

SOME UNINTENDED FALLOUT FROM DEFENSE
POLICY:
MEASURING THE EFFECT OF ATMOSPHERIC
NUCLEAR TESTING ON AMERICAN MORTALITY
PATTERNS

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June 16, 2017

Abstract

During the Cold War the United States detonated hundreds of atomic weapons at the Nevada Test Site. Many of these nuclear tests were conducted above ground and released tremendous amounts of radioactive pollution into the environment. This paper combines a new dataset measuring annual county level fallout patterns for the continental U.S. with vital statistics records. This paper finds that fallout from nuclear testing led to persistent and substantial increases in overall mortality for large portions of the country. The cumulative death toll attributable to nuclear testing is seven to fourteen times larger than previous estimates. JEL Codes: I10; N32; Q50

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Pollution is often the byproduct of human activity and imposes significant costs upon the public. In many settings, the government attempts to address the external costs associated with polluting activities, but there are cases where government policy is the direct cause of harmful pollution. During the Cold War the United States detonated hundreds of nuclear weapons just northwest of Las Vegas at the Nevada Test Site (NTS). Prior to 1963 many of these tests were conducted above ground and released tremendous quantities of radioactive material into the environment. When a bomb was detonated, it would vaporize and irradiate thousands of tons of material. The mushroom cloud would send much of this debris high into the atmosphere where high altitude winds would carry this pollution hundreds to thousands of miles from the test site. One estimate places the total atmospheric release of radioactive material from the NTS as over 12 Billion Curies for the years 1951 to 1963. In comparison, Chernobyl released an estimated 81 Million Curies of radioactive material (LeBaron, 1998).

These nuclear tests exposed millions of Americans to harmful radioactive material and many people are still living with the consequences of this pollution today. This paper measures the effect of domestic atmospheric nuclear testing on the crude death rate for the entire continental United States. I present evidence that nuclear testing had broad and adverse effects on human capital in the extreme. The current medical and scientific literature studying the health effects of nuclear testing has focused primarily upon small samples of populations who lived in the regions surrounding the Nevada Test Site.¹ These studies examine the health effects of fallout exposure in downwind populations and then extrapolate out the potential health consequences for the nation from these results. Simon and Bouville (2015) of the National Cancer Institute (NCI) note that there is great uncertainty underlying these estimates. They estimate that fallout from domestic nuclear testing caused 49,000 thyroid

¹The region surrounding the Nevada Test Site is termed Downwind in the literature and this area consists of the few counties in AZ, NV, and UT surrounding the test sight.

cancer deaths.² One of the major drawbacks of these medical and scientific studies is that they fail to capture the temporal and geographic scope of these health effects.

Using an alternative empirical approach, this paper provides substantial evidence that nuclear testing had profound effects on American health. I combine measures of radioactive fallout exposure from National Cancer Institute (1997) and mortality data for the continental U.S. to analyze the mortality effects of atmospheric nuclear testing. By using within county variation in fallout deposition across years, this paper measures both the geographic and temporal extent of the harm caused by nuclear testing. The results from the empirical analysis reveal that nuclear testing led to prolonged increases in the crude death rate in many regions of the country. Oddly, the largest mortality effects occurred in the Great Plains and Central Northwest U.S., far outside of areas studied by the current literature. Back-of-the-envelope estimates suggest that fallout from nuclear testing contributed between 340,000 to 460,000 excess deaths from 1951 to 1973.

The empirical analysis of this paper contributes to a series of studies measuring the social costs of radioactive pollution by being the first paper in the economics literature to measure the cost of atmospheric nuclear testing for American populations. This paper and a concurrent paper on the agricultural effects of nuclear testing are the first economics papers to study the effects of radioactive pollution for American populations (Meyers, 2017). Even though radioactive pollutants pose significant health risks and the recent problems at Fukushima Daiichi reignited the debate about nuclear power, the societal consequences of radioactive pollution have largely been understudied.

The economic research studying the economic effects and consequences of radioactive pollution has focused entirely on Scandinavian and Ukrainian populations. Danzer and Danzer

²The 95 percent confidence interval for this estimate is 11,300 and 220,000 deaths. Simon and Bouville (2015) suggest testing contributed up to 11,1000 additional of other cancer deaths. Without nuclear testing they estimated that 400,000 cases of thyroid cancer would arise naturally in the same population.

(2016) and Lehmann and Wadsworth (2011) study the cost of the Chernobyl disaster to Ukrainian populations using cross sectional variation in exposure. Another body of research has successfully used variation in multiple sources of air pollution as a shock to test the fetal origins hypothesis (Almond et al., 2009a; Almond and Currie, 2011; Currie, 2013; Currie et al., 2015; Isen et al., 2014). With respect to radioactive pollution, both Almond et al. (2009b) and Black et al. (2013) use radioactive pollution to test the fetal origins hypothesis in Scandinavia. Almond et al. (2009b) use radioactive fallout from the Chernobyl disaster and associate negative educational outcomes with in-utero exposure to fallout in Swedish cohorts. Black et al. (2013) use data from 14 radiation monitoring stations in Norway to study exposure in cohorts born between 1956 and 1966. They discover persistent and statistically reductions in educational attainment, earnings, and IQ scores among cohorts exposed during months three and four of gestation.

The results of this paper corroborate the negative effects found in previous research and improves upon the identification by exploiting the specific biological mechanisms through which American populations were exposed to harmful radioactive toxins. Radioactive fallout deposition can be an imprecise measure of human exposure to harmful ionizing radiation. Humans only metabolize specific radioactive isotopes created through fission. The primary mechanism through which people were exposed to concentrated doses of radiation was through the ingestion irradiated food products. Fallout deposition may approximate the presence of fallout in the local food supply, but radiation exposure proxied through deposition becomes more inaccurate if local deposition fails to enter the local food supply. The National Cancer Institute (1997) finds that the consumption of irradiated dairy products served as the primary vector through which Americans ingested large concentrations of radioactive material. During the 1950's most milk was consumed in the local area it was produced. It is through this channel where local fallout deposition would enter the local food supply

(National Cancer Institute, 1997). This paper leverages estimates of I-131 concentrations in locally produced milk to provide a more precise estimate of human exposure to fallout than previous studies. The results from this paper reveal that including regions where fallout deposition was uncorrelated with fallout in the dairy supply biases the mortality effect of radioactive fallout towards zero.

Recent work studying the effects of coal consumption and lead water pipe adoption have highlighted the influence of policy on health and how the social consequences of these decisions can have persistent long run effects. Work by Hanlon (2015, 2016) has shown that coal consumption in 19th Century England had substantial effects on mortality rates and that coal utilization had persistent effects on wages and urban growth. Barreca et al. (2014) and Clay et al. (2016) study the long-term health consequences of using coal for heating and electricity generation for the United States. Troesken (2008) and Clay et al. (2014) study how historic municipal decisions relating to the adoption of lead water pipes had long run effects on public health. This paper adds to these studies by examining a specific polluting defense policy and suggests that atmospheric testing affected more people and had greater social costs than previously thought.

