In the Shadow of the Mushroom Cloud: Nuclear Testing, Radioactive Fallout and Damage to U.S. Agriculture

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Abstract

In the 1950's the United States conducted scores of nuclear tests at the Nevada Test Site just northwest of Las Vegas. Each test was a controlled catastrophic event that created tremendous amounts of radioactive matter. Much of this radioactive pollution deposited across large portions of the continental U.S.. This paper uses annual county level deposition of radioactive material as an exogenous shock to agricultural productivity and measures adjustments the agricultural sector made in response to damage caused by this radioactive pollution. This paper finds that radioactive fallout from atmospheric tests conducted in Nevada directly altered agricultural production. Fallout led to large reductions in wheat yields, caused farmers to alter their production decisions in the subsequent years, and may have led to permanent changes in long run agricultural production. [1]

1 Introduction

Pollution and disaster often alter trajectories of economic development. Economists have studied the implications of many shocks and even measured to what extent adaption mitigates these events (Hornbeck and Naidu, 2014; Hornbeck, 2012; Boustan et al., 2012; Lange et al., 2009). At times, government policy and actions act as the source of these shocks and distortions (Barreca et al., 2014; Troesken, 2008). With domestic atmospheric nuclear testing in the 1950's there is a unique intersection between government policy, pollution, and

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disaster. The scientific and medical literature shows that fallout from these tests harmed human and animal populations (Bustad et al., 1957; Garner, 1963; Simon and Bouville, 2015; Kerber et al., 1993; Gilbert et al., 2010). This radioactive material did enter the food supply (National Cancer Institute, 1997) and it is quite plausible that pollution created from nuclear testing harmed domestic agriculture. This paper studies the direct effects this radioactive pollution had upon the domestic agriculture sector and examines the adjustments farmers made in response to these fallout induced damages. This is the first paper in the economics literature to study the unintended consequences of nuclear testing conducted at the Nevada Test Site . I find evidence that radioactive pollution from these tests caused direct harm to the American agriculture and show that this damage occurred far beyond the downwind region. Figure 1 provides a map of areas defined as downwind of the NTS according to the U.S. Justice Department.

Using a new dataset, I exploit annual county level variation in radioactive fallout deposition for the continental United States to identify the effect of exogenous output shocks to wheat on the planting decisions made by farmers in subsequent years.[2] Wheat provides a suitable context to study the effects of exogenous output shocks under policy constraints. First, winter wheat yields show a substantial sensitivity to radiation exposure during winter hibernation (Sparrow et al., 1971). Second, wheat is grown over a large geographic area and annual production data is available at a detailed level for many years prior to testing. Finally, wheat production was subject to regulation by Federal agriculture policy. Unlike other regulated crops, farm level production restrictions for wheat were a function of a farmer's previous planting and harvesting decisions.

Radioactive pollution is generally an unobservable threat and provides an exogenous shock to wheat productivity. This paper provides insight into how farmers responded to unanticipated exogenous shocks to production when facing institutional policy constraints. Understanding how farmers adjust in response to adverse productivity shocks is of growing importance. Shifting climatic patterns present many significant challenges to agriculture. Increasing variability in weather patterns and extreme weather events pose significant risk to agricultural productivity. The likelihood of extreme weather events and variability of weather patterns has been increasing as a result of human caused climate change (Melillo et al., 2014; Intergovernmental Panel on Climate Change, 2014). Economists have sought to

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[2] In the appendix I measure direct effects of radioactive pollution on sheep populations, dairy production and long run development of the agriculture sector.

understand the potential consequences of these climate shifts through exploiting variation in weather patterns, but the current literature has focused little on how agricultural policy shapes adaptive response. Furthermore, changes in agricultural output caused by weather not only has an effect on farm income but also carries an information signal regarding future weather patterns. Adaptive responses made by farmers in subsequent years are driven by both of these effects. This paper disentangles the direct output effect from this information signal by using an alternative exogenous source of variation in agricultural output.

Agriculture policy for wheat during the 1950's created a scenario of "use it or lose it" for wheat farmers. If a farmer abandoned acreage or decreased planting in a given year they risked losing their acreage allotments. In this paper I present a simple theoretic model to motivate my analysis of adaptive responses under a policy constraint. This model describes the effect of an acreage restriction that is a function of past behavior. I provide a brief history of domestic agricultural policy regarding wheat production during the nuclear testing period to substantiate this model. To substantiate the negative biological effects of fallout upon agriculture and the exogeneity of radioactive fallout deposition, I provide both historical context regarding nuclear testing and scientific evidence that radioactive pollution from these tests would indeed affect agricultural production. The empirical section substantiates that radioactive fallout directly decreased wheat yields and measures the adaptive responses made by farmers in response to radiation induced damage.

