	0.000	0.012	−0.001
		(0.032)	(0.034)	(0.043)
4 yrs after	0.400	0.028	0.038	0.043
		(0.034)	(0.039)	(0.049)
6 yrs after	0.471	0.060	0.078**	0.064
		(0.040)	(0.036)	(0.042)
8 yrs after	0.508	0.021	0.028	0.035
		(0.035)	(0.035)	(0.042)
10 yrs after	0.558	−0.007	0.007	0.006
		(0.038)	(0.039)	(0.047)
12 yrs after	0.602	0.075**	0.098**	0.084*
		(0.037)	(0.038)	(0.045)
14 yrs after	0.635	0.028	0.051	0.048
		(0.030)	(0.035)	(0.039)
16 yrs after	0.666	0.017	0.026	0.033
		(0.028)	(0.033)	(0.038)
18 yrs after	0.671	0.054*	0.065*	0.068
		(0.030)	(0.037)	(0.045)
20 yrs after	0.663	0.063**	0.057*	0.069*
		(0.027)	(0.033)	(0.039)
Obs.		723,323	672,266	636,585

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the*Austrian Social Security Database* in the period from 08/1984 through 07/1987. Each entry represents the coefficient for treated units from the BC_{II} interacted with years since the birth of the child (ranging from 9 years before to 21 years after birth). This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the mother participates in the labor force in the respective number of years after childbirth.

Table C.2.3: Radiation effects (culling & scarring) — labor force participation[a]

	Low SES			
	Mean	37 kBq	42 kBq	47 kBq
Age 15	0.056	−0.016	−0.027**	−0.028**
		(0.011)	(0.011)	(0.013)
Age 16	0.475	−0.069**	−0.078*	−0.082*
		(0.033)	(0.040)	(0.046)
Age 17	0.591	−0.064*	−0.099**	−0.098**
		(0.037)	(0.040)	(0.044)
Age 18	0.613	−0.068	−0.093**	−0.082*
		(0.042)	(0.041)	(0.046)
Age 19	0.585	−0.055	−0.074*	−0.052
		(0.036)	(0.039)	(0.042)
Age 20	0.581	−0.098**	−0.134***	−0.109**
		(0.038)	(0.040)	(0.044)
Age 21	0.671	−0.022	−0.033	−0.018
		(0.035)	(0.041)	(0.047)
Age 22	0.710	−0.063*	−0.083**	−0.092*
		(0.035)	(0.041)	(0.048)
Age 23	0.727	−0.058*	−0.066*	−0.088**
		(0.033)	(0.037)	(0.044)
Obs.		144,180	133,929	126,576

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the*Austrian Social Security Database* in the period from 08/1984 through 07/1987. Each entry represents the coefficient for treated units from the BC_{II} interacted with age. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the child participates in the labor force at the respective age.

Table C.2.4: Radiation effects (culling & scarring) — apprenticeship training & income

		Low SES		
	Mean	37 kBq	42 kBq	47 kBq
Apprenticeship training[a]				
Age 16	0.378	−0.039	−0.035	−0.051
		(0.033)	(0.039)	(0.044)
Age 17	0.487	−0.078**	−0.078*	−0.090**
		(0.034)	(0.040)	(0.044)
Age 18	0.489	−0.036	−0.035	−0.024
		(0.037)	(0.042)	(0.046)
Obs.		144,180	133,929	126,576
Income[a]				
Age 15-23 (wage sum)	9.533	−0.506	−0.719**	−0.910**
		(0.325)	(0.328)	(0.391)
Age 15-23 (total wage sum)	9.702	−0.527	−0.748**	−0.940**
		(0.327)	(0.329)	(0.392)
Obs.		16,020	14,881	14,064

This table summarizes estimation results based on individual-level data from the *Austrian Birth Register* and the*Austrian Social Security Database* in the period from 08/1984 through 07/1987. Each entry represents the coefficient for treated units from BC_{II} interacted with age. This cohort was conceived between 02/1986 and 04/1986 and was between 0 and 3 months post conception at the time of the accident. Each specification controls for community, conception-year, and conception-month fixed-effects. Method of estimation is a least squares. Robust standard errors in parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent. Means refer to the 37kBq-cutoff sample. [a] The dependent variable is equal to one if the child is in apprenticeship training at the respective age. [b] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in the main job. [c] The dependent variable is equal to the sum of the deflated annual labor income between ages 15 and 23 in all jobs.

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1 Halla, Martin and Martina Zweimüller**. Parental Responses to Early Human Capital Shocks:** Evidence from the Chernobyl Accident. CINCH 2014.