The paper is divided into five additional sections. Section 1 provides a brief history of the NTS and context pertaining to atmospheric nuclear testing. Section 2 discusses the biological effects of radiation poisoning and the scientific evidence that provides the foundation for the analysis. Section 3 presents the empirical models and describes the data used in the empirical analyses of this paper. These models use within county variation in fallout patterns across time to measure the short run and long run mortality effects of radioactive fallout for American populations. Section 4 discusses the empirical results measuring the effect of fallout on the crude death rate and their magnitude, and it provides information on the geographic

distribution of the mortality effect. The findings suggest that radiation from nuclear testing in Nevada increased local crude death rates in many counties for at least 10 years. Finally, section 5 measures the value of lives lost due to NTS activities and measures the potential lives saved by the 1958 nuclear testing moratorium and Partial Nuclear Weapons Test Ban Treaty in 1963.

I History of the NTS and Victims of Atomic Testing

In the 1950's, millions of Americans were unknowingly exposed to radioactive fallout through both the environment and the food supply. With respect to economic and demographic activities, exposure to radioactive matter from atmospheric nuclear testing can generally be considered as a plausibly exogenous event. Radioactive pollution is often an invisible and imperceptible threat to human health. National security concerns in the 1950's motivated atomic testing at the NTS. While the location of the base was not random, the base was not chosen due to surrounding characteristics of the residing population.³

Atmospheric atomic testing on U.S. soil was a deliberate policy decision made by domestic political leaders. In 1949 the Soviet Union detonated its first nuclear bomb Joe-1. Provoked and surprised by this sudden event, U.S. political and military leaders sought to accelerate America's own nuclear weapons program. Prior to this event, nuclear testing occurred in the Pacific.⁴ The Pacific tests proved logistically costly, slow to implement, and expensive. American leaders sought a convenient testing location and settled on the Nevada Test Site due to its proximity to U.S. government labs, low levels of precipitation, and relatively secluded location (Center for Disease Control, 2006; National Cancer Institute, 1997). Located in Nye County, Nevada, this military zone became the epicenter of the American

³The base was chosen over more environmentally friendly locations due to its proximity to government labs, access to public land, and rapid ease of establishment (Schwartz, 2011).

⁴The three Trinity test in 1945 were conducted in White Plains New Mexico. All other tests conducted prior to the opening of the NTS occurred in the Pacific.

nuclear weapons program. Nuclear testing occurred from 1951 until 1992. The period of atmospheric nuclear testing occurring between 1951 and 1963. During this period, the U.S. detonated 100 atmospheric bombs at the NTS (US Department of Energy, 2000).

During the 1950's, the public was largely unaware of the dangers that the NTS posed to public health. The Public Health Service (PHS) and Atomic Energy Commission (AEC) sought to dismiss fears regarding the atomic testing and often misled the public. Official government statements made during the testing period asserted that all dangerous radioactive material remained within the confines of the NTS.⁵ At best these organizations failed to adequately warn civilians living downwind of the test site of the health risks associated with these atomic tests. At worst, they actively disseminated misinformation regarding radioactive threats (Ball, 1986; Fradkin, 2004; LeBaron, 1998). Only in 1978 did the plight of downwind populations receive national media attention. Subsequent Freedom of Information Act requests later revealed that the government knew of the dangers to public health the NTS tests posed and that the AEC had suppressed these medical reports (Fradkin, 2004).

II The Health Consequences of Radiation Exposure

II.i Related Scientific and Medical Literature

Radioactivity generally refers to dangerous particles given off by radioactive decay of matter. The weakest forms of ionizing radiation are alpha particles, and these particles generally cannot penetrate most thin physical barriers. Beta radiation is more dangerous and can penetrate deep into flesh and cause damage. Gamma radiation is the most dangerous

⁵In the Appendix is an example of a 1951 AEC flyer explicitly iterating this official claim. The website for the Official Department of Energy Nuclear Testing Archive where this flyer is from is <https://www.nss.gov/pages/resources/NuclearTestingArchive.html>. The government circulated flyers such as these in the areas surrounding the NTS, all while the AEC and PHS detected substantial quantities of fallout depositing in populated areas far beyond the confines of the atomic test range.

form of radioactivity and consists of highly energetic photons. Gamma radiation can travel easily through the body and causes immense damage to biological tissues.

With regards to nuclear testing, there are three radioactive isotopes of concern to human health because of their relative radioactivity, prevalence, and how they are metabolized. These isotopes are Iodine-131, Strontium-90, and Cesium-137. Other isotopes created during nuclear fission are less dangerous to human health because they do not remain in the body for extended periods or because they are created in minuscule quantities. Many radioactive isotopes pass through the body and are secreted following ingestion. In particular, Iodine 131 is a potent radioactive poison. It possesses an eight day half-life, concentrates in the thyroid gland, and emits highly active forms of beta and gamma radiation as it decays (LeBaron, 1998). These traits of I-131 cause acute and rapid damage to tissue surrounding the thyroid. Strontium 90 also appears in wheat and plant products in limited quantities. This isotope collects in bones and teeth. It decays over a long period and causes prolonged damage. Sr-90 possesses a 25 year half-life, diffuses across the body uniformly and emits beta radiation (LeBaron, 1998). Finally, Cs-137, which was released in large quantities during the recent Fukushima Daiichi disaster, collects in fleshy tissue and does not concentrate in any particular organ. It has a half-life of 33 years and emits both alpha and beta radiation (LeBaron, 1998).

The medical and scientific knowledge regarding the effects of human exposure to ionizing radiation comes from many sources. Studies of Japanese atomic bomb survivors and persons living downwind of nuclear test sites provide much of this knowledge. In human population studies of radiation exposure, researchers have measured a variety of negative health and developmental consequences from exposure to ionizing radiation. Studies of atomic bomb survivors and persons exposed during pregnancy demonstrate increased cancer risks, negative developmental and cognitive effects due to radiation exposure (Lee, 1999; Otake et al.,

1993; Otake, 1996; Schull, 1997). Researchers studying Chernobyl have found greater incidences of thyroid cancers, and lesions indicative of I-131 poisoning in exposed population (Shibata et al., 2001; Williams, 2002). Researchers studying downwind American populations have also found evidence of increased thyroid cancer and leukemia risks in domestic downwind cohorts (Gilbert et al., 2010; Kerber et al., 1993; Stevens et al., 1990). Together, the medical and scientific literature suggest that exposure to ionizing radiation increases the risks of various types of cancer and can have detrimental effects upon human growth and development.

II.ii Exposure Mechanisms

Exposure to harmful radioactive fallout can occur either through direct channels or indirect channels. Radioactive material can enter the body if it lands on the skin with radioactive dust. Many people and animals living in the downwind counties surrounding the NTS were exposed to harmful fallout in this matter. People can inhale radioactive material when it is suspended in the air. Inhalation of radioactive dust would be the most likely in the downwind region. Research by the National Cancer Institute (1997) and Center for Disease Control (2006) establishes that the food supply served as the main indirect vector of exposure for most Americans during the atomic testing period. Scientific evidence contemporaneous with the testing period also substantiates that radioactive materials resulting from nuclear fission appeared in crops, people, and animals (Beierwaltes et al., 1960; Garner, 1963; Kulp et al., 1958; Olson, 1962; Van Middlesworth, 1956). Similarly, the PHS also released research corroborating this evidence but downplayed the health risks associated with the radiation levels reported (Flemming, 1959, 1960; Wolff, 1957, 1959). These studies often dismissed the risk associated with the levels of radioactive material found in independent studies as alarmist.