1.1 Related Literature

This paper contributes to a number of developing literatures. The previous literature studying the interaction between policy, adverse shocks, and agriculture specifically studies damage from observed or anticipated events. Farmers can react and mitigate damage from known pests and observed weather shocks. My paper provides a rare opportunity to study production responses in agriculture where the proximate cause of damage is unknown and unobserved. Much research on the economic consequences of climate change have focused on agricultural responses to weather shocks. Since the full effects of climate change are unknown, researchers know little about how the agricultural sector may react to these unanticipated events. Schlenker et al. (2006) find declines in agricultural land values and yields using variation in weather patterns to explain the potential risks of climate change. Deschenes and Greenstone (2007) replied to Schlenker et al. (2006) with an analysis that suggested climate change would increase agricultural productivity. Their results were inconsistent with the literature and was later found to have been the result of multiple errors (Fisher et al., 2012;

Deschênes and Greenstone, 2012). Schlenker and Roberts (2009) predict large declines in U.S. agricultural productivity as a consequence of climate change. Nelson et al. (2014) use an integrated model to study how climate change will reduce global yields and to measure the sensitivity of the agricultural sector. Burke and Emerick (2012) employ a long differences methodology and a long weather panel to observe whether or not farmers adapt to shifting climatic conditions. They find evidence that U.S. corn and soybean farmers failed to readily adapt to shifting climatic conditions.

Another body of literature uses distortions caused by disaster and catastrophic events to measure adaptive responses. Atmospheric nuclear testing was a deliberate policy of controlled catastrophic events which released large quantities of harmful radioactive pollutants into the atmosphere. Recent literature studying economic effects of disaster observe both short and long term consequences for such events. Boustan et al. (2012) study the adaptive migratory responses to tornadoes and floods. They find that people were less likely to migrate to areas that had experienced recent tornadoes and more likely to migrate to areas that had experienced recent floods. With regards to agriculture responses to disaster this paper draws much inspiration from Hornbeck's (2012) work on the Dust Bowl. Hornbeck highlights the short run and long run productivity responses to Dust Bowl soil erosion. While Hornbeck finds some evidence of adjustment through altered production choices by farmers, he attributes most of the economic adjustment in eroded counties to migration. Further work by Hornbeck and Keskin (2014) finds limited benefits from agricultural spillovers using the Olegeighny aquifer as a shock to agricultural production. Other work examining the effects of anticipated disaster and the Boll Weevil by Lange et al. (2009) shows that in anticipation of large productivity losses, farmers increased production of cotton in the years proceeding pest arrival, and switched to less valuable crops such as corn in the years following pest arrival. I add to this agricultural adaptation literature by studying responses to unanticipated productivity shocks where the proximate cause of damage is unobserved. Future threats to agriculture may not be anticipated and studying the effects of radioactive fallout had upon this sector can help us understand how resilient agriculture is to adverse events and how policy shapes decisions.

Finally this paper contributes to a growing literature studying the unintended consequences of pollution. Historical studies by Barreca et al. (2014); Clay et al. (2016); Troesken (2008) focus on the effects of technology and policy upon mortality with respect to coal consumption and the municipal adoption of lead water pipes. There is also a small but growing literature studying the economic effects radioactive pollutions. The limited research has focused primarily upon human capital effects of low dose ionizing radiation on Scandinavian populations and the effects of the Chernobyl disaster in Ukraine. My paper expands upon the current literature to show that radioactive pollution harmed sectors of the economy and U.S. populations. Almond et al. (2009) test the fetal origins hypothesis with respect to radiation exposure following the Chernobyl incident in April 1986. They examine Swedish birth cohorts and find that Swedes in-utero in areas with substantial fallout exposure were less likely to qualify for high school than adjacent birth cohorts. Black et al. (2013) have a current working paper which attempts to extend these results to nuclear weapons tests. Using Norway's draft and census records with information from fourteen monitoring stations they were able to estimate radiation deposition both in the air and ground during the 1950's and 1960's. They exploit variation in low dose fallout exposure across time and Norwegian communities from 1956-1966 to find that individuals exposed during months 3-4 in-utero had lower IQ scores relative to comparison cohorts. The authors also find that negative schooling outcomes persisted in the descendants of exposed cohorts. Lehmann and Wadsworth (2011) employ Ukrainian longitudinal surveys to study self reported health and labor market outcomes of irradiated cohorts. Danzer and Danzer (2016) exploit the same variation to measure how uncertainty with respect to exposure risk affected mental wellbeing.