The NCI establishes the dairy channel as a primary vector through which Americans were exposed to significant quantities of radioactive material. Most Americans would not be exposed to radioactive dust carried by low altitude winds. Instead, high altitude winds would carry the material far from the test site and the material would only deposit on the ground if it happened to be precipitating while the radiation cloud was overhead. In the few days following the nuclear test, this radioactive material would deposit on crops and pasture. Some radioactive material would enter wheat and other plant products, but consumption of these products would not necessarily be in the same region where they were produced. Dairy, however, during the 1950's and 1960's was generally produced and consumed locally (National Cancer Institute, 1997). This channel is unique in that cows would consume large quantities of irradiated pasture and concentrate radioactive material, specifically I-131, in milk.

People living in the region where deposition occurred would then be more likely to consume this irradiated food product containing a potent radioactive poison in the days following the atomic test. Pasturing practices would affect the quantities of fallout entering the dairy supply. The areas surrounding the NTS experienced the greatest quantities of radioactive fallout deposition, but often had very little I-131 entering the dairy supply. Dairy farming practices in much of AZ, NV, and UT in the 1950's relied on importing hay from outside regions and as such very little radioactive matter would enter the food supply. This in turn makes deposition itself a less accurate proxy for human exposure to fallout in these areas.

III Empirical Strategy: Measuring Short Term and Long Term Mortality Effects

III.i Public Health Data

The empirical analysis uses a county-level annual panel constructed by Bailey et al. (2016) of crude deaths from 1915 to 2007 from Annual Reports of the U.S. Vital Statistics. A subsample from 1940 to 1988 forms the panel for the bulk of the empirical analysis and is selected for its completeness of county level coverage. This panel is used to measure the geographic and temporal extent to which radioactive pollution from the NTS harmed human health. The crude death rate per 10,000 individuals approximates the total mortality effect associated with fallout exposure. Exposure to ionizing radiation can increase cancer risks, but exposure might also make persons less healthy overall and increase non-cancer related mortality rates.

III.ii Fallout Exposure Data

In 1983, Congress authorized the Secretary of Health and Human Services to investigate and measure thyroid doses from I-131 in American citizens. The NCI undertook the task of gathering radiation monitoring station data from historical records. With these records and weather station data the NCI could track the position of the radiation cloud, determine how much radiation would deposit with precipitation, and employ kriging techniques to estimate fallout deposition in counties without monitoring stations. Much of the raw data came from national monitoring stations whose number varied across time, but never exceeded 100 stations. The military also engaged in air monitoring and used city-county stations around the NTS to track the radiation cloud (NCI 1997). These are the most complete and comprehensive measures for fallout deposition from nuclear tests for the United States. The

data employed in this paper are derived from the NCI estimates. The NCI provides estimate for I-131 deposition for each nuclear test conducted from 1951 to 1958, except for three tests in the Ranger 1951 series.⁶ The depositions are measured as nanoCuries (nCi) per meter squared and are reported for each day following a nuclear test until the next subsequent test in the series. Figure I provides a map of my deposition data for the Upshot Knothole test series. This map show how geographically extensive and heterogeneous fallout patterns are across the country. Notice how states such as Vermont and New Jersey experienced large depositions in 1953.

Relative to previous economics studies of radioactivity using variation of fallout deposition, these data measure radioactive pollution at much higher levels and cover a vastly larger geographic area. The largest deposition observation in Almond et al. (2009b) is 1,459 nCi per m^2 and in Black et al. (2013) is 883 nCi per m^2 . In comparison, the average county level deposition for the U.S. from the 1957 Plumbbob test series for 3,067 counties in the raw data is 754 nCi m^2 and the largest amount for this series is 13,736 nCi per m^2 .⁷

The NCI also provides daily integrated estimates for I-131 secreted in locally produced milk. These measures are a function of how cows metabolize and secrete iodine at different levels of exposure, grazing practices during the testing window, and the levels of radiation deposition estimated in the kriging model. This methodology can cause substantial differences between radiation presence in milk estimated at the county level and deposition. During the 1950's, many households consumed locally produced dairy, and I-131's short eight-day half-life means that persons would consume it before the radioactive I-131 would decay. Children would be especially vulnerable to this radiation exposure channel because they tended

⁶The National Cancer Institute is currently trying to create estimates for deposition using weather patterns. These tests are not included in this paper's analysis.

⁷This paper reports radiation in SI rather than metric units. Almond et al. (2009b); Black et al. (2013) use Becquerels and I use Curies. For conversion $37 \text{ bq} = \text{nCi}$. Another caveat is that Almond et al. (2009b) and this paper use radioactivity attributable to specific isotopes and Black et al. (2013) use total radioactivity.

to drink more milk than adults, had smaller thyroids, and were still growing during this period (NCI 1997). Since a child's thyroid is smaller than an adult's, the same quantity of I-131 would cause greater damage because it would be concentrated into a smaller area. Furthermore, the thyroid regulates growth and development. Harm to this organ might lead to unanticipated long term health problems. Figure II provides a map of my milk exposure data for the Upshot Knothole test series.⁸ Notice how milk measures vary from the deposition measures. Areas with the highest levels of ground deposition around the NTS have relatively low levels of I-131 present in the local milk supply.

The counties downwind of the NTS experienced fallout mostly as dry precipitate, and according to the agronomic data provided by the NCI, dairy cows in these areas consumed very little local pasture. This can create a substantial difference in the estimated exposure via milk versus estimated exposure via deposition.

$$ICM_{pij} = \int_0^{\infty} C_p(ijt) * P(ijt) * f_m dt \quad (1)$$

Equation (1) refers to the NCI's methodology for estimating daily I-131 concentrations in milk from deposition data. ICM_{pij} denotes the Integrated I-131 concentration in milk produced in pasture p in county i on day j and is measured in daily nCI per liter of milk. $C_p(ijt)$ denotes average daily concentration after deposition day. It is a function of deposition of I-131 and the fraction of this I-131 intercepted by plants. P_{ijt} denotes the average pasture consumption rate by cows and was constructed from agronomic studies relating to pasturing behavior of dairy farmers during the 1950's. The value f_m denotes I-131 intake to milk transfer coefficient. This value was constructed from milk secretion studies where cows were fed radioactive iodine. These adjustments are made at the state level and should

⁸A small number of counties in both the deposition and milk measures consist of sub county units. I created weighted averages of exposure at the county level from these subcounty units. In the analysis, these counties are excluded from the main sample. Other counties and Virginia Independent Cities are omitted from the sample due to data limitations.

not be systematically correlated with any unobserved underlying economic or environmental conditions that would affect local mortality. The quantity of pasture a cow consumes on an average day and how long pastures are available to farmers during the year do not have any apparent relationship with crude death rates. These factors affect annual mortality rates only by altering the amount of I-131 entering the local food supply.