My paper possess some advantages relative to Black et. al. (2013) and Almond et. al. (2009). First my radiation deposition data is broader in geographic scope than the data used in the existing literature. Second, the amount of radiation exposure I am measuring is substantially larger in magnitude than what was observed in the Scandinavian studies. The largest deposition in Almond et al. (2009) was 1,459 nCi per m^2 and 883 nCi per m^2 for Black et al. (2013). The average county level deposition for the 1957 Plumbbob test series for the continental U.S was 754 nCi per m^2 and the largest deposition was 13,736 nCi per m^2. Finally, my data can connect fallout in counties to specific U.S. atomic tests, which is something not done in the Black et. al. (2013). The benefits of my data over that of Chernobyl studies is that the nature of nuclear testing allows me to exploit panel variation to identify the effects of radiation exposure rather than the cross sectional variation provided by a single disaster.

2 Theoretic Model and Agriculture Policies from 1938-1970.

Substantial government intervention into the agricultural sector began with the Agricultural Adjustments Act (AAA) in 1933. Much of this act was ruled unconstitutional and was succeeded by the Agricultural Adjustment Acts of 1938, 1948, and 1949. These laws set fixed price supports for crops, land allotments restrictions, and marketing quotas (Rasmussen et al., 1976). Acreage allotments were restrictions on acreage planted and were set according a farm's historical base acreage. Marketing quotas were restrictions on the quantity of crops permitted for sale or on farm use during a specific growing year. Farmers would be eligible for price supports and government aid if they complied with government market quotas and land allotment restrictions. If a farmer failed to abide by market quotas they might receive a per bushel fine on marketed crops. Acreage allotments and farm specific marketing quotas were calculated from a value called base acreage and would be strictly increasing in base acreage (Cochrane and Ryan, 1976). Basic crops of corn, cotton, peanuts, rice, tobacco, and wheat received mandatory price supports.

The historic base acreage of wheat farms was set as a function of the past three year's wheat plantings. The particular language of the 1948 Farm Bill states acreage "planted for harvest" determines base acreage. Farms that did not possess allotments could to request new allotments. The total value of requests could not exceed 3% of the total county allotment. In 1955 this formula switched to using harvested acres rather than planted acreage (Cochrane and Ryan, 1976). Farmers who failed to abide by market quotas or allocation restrictions the years they were in effect would lose access to price supports and face possible fines. These restrictions create a "use it or lose it" scenario for many wheat farmers. If a farmer reduced planting (or harvesting) of wheat in a single year, it could negatively affect their future base acreage and thus future stream of income. The switch to using harvested acreage to calculate base acreage also introduces an incentive to over plant winter wheat because the farmer can strategically adjust harvesting to comply with allotment mandate and hedge against crop failure (Cochrane and Ryan, 1976). However, if radioactive fallout induced crop failure and led farmers to abandon cultivated acreage, this policy shift magnifies the cost of damage as the radiation shock could affect their base acreage in the future. In years where allotments were not enforced farmers could increase their total wheat acreage and in years where allotments were enforced they would be hesitant to cut wheat acreage because it could result in decreased wheat acreage in the future. From 1940 to 1949 and 1951 to 1953 there were no restrictions on wheat planting. From 1954 to 1972 acreage allotment restrictions for wheat were in effect and became generally more restrictive. Marketing quotas were in effect from 1954 to 1964 (Burt and Worthington, 1988).[3]

2.1 Theoretical Model

To motivate and understand the channels through which radioactive pollution altered productivity, I provide a simple model similar to that of Hornbeck (2012). This model examines the effect of how a farmer would react to a transitory productivity shock under a policy restriction that penalizes for abandoning wheat acreage. In this model the agent farmer must choose between allocating inputs between two different agricultural products. For simplicity, I call this input land and the outputs winter wheat and spring sown crops. Winter wheat is generally higher yielding than spring wheat but is also more susceptible to frost damage. Spring wheat competes with other spring sown crops such as barley, oats, and flax seed. A farmer can also observe winter wheat performance in the spring and can decide to alter planting decisions in response to this information.

In a single period the representative farmer must choose to allocate a k units of input θ. Let the profit functions for winter wheat and spring wheat be denoted by $f(\theta)$ and $g(\theta)$. Both of these profit function are concave and increasing with respect to their arguments. The single period expected profit function from this allocation is represented by the following function, $\Pi = f(\theta) + g(k - \theta)$. Under unconstrained optimization the optimal allocation ensures that $\frac{df(\theta^*)}{d\theta} = \frac{dg(k-\theta^*)}{d\theta}$, i.e. the expected marginal profits from technology f equals that of g at the optimal allocation.

Now suppose the farmer needs to optimize their allocation facing a policy constraint. For simplicity I assume that acres harvested is increasing in acres planted. The farmer has an initial state η, which represents how much wheat acreage the farmer had harvested in the previous year. Radioactive fallout would decrease this η. The farmer has a single period choose to allocate θ between both production technologies. Farm policy regulates the future path of land allocations denoted by θ_B in all subsequent years. θ_B is a function of η and θ and is increasing in both variables. In this model the farmer wishes to maximize his or her stream of present discounted profits, β denotes the discount rate.

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[3] In 1956, the Soil Bank act enabled farmers to place allotted acreages into conservation for payment. The Soil Bank accepted land for short and long term conservation. It accepted land in 1956, 1957, and 1958. This decision would not decrease base acreage for farmers opting into the program. Winter wheat had the unique advantage over other crops in that farmers could observe the productivity of the crop and then decide whether or not to strategically put the land into conservation temporarily. This would reduce the cost of over planting.

$$\max_\theta f(\theta) + g(k-\theta) + \Sigma_{t=1}^{\infty}\beta^t * (f(\theta_B(\eta,\theta)) + g(k-\theta_B(\eta,\theta)))$$

This stream of profits can also be represented by a value function.

$$\max_\theta V(\eta,\theta) = f(\theta) + g(k-\theta) + \beta * V(\theta_B(\eta,\theta))$$

The first order conditions of this value function state that for any optimal allocation the value of any change made in current period has to equal the effect of this decision in future periods. If the farmer experiences a negative draw of η this decreases the partial derivative on the right hand side of the equality such that the previous allocation is no longer optimal. If the farmer decides to allocate more resources to winter wheat in the current period, this decision increases the value on the right hand side and decreases the value on the left hand side of the equality. The farmer chooses to over allocate resources towards winter wheat production because it offsets the negative effect η has on his or her future profits.

$$\frac{\delta f(\theta^*)}{\delta\theta} - \frac{\delta g(k-\theta^*)}{\delta\theta} = \beta * \frac{\delta V(\theta_B(\eta,\theta))}{\delta\theta_B(\eta,\theta)} * \frac{\delta\theta_B(\eta,\theta)}{\delta\theta}$$

Table 1 describes the scientific predictions of radiation's effects on agricultural output and discusses the predictions of this model. There are two scenarios to examine. The first scenario is that the productivity shock to wheat does not cause the farmer's policy constraint to reduce base acreage and thus there is no change in planting or harvesting behavior in subsequent years. In the second scenario, the productivity shock causes the policy constraint to reduce a farmer's base acreage. The farmer offsets this bad year by increasing planting and harvesting of wheat in the subsequent year.

3 The Biological Effects of Ionizing Radiation on Agricultural Products

Academic researchers and persons in the medical field noticed that radioactive Iodine-131 started to appear in animal and human thyroids and connected these results with the timing and incidence of domestic atomic tests (Comar et al., 1957; Van Middlesworth, 1956; Beierwaltes et al., 1960). Other researchers found long lived isotopes of Strontium-90 absorbed by wheat hundreds to thousands of miles from the test site (Lee 1959; Kulp and Slatter 1958; Olson 1959 & 1962; and Rivera 1961). The Public Health Service (PHS) and Atomic Energy

Commission (AEC) at the time corroborated these findings but downplayed the risks. In PHS Publications, Flemming (1959, 1960); Wolff (1957, 1959) stated that radioactive I-131 in dairy products and Sr-90 present in wheat and foods did not pose a human health risk. The scientific literature also shows that fallout exposure may adversely affect agricultural production (Bustad et al., 1957; Garner, 1963; Sparrow et al., 1971).