III.iii Panel Regression Specifications

The empirical analysis of this paper focuses upon two different panel regressions to ascertain the geographic and temporal extent of the health cost of atomic testing. The first set of regressions test whether within county variation in radioactive fallout exposure across years had an immediate effect upon crude death rates using a distributed lag framework. Short run changes in the crude death rate from fallout exposure are potentially less vulnerable to measurement error in treatment and migration bias than regressions measuring the long run effects of fallout. These regressions, however do not fully capture the temporal extent of these increases in mortality rates. The negative health effects of radiation poisoning often materialize long after the damage has occurred. A set of long run regressions employ a distributed lagged framework and pool exposure into five year averages. Estimation of this model measures how persistent the effects of fallout were on crude death rates, accounts for the cumulative effect of fallout exposure over multiple years, and whether exposure to fallout led to harvesting. If exposure to radioactive fallout shortened lifespans and exposed populations who died tended to die at younger ages, then these people would not appear in subsequent years in the county panel. This harvesting effect would decrease estimated mortality rates many years following the initial exposure event, because people who would have died in these periods died earlier in the sample.

Equation (2) describes the most restrictive model specification of this paper. This model tests whether radioactive fallout in locally produced milk or in the environment had a statistically significant effect upon mortality in the years directly following the test. Three different specifications are reported.

$$y_{it} = \sum_{k=0}^5 \beta_k * X_{it-k} + \alpha_i + \gamma_{st} + \epsilon_{it} \quad (2)$$

The outcome denoted by y_{it} measures the number of total deaths per 10,000 people in a given county i and year t . X_{it-k} denotes the exposure variable used to proxy for fallout exposure. There are two different measures of radiation exposure used in the analysis. These measures are ground deposition of I-131 and I-131 concentrations on locally produced milk. The variable *Deposition Exposure* $_{it}$ denotes the cumulative measure of total radioactive iodine deposited per square meter in each county year.⁹

The variable *Milk Exposure* $_{it}$ denotes the measure of radioactive iodine in locally produced milk in each county year in thousands of nCi per day/Liter. The NCI created daily integrated estimates of secreted iodine per liter of milk for each nuclear test. They then summed up these secretions over the entire test series. If a cow in a county produced one liter of milk each day, this would measure the amount of radioactive iodine secreted in all those liters of milk in each year. Furthermore, the milk variable accounts for grazing practices across regions. Cows in upstate New York would not have been exposed to much radiation from February tests as they would have been inside barns consuming fodder while cows in Nevada or Arizona would have been exposed.

The variables α_i and γ_{st} denote county and state-by-year fixed effects. These county fixed effects control for time invariant county characteristics. The state-by-year fixed effects ac-

⁹Alternative functional forms find similar results. These alternative specifications are reported in the online appendix.

count for unobserved annual shocks shared across counties within the same state and year. One drawback of this control is that state-by-year fixed effects might absorb much of the variation in radioactive fallout exposure observed in the data.¹⁰ Alternative specifications replace these state-by-year fixed effects with year fixed effects and state specific time trends to control for any spurious underlying trends in the data that might be correlated with the exogenous variable of interest. The variable ϵ_{it} denotes the heteroskedastic error term and is clustered at the county level.¹¹

$$y_{it} = \sum_{j=0}^5 \theta_j * Avg_X_{it,j} + \alpha_i + \gamma_{st} + \epsilon_{it} \quad (3)$$

Equation (3) describes the distributed lag specification for the long run panel regressions. This model uses a similar framework to that of Equation 1, but the exposure of interest consists of lagged five year averages of the I-131 exposure measures. The variable $Avg_X_{it,j}$ denotes the average exposure term with j lags. This distributed lag structure measures the dynamic mortality response to county level radiation exposure over a longer time horizon. Fallout in the current year is excluded from the regression and only past deposition patterns provide variation. This model uses variation in average fallout exposure one to five years prior, six to ten years prior, eleven to fifteen years prior, sixteen to twenty years prior, and twenty-one to twenty-five years prior to identify the temporal extent to which fallout affected mortality patterns.

¹⁰Only variation in county level exposure above or below the state average for exposure provides identification. It is quite likely that the effect of fallout exposure will be underestimated when using state-by-year fixed effect, since the identifying variation is narrower and within some state year observations fallout deposition is highly correlated.

¹¹Multiple yearly lag structures were tried and the results are generally robust with respect to the number of lags. A specification with five lags was selected since the long run specifications use five year averages. Using five year lags identifies the mortality effect of fallout exposure that is being averaged in the long run panel.

III.iv Identification and Sample

The source of identifying variation in the empirical analysis comes from within county variation in radiation exposure across time after controlling for state specific annual shocks. There are two main assumptions that allow for measurement of the causal effect of fallout upon mortality. The first assumption is that the exposure variable is orthogonal to the unobserved error term. The second assumption is that most people who were exposed to radioactive fallout eventually die in the county where they were exposed.

Fallout exposure from nuclear testing is a plausibly exogenous event. First, the public generally cannot observe whether they are exposed to radioactive pollution. Radioactive threats generally are imperceptible. Second, the public generally did not know about the polluting effects of the NTS until long after atmospheric testing was suspended. Government disinformation in the 1950's and the imprecise public knowledge regarding the effects of fallout exposure prior to 1978 suggests such behavior would be unlikely for much of the country. One challenge to the orthogonality assumption is that people living in the counties surrounding the NTS could observe radioactive dust blows from atomic tests and might have engaged in avoidance behaviors. In order to avoid these potential endogeneity issues, I exclude the counties surrounding the NTS and those counties listed as Downwind by the US Department of Justice (2016) from the empirical analysis.¹² Outside of these counties, people would have been exposed to fallout through the irradiated food supply and not by visible radioactive dust blows.

The second assumption is necessary to measure the treatment effect of fallout upon mortality patterns. Since exposure is at the county level rather than individual level, identification

¹²A total of 26 counties are excluded from the analysis. These counties are all located in AZ, CA, NV, and UT. Relatively speaking, very few individuals resided in these counties during the testing period and these areas experienced large quantities of fallout deposition. Including these counties into the sample does not substantially affect the estimates using milk exposure but substantially affects the precision of the deposition measures. Including an interaction term for these counties or taking the log of the outcome variable corrects for the imprecision these counties introduce for the deposition measure.

relies on people dying in the counties where exposure is reported. In and out migration would introduce measurement error in the treatment variable. If migration decisions are not systematically correlated with radiation exposure, then migration bias should attenuate the effect of radiation exposure on mortality as the time between the exposure event and reported deaths widen.

IV Empirical Results

IV.i Panel Regression Results

The empirical results suggest that fallout exposure due to NTS atomic testing led to persistent and sizable increases in mortality for large areas of the continental United States. The measured effect is generally larger for specifications using the milk exposure measure than the raw deposition measure. In the short run panel regressions, exposure to fallout through milk leads to immediate and sustained increases in the crude death rate. In the long run panel regressions, both deposition and the milk exposure regressions are associated with large increases in mortality following fallout exposure events. Finally, human exposure to fallout measured by I-131 in milk continues to have positive and statistically significant effects after the inclusion of state-by-year fixed effects, while the coefficients of the deposition measures attenuate towards zero.

Summary statistics for the sample used in the empirical regressions are provided in Table I. Six different specifications are reported in each table of the empirical section. Specifications 1 through 3 report the effect using the milk exposure variable and specifications 4 through 6 report the effect using the deposition variable.¹³ For both the milk and deposition measures, specifications with only fixed effects, including time trends, and the full specification are

¹³Using both variables together introduce substantial multicollinearity but results in positive and statistically significant effects for the milk measures and statistically insignificant effects for deposition measures.

reported.

The discussion for the results refer to the specification with the most controls, which are specifications 3 and 6 in the tables. The results regarding short term mortality effects of radiation exposure appear in Table II. Both milk exposure and deposition exposure measures are associated with increases in crude death rates over several years of lags. All of the milk exposure coefficients are statistically significant at the 5 percent level, but only the deposition coefficients for the first and second lags are statistically significant at the 10 percent level. Comparisons across specifications show that the inclusion of state-by-year fixed effects increases the magnitude of the estimated coefficients. The results suggest that 1,000 nCi of I-131 in the local milk supply leads to an additional 2.469 additional deaths per 10,000 residents in a given year, 2.89 deaths the subsequent year, 4.379 deaths two years later, 2.87 deaths three years later, and 2.708 four years later. The deposition estimates suggest that 1,000 nCi of deposition per m^2 increases the mortality rate by an additional 0.949 deaths per 10,000 two years following deposition and 0.879 deaths per 10,000 three years following deposition.

The long run mortality effects for both I-131 deposition and milk exposure channels appear in Table III. Across most specifications there are positive and statistically significant increases in mortality attributable to NTS activities up to 25 years following the last atmospheric nuclear denotation at the NTS. Specifications including state-by-year fixed effects have negative coefficients on average exposure measures sixteen to twenty and twenty-one to twenty-five years following deposition. These results might arise from a harvesting effect if exposure to NTS fallout led to more people dying younger.

In specification 3, an average of 1,000 nCi in I-131 in milk one to five years prior contributes to an additional 12.93 deaths per 10,000 residents. An average of 1,000 a Ci in I-131

in milk six to ten years prior causes 7.04 additional deaths per 10,000. For average milk exposure eleven to fifteen years prior, and the coefficient reduces to 0.143 deaths per 10,000. The negative coefficients that appear after the inclusion of state-by-year fixed effects suggest that an average of 1,000 nCi in I-131 in milk sixteen to twenty and twenty-one to twenty-five years prior led to 7.894 and 5.779 fewer deaths per 10,000 individuals. Specification 6 finds no statistically significant and positive relationship between fallout deposition and mortality. The same coefficients for the exposure lags sixteen to twenty-five years following deposition suggest that 1,000 nCi of deposition led to 5.502 and 2.909 fewer deaths per 10,000. These coefficients are statistically significant at the 1 percent level.

IV.ii Quantifying the Magnitude of the Effects and the Policy Implications of the Partial Nuclear Test Ban Treaty

The effects upon crude mortality are large relative to estimates by Simon and Bouville (2015) and comparable (or even larger) to the number of deaths attributable the atomic bombings of Hiroshima and Nagasaki. I perform a series of back-of-the envelope calculations to quantify the total mortality effect of NTS atomic testing. I use the long run coefficients of average exposure one to five, six to ten, and eleven to fifteen years prior to calculate this increase and then multiple them by the national crude death rate for the given year to estimate the total increase in the crude death rate per 10,000 individuals. I add together the three coefficients of interest to measure the total increase in the crude death rate for each specific county year observation between 1951 and 1973.¹⁴ I multiply the estimated mortality effect by annual county populations and sum the totals across counties across years to estimate the total number of deaths attributable to atmospheric testing.¹⁵ Table IV presents these calculated cumulative mortality effects.

¹⁴The final atmospheric test in my data was in 1958.

¹⁵Specification 6 is excluded from these calculations because it reports a null effect upon mortality.

Depending on the regression specified, I-131 in milk contributed between 395,000 and 695,000 excess deaths from 1951 to 1973. The average increase in mortality across counties is between 0.65 and 1.21 additional deaths per 10,000 people for this same period. The estimates from deposition suggest that fallout contributed between 338,000 and 692,000 excess deaths over the same period. These effects are approximately 7 to 14 times larger than estimates provided by the NCI. When these effects are mapped out many of these estimated deaths occurred in regions far from the NTS. Figure III reports the average annual effects of radiation exposure through milk on mortality for years 1951 to 1973. Figure IV reports the total increase in state deaths for the same period.

The model suggests much of the death effect appears in the Midwest and Eastern U.S. where larger populations would have been exposed. The per capita mortality effects tend to be greatest out west in the Plains and in states north and east of the NTS.¹⁶

IV.iii Robustness Checks

I perform a falsification test to test whether unobserved underlying factors were driving the crude death results. I select a sample of counties from 1937 to 1950 and reassigned the radiation exposure measures to the years of 1938, 1939, 1940, 1942, 1944, and 1945. The results are available in Table V.

I find no evidence that either the fallout deposition or fallout in milk from the 1950's had a systemic relationship with the log crude death rate between 1911 and 1950.¹⁷

¹⁶Running the regressions and including the excluded counties surround the NTS does not substantially change the patterns described in these maps.

¹⁷Additional robustness checks included taking the log of the exposure variable, adjusting the number of lags, including the excluded counties, and interacting the structural parameters used in calculating the milk measures with deposition. The mortality effect remains robust to specification choice. The inclusion of the excluded counties does not change the mortality effect for the dairy measures but introduces additional imprecision with the deposition estimates. This imprecision is resolved either through interacting the exposure variable with an indicator variable for these counties or by logging the treatment variable.

V Policy Implications of Nuclear Testing

America's nuclear weapons program was (and still is) a costly national defense policy. From 1940 to 1996 the estimated cost of America's nuclear weapons program was approximately \$8.93 Trillion in 2016\$ (Schwartz, 2011). These monetary costs, however, do not fully capture the full social cost of America's nuclear weapons program. Since the 1990's the Federal Government has paid some compensation to victims of America's domestic nuclear weapons program. This compensation has focused on workers involved in the nuclear weapons program and those who lived downwind of the NTS during the 1950's. The U.S. Department of Justice pays out compensation to domestic victims of the nuclear weapons program through the Radiation Exposure Compensation Act. As of 2015 the U.S. Department of Justice has paid out over \$2 billion in compensation to victims (US Department of Justice, 2016).

Policy makers often assign accounting values to human lives when evaluating policy decisions. Viscusi (1993) and Viscusi and Aldy (2003) survey these valuations placed on human life. From 1988 to 2000, valuations of human life by U.S. Federal Government agencies ranged between \$1.4 million and \$8.8 million in 2016\$. These values and my estimates from the preferred specification place the value of lost life between \$473 billion and \$6,116 billion in 2016\$. Costa and Kahn (2004) use a hedonic wage regressions on industrial sector mortality risks to back out plausible market values for human life for each decade from 1940 to 1980. Using their values, I estimate the value of lost life from ground deposition between \$1.24 and \$2.56 trillion in 2016\$. The estimates from milk exposure places the value of lost life between \$1.17 and \$2.63 trillion. The social cost of excess deaths attributable to atmospheric testing at the NTS ranges from approximately 5.3 percent to 68.4 percent of the total cost of America's nuclear weapons program. These values, however likely understate the magnitude of the social costs of this polluting and environmentally destructive activities. Exposure

to radioactive fallout likely made millions of people less healthy, negatively affected human capital, and increased the cost of providing health services to these populations. These costs are not fully captured by measuring the effect of nuclear testing upon mortality rates.

The cessation of atmospheric nuclear testing drastically reduced the release of harmful radioactive material into the air and likely saved many American lives. Two policies restricted atmospheric testing at the NTS. The first was a testing moratorium from 1958 to 1961, which moved almost all nuclear tests underground. The signing of the Partial Nuclear Test Ban Treaty ultimately ended all atmospheric nuclear tests by the U.S. in 1963. The cumulative kilo-tonnage of the atmospheric tests analyzed in this paper's data is 992.4kt. During the moratorium period the cumulative tonnage of underground testing at the NTS from 1958 to 1963 was 621.9kt. From 1963 to 1992, the total tonnage of nuclear explosions at the NTS was 34,327.9kt, approximately thirty-four times larger than the NTS atmospheric tests (US Department of Energy, 2000).¹⁸

Assuming that the domestic mortality effect of atmospheric testing is proportional to the tonnage of the weapons tests, one might estimate approximately how many American lives were saved by the moratorium period and the Partial Nuclear Test Ban Treaty. Multiplying the smallest and largest cumulative mortality effects by the ratio of the moratorium tonnage to atmospheric tonnage suggests that the moratorium possibly saved between 212,000 and 435,000 lives. Employing the same back of the envelope calculation, the Partial Nuclear Test Ban Treaty might have saved between 11.7 and 24.0 million American lives. These calculations have some caveats. First, it is likely that the transition to underground testing increased the size of the weapons tested. This likely would overestimate the potential effect of shifting underground testing above ground. Second, even without the moratorium and

¹⁸For the NTS, almost all tests were underground from 1958 to 1963. Some underground tests did not report bomb yields but instead ranges of yields. In these cases bomb yield was taken as the average value. In cases where the bomb yield was greater than a certain value, the lowest value was assigned.

treaty, there was mounting scientific and medical evidence that NTS activity were harmful to public health. It is likely that atmospheric testing at the NTS would have become politically untenable as more of the negative health effects associated with atmospheric testing became realized. Finally, continuation of atmospheric testing likely would have increased repeated public exposure to radioactive fallout. This increase in average frequency of exposure might alter the point estimates identified in the panel regressions. Therefore, using the realized estimates might underestimate the potential effect of continued atmospheric testing upon mortality patterns.

The location of the NTS in Nye County, Nevada might have contributed towards the level of human exposure to radioactive pollution. In 1950 military and political leaders narrowed down list of potential atomic bombing ranges to a few locations (Schwartz, 2011). Other locations given serious consideration include the Trinity Test Site located in White Sands, New Mexico and Cape Hatteras, North Carolina. I use AP2 model from Muller et al. (2011) to construct a counter-factual scenario of potential pollution exposure from these alternative nuclear testing ranges. Nicholas Muller provides a county to county matrix which measures the effect of pollution emissions from one source county on PM2.5 concentrations in all other counties. If radioactive dust created by atmospheric atomic tests follows similar dispersal patterns as other pollutants, then AP2 can provide a counter-factual scenario and rank counties by how polluting they could have been.

For all counties other than the source county, I weight the PM2.5 coefficients by county population in 1950. I then sum the cumulative effect of a single unit of emissions for each of the 3,100 source counties. This procedure allows me to rank the relative downwind effect of locating the NTS in an alternative county. Counties are ranked from least polluting to most polluting.¹⁹ If policy makers sought to minimize human exposure to fallout, then

¹⁹I rank the relative dirtiness of the three mentioned locations and the top and bottom five alternative locations provided by the model in the Appendix.

the location of the NTS is quite fortunate. According to AP2, the NTS ranks 39th out of 3,100 counties. The White Sands and Cape Hatteras locations rank as the 953th and 495th least potentially polluting locations. Relatively speaking, White Sands would have been 3.45 times more polluting than the NTS and Cape Hatteras would have been 2.25 times more polluting.²⁰ These results reveal that atmospheric testing in the continental U.S. could have plausibly been much worse for American populations and public health.

VI Conclusion

This paper explores the temporal and geographic extent of harm caused by atmospheric atomic tests conducted in Nevada between 1951 and 1958. Using a new national dataset of radiation deposition and quantities of I-131 in the dairy supply, this paper finds that radiation exposure increased crude deaths in areas hundreds to thousands of miles from the test site. There are a few notable findings revealed through the application of modern panel data methods to public health data. First, this paper finds that the health consequences of atmospheric nuclear testing are vastly larger than previously thought. At a minimum, I find that nuclear testing at the NTS contributed to approximately as many deaths as the atomic bombings of Hiroshima and Nagasaki. The magnitude of these results are seven to fourteen times greater than estimates calculated by the National Cancer Institute.

Second, the geographic scope of the mortality consequences of NTS activities is broader than previously thought. The largest health effects appear in areas far beyond the scope of previous scientific and medical studies. The scientific and medical literature has studied the effects of atmospheric testing on populations residing in Downwind counties in Arizona, Nevada, and Utah. Counter-intuitively, the areas where fallout had the largest impact on

²⁰Intuitively the most polluting locations in the model would be the region surrounding New York City. These predictions are confirmed by the AP2 model. Interestingly, the Pacific Northwest, the Florida Keys, and Upstate Maine are locations that AP2 suggests would have been cleaner locations for testing than Nye, County.

the crude death rate was not in the region surrounding the test site, but rather in areas with moderate levels of radioactive fallout deposition in the interior of the country. Due to pasturing practices, large quantities of fallout wound up in local dairy supplies in these regions but not in the Downwind regions. It is quite plausible that extrapolating out the health effects from small samples of persons who lived around the NTS substantially underestimates the health costs associated with atmospheric testing.

Third, the empirical results of this paper suggest that nuclear testing contributed to hundreds of thousands of premature deaths in the United States between 1951 and 1972. The social costs of these deaths range between \$473 billion to over \$6.1 trillion dollars in 2016\$. These losses dwarf the \$2 billion in payments the Federal Government has made to domestic victims of nuclear testing through the Radiation Exposure Compensation Act and are substantial relative to the financial cost of the United States' nuclear weapons program. Furthermore, it is likely that the value of the both testing moratorium enacted in 1958 and the Partial Nuclear Test Ban Treaty is understated. These political compromises likely saved hundreds of thousands of lives at a minimum.

Finally, the evidence presented in this paper suggests that the health cost of domestic nuclear testing is larger and broader than previously thought. The mortality estimates may understate the magnitude of the true number of deaths attributable to nuclear testing and the magnitude of the health costs of this polluting defense policy. It is plausible that these estimates are lower bounds of the true health effects. Migration and measurement error in treatment introduces attenuation bias, and the health effects of radiation exposure may only appear later in life for many individuals. Millions of persons growing up during the testing period are now retiring from the labor force and are drawing upon Medicare and other government provided services. Therefore, nuclear testing may have made an entire generation of people less healthy and thus increased the cost of providing health care well

into the present. This paper reveals that there are more casualties of the Cold War than previously thought, but the extent to which society still bears the costs of the Cold War remains an open question.

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Table I: Summary Statistics

	mean	sd	count	min	max
Crude Death Rate (CDR) per 10,000	100.9774	25.07475	124,260	8.596973	564.8707
I-131 Deposition, 1,000's nCi	.0473485	.2286606	124,260	0	7.837
Avg Deposition 1 to 5 years prior, 1,000's nCi	.0517889	.1408517	124,260	0	6.6078
I-131 in Milk, 1,000's nCi	.0301848	.1358054	124,260	0	4.6
Avg Milk 1 to 5 years prior, 1,000's nCi	.0318766	.0786718	124,260	0	1.857

Table II: Short Run Mortality Effects, Crude Death Rate, 1940-1988

	(1)	(2)	(3)	(1)	(2)	(3)
	Milk Exposure, 1,000's nCi			Deposition Exposure, 1,000's nCi		
Exposure, t	-0.113 (0.551)	0.997 (0.505)	2.469 (0.981)	0.181 (0.333)	-0.352 (0.296)	0.635 (0.457)
Exposure, t-1	1.475 (0.524)	2.115 (0.461)	4.286 (0.764)	1.029 (0.297)	0.415 (0.275)	0.949 (0.566)
Exposure, t-2	2.006 (0.570)	2.509 (0.493)	4.379 (0.937)	1.238 (0.277)	0.689 (0.246)	0.879 (0.406)
Exposure, t-3	1.554 (0.514)	1.378 (0.461)	2.287 (0.852)	0.884 (0.282)	0.320 (0.279)	0.556 (0.462)
Exposure, t-4	2.866 (0.539)	2.664 (0.497)	2.708 (0.833)	1.370 (0.321)	0.806 (0.283)	0.531 (0.366)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	No	Yes	No
State Year FE	No	No	Yes	No	No	Yes
N	124,260	124,260	124,260	124,260	124,260	124,260
<i>Adj r</i> ²	0.647	0.686	0.693	0.647	0.686	0.693

All Standard Errors are Clustered by County. Exposure denotes the yearly cumulative I-131 measures at the county level.

Table III: Long Run Mortality Effects, Crude Death Rate, 1940-1988

	(1)	(2)	(3)	(4)	(5)	(6)
	Milk Exposure, 1,000's nCi			Deposition Exposure, 1,000's nCi		
Exposure, t-1 to t-5	13.59 (1.684)	11.29 (1.584)	12.93 (2.774)	7.734 (1.264)	3.881 (1.204)	1.878 (2.083)
Exposure, t-6 to t-10	13.11 (1.599)	8.676 (1.565)	7.041 (2.962)	6.797 (1.263)	3.501 (1.181)	-0.362 (1.794)
Exposure, t-11 to t-15	10.39 (1.662)	4.854 (1.588)	0.143 (2.888)	5.314 (1.167)	2.346 (1.018)	-1.507 (1.425)
Exposure, t-16 to t-20	7.239 (1.786)	1.411 (1.680)	-7.894 (3.520)	2.667 (1.140)	0.0859 (0.979)	-5.502 (1.353)
Exposure, t-21 to t-25	7.834 (1.915)	-2.317 (1.414)	-5.779 (2.801)	2.513 (0.847)	0.0434 (0.587)	-2.909 (1.110)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	No	Yes	No
State Year FE	No	No	Yes	No	No	Yes
N	124,260	124,260	124,260	124,260	124,260	124,260
<i>Adj r</i> ²	0.648	0.686	0.693	0.648	0.686	0.693

All Standard Errors are Clustered by County. Exposure denotes the pooled five year averages of cumulative I-131 measures at the county level.

Table IV: Changes in County Mortality Patterns Attributable to NTS Fallout, 1951 to 1973

I-131 In Local Milk				
	Mean	SD	Max	Total Deaths
Specification 1	1.208	1.899	26.259	695436.300
Specification 2	0.806	1.320	20.975	458506.700
Specification 3	0.649	1.280	24.012	359360.700
I-131 Ground Deposition				
	Mean	SD	Max	Total Deaths
Specification 4	1.056	1.779	51.102	692407.400
Specification 5	0.517	0.883	25.644	338472.700
Specification 6	-	-	-	-

Source: Author's calculations

Table V: Placebo Test: Log Crude Death Rate, 1937-1950

	(1)	(2)	(3)	(4)	(5)	(6)
	Milk Placebo , 1,000's nCi			Deposition Placebo, 1,000's nCi		
Exposure, t	-1.215 (0.688)	-0.476 (0.707)	-1.563 (1.751)	-0.339 (0.269)	-0.461 (0.281)	-0.232 (0.369)
Exposure, t-1	-0.511 (0.589)	-1.216 (0.594)	-3.388 (2.425)	-0.297 (0.298)	-0.480 (0.312)	-0.460 (0.647)
Exposure, t-2	0.548 (0.570)	-1.219 (0.584)	0.189 (0.903)	-0.114 (0.246)	-0.333 (0.266)	-0.0243 (0.307)
Exposure, t-3	2.999 (0.624)	0.651 (0.621)	0.603 (0.970)	0.525 (0.234)	0.258 (0.230)	-0.111 (0.351)
Exposure, t-4	2.824 (0.589)	-0.589 (0.600)	1.055 (0.867)	0.464 (0.255)	0.0748 (0.247)	0.0660 (0.334)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	No	Yes	No
State Year FE	No	No	Yes	No	No	Yes
N	42,096	42,096	42,096	42,096	42,096	42,096
<i>Adj r</i> ²	0.607	0.615	0.618	0.606	0.615	0.618

All Standard Errors are Clustered by County. Placebo Exposure denotes the yearly cumulative I-131 measures at the county level. These placebo measures consist of I-131 measures being shifted forward thirteen years. i.e. Exposure in 1951 recoded as 1938, 1952 as 1939, 1953 as 1940, etc. Three tests for 1945 were conducted in New Mexico but their yields were relatively small. The corresponding Hardtack tests of 1958 were also small in scale and most radiation release remained near the Nevada test site in 1958.

Table VI: AP2 Ranking of 3,100 Alternative Nuclear Test Site Locations

Location	Pollution Intensity	Rank
Locations Under Consideration by Policy Makers		
Nevada Test Site (Nye County), NV	1	39
White Sands (Dana Ana County), NM	3.327	953
Cape Hatteras (Dare County), NC	2.167	495
Top Five Least Polluting Counties		
Modoc County, CA	0.251	1
Lake County, OR	0.303	2
Monroe County FL	0.342	3
Klamath County, OR	0.394	4
Del Norte County, CA	0.394	5
Top Five Most Polluting Counties		
Nassau County, NY	186.829	3,096
Essex County, NJ	196.218	3,097
Hudson County, NJ	262.022	3,098
Bergen County, NJ	362.736	3,099
Queens County, NY	440.651	3,100

Parameters for AP2 provided by Nicholas Muller. Rank denotes order of least polluting counties 1 to 3,100.

Pollution intensity denotes population weighted PM2.5 exposure for all recipient counties relative to the NTS.

Emission location is excluded from the calculation.

1000's of nCi per square meter for Upshot Knothole 1953 Test Series

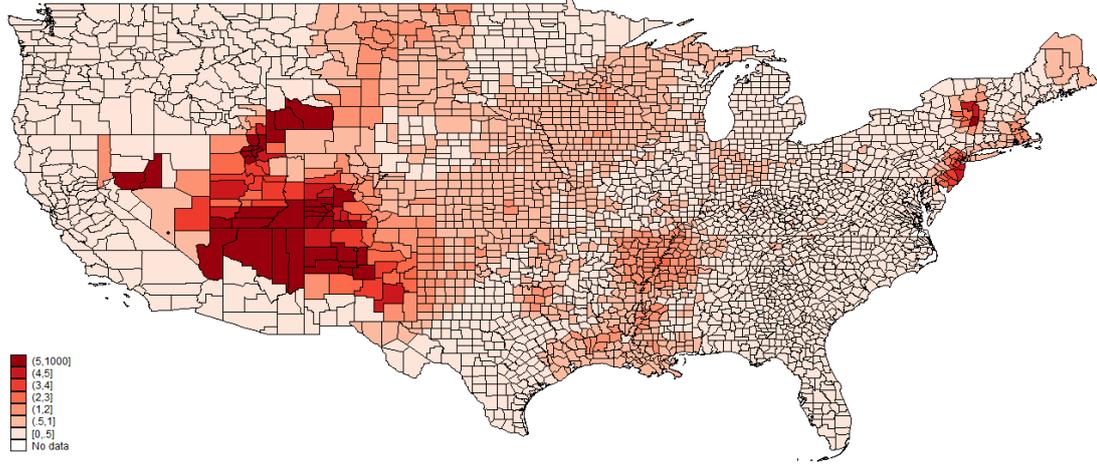


Figure I: Cumulative I-131 Deposition from Upshot Knothole Series. Source: Created from NCI data.

Cumulative I-131 Measure in Milk, 1000's nCi, Upshot Knothole 1953 Test Series

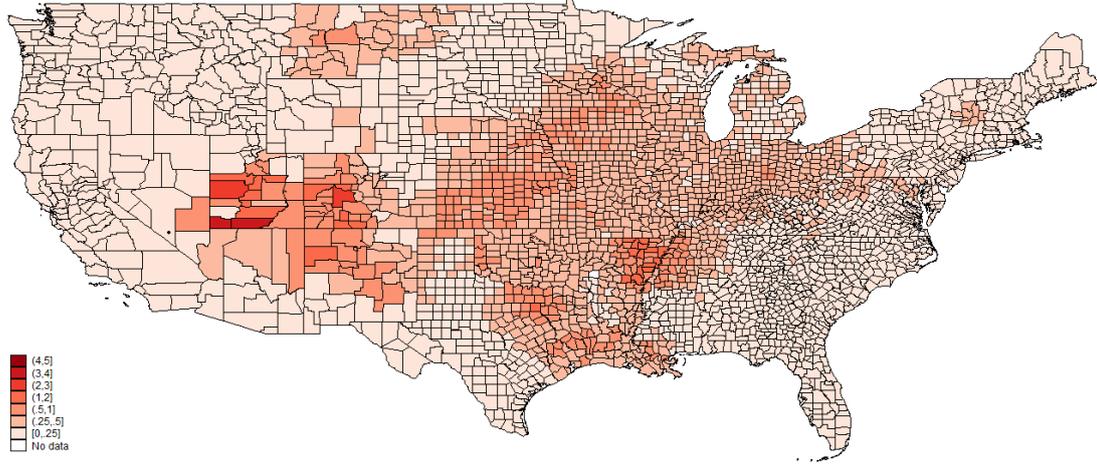


Figure II: Cumulative I-131 Milk Measures from Upshot Knothole Series. Source: Created from NCI data.

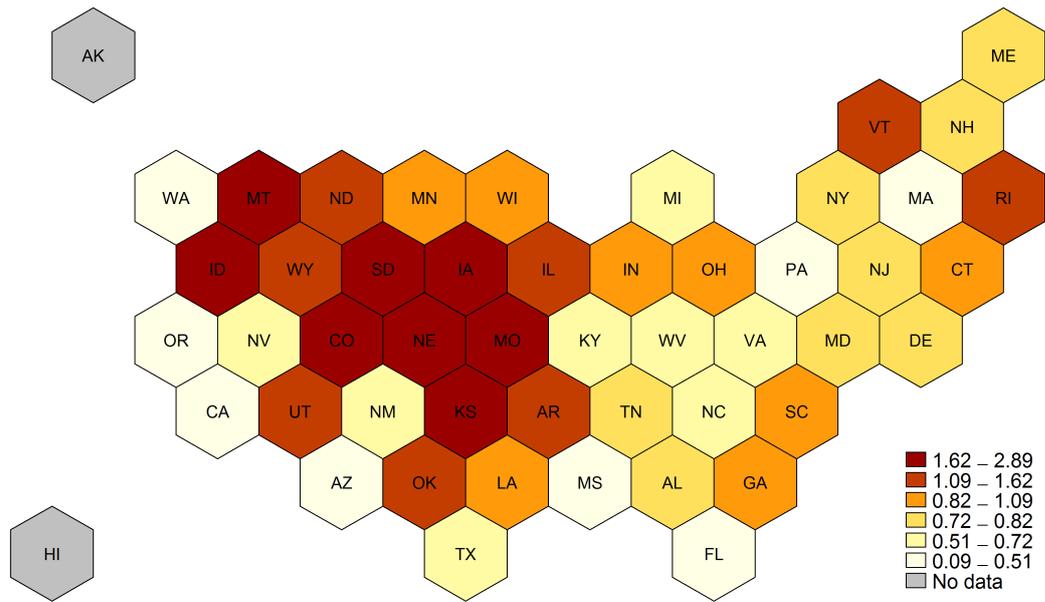


Figure III: Average Increase in Crude Deaths Per 10,000 attributable to I-131 in Milk, 1951 to 1973. Source: Author's calculations

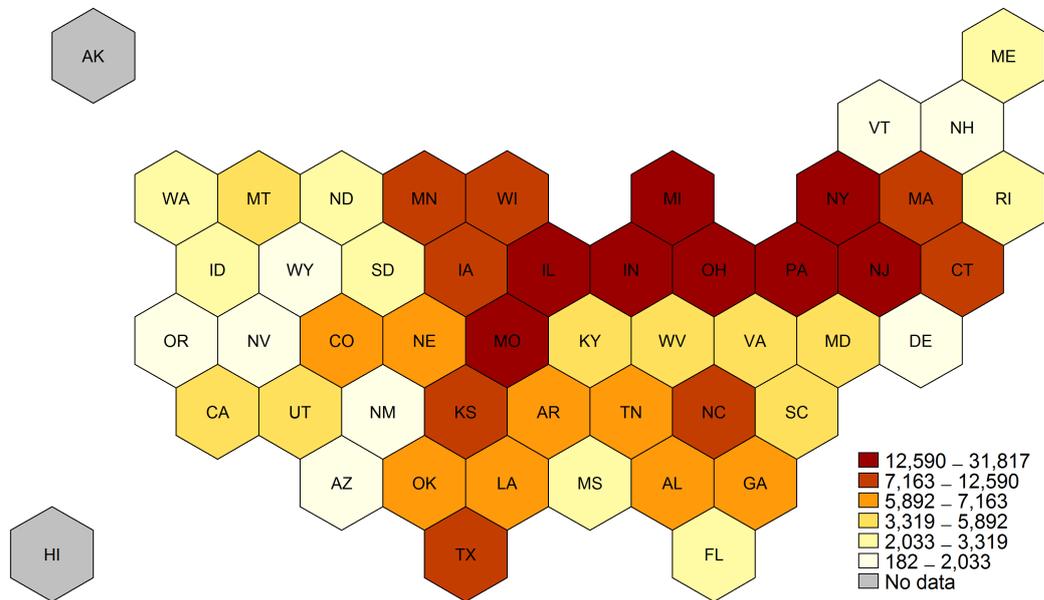


Figure IV: Total Increase in Crude Deaths to I-131 in Milk, 1951 to 1973. Source: Author's calculations