After radiation dispersed across agricultural fields plants would absorb radioactive material and animals would consume contaminated grass. This radiation then could cause sickness in animals and be secreted in animal milk. Anecdotal and legal evidence suggests that nuclear weapons fallout did harm ranchers and farm animals living downwind of the NTS. In 1954, ranchers in Iron County, UT sued the U.S. Federal Government asserting that their animals had died as a result of radioactive fallout from 1953 tests at the Nevada Test Site (NTS). The PHS and AEC actively spread disinformation regarding the dangers of radioactive pollution resulting from atomic tests. A Freedom of Information Act request in 1978 brought the dangers and the cover up to national attention (Ball, 1986; LeBaron, 1998; Fradkin, 2004). In 1979 the U.S. Interstate and Commerce Committee opened an investigation into reported incidents of animal deaths from radiation poisoning as a result of the 1953 Upshot Knothole test series. The report discussed the fact that thousands of sheep and lambs died during the spring and summer of 1953; with around 12.1% of lambing ewes and 25.4% of new lambs dying (or being born stillborn.) The report also details independent veterinary assessments identifying radiation poisoning and birth defects in the animals and the subsequent government cover-up conducted by both the Atomic Energy Commission and Public Health Service (US Government Printing Office, 1980).

Further corroborating the story of the Utah ranchers, General Electric scientists Bustad et al. (1957) studied the biological and health effects of radioactive I-131 in sheep. Starting in 1950, they fed groups of sheep varying daily doses of I-131 from .005 nCi to 1800 nCi and followed the effects across years and generations. Starting at 15 nCi animals showed growth retardation and deformities, thyroid damage, reduced fertility, trouble nursing, motor difficulty and patchy skin/balding. At higher doses researchers found that ewes that were impregnated failed to give birth to viable offspring. A comprehensive survey of the literature on the toxicity of radioactive isotopes generate from tests by Garner (1963) suggests that radioactive toxicity is greater in sheep than cattle and that relatively low amounts of exposure reduces offspring viability, increases difficulty nursing, and stunts development in sheep.

There is also scientific evidence that ionizing radiation can affect crops and that winter wheat is particularly vulnerable to damage. Radiation can hamper seedling development, weaken resilience, and cause plant sterility. Studies into how gamma and beta radiation exposure alter plant growth suggest that ionizing radiation hampers seed germination, growth, and reproduction (De Micco et al., 2011). Sparrow et al. (1971) summarize the effects of different levels of radiation for crop survival in experiments to explore the effects of a nuclear war upon agriculture. Figure 2 provides a summary of radiation sensitivity for numerous crops from their survey. They found that large radiation doses can lead to significantly diminished yields depending on the time sprouting crops are exposed. There was much heterogeneity in observed effects of radiation upon crop yields across different plant species. The main crops of interest in this paper are barley, corn, spring wheat, and winter wheat. These are major commodity crops with a broad geographic profile and would serve as the main source of agricultural revenue for many farmers. Winter wheat is particularly susceptible to harm. Irradiated winter wheat failed to survive the cold in the studies and this evidence suggests that radioactive fallout might reduce wheat's cold tolerance. Furthermore, winter wheat is planted in the fall and is harvested in the subsequent late summer or fall. This long growing period means that the crop would have had prolonged exposure to ionizing radiation. Most of the nuclear tests examined in this paper were conducted in March and April and thus radiation would land on fields when winter wheat is most vulnerable. This radiation may have stunted plants and led to crop failure. If farm fields experienced substantial fallout deposition during the period of above ground nuclear testing, then it is possible that crop yields could diminish substantially. This may have caused farmers to substitute cropland for other uses or let fields fallow. If damages were severe enough, farmers may have chosen to exit agriculture all together.

4 Data

4.1 Fallout Data

The period of domestic nuclear testing lasted from 1945 until 1992, with the United States conducting 1,030 tests in total. A total of 828 underground blasts and 100 above ground detonations occurred at the NTS (US Department of Energy, 2000). Above ground nuclear testing occurred at the site from 1951 – 1963 and ended with the signing of the Partial Nuclear Test Ban Treaty. Figures 3 and 4 provide county specific radiation deposition maps for the 1953 Upshot Knothole and 1957 Plumbbob test series for the continental United

States. There is much variation in exposure from these tests. The West Coast is upwind of the NTS and is relatively unexposed; regions surrounding the NTS would only experience dry precipitate from the tests as experimenters accounted for meteorological conditions within a few hundred km of the test sites. The overwhelming majority of the fallout landed in the eastern United States as wet precipitate, far away from the NTS (National Cancer Institute, 1997).

The U.S. Congress in 1983 authorized the Secretary of Health and Human Services to investigate and measure thyroid doses from I-131 resulting from above ground nuclear tests to American citizens. The National Cancer Institute (NCI) undertook the task of gathering radiation data from historical records and estimating exposure from tests conducted at the NTS. In 1997, NCI released a report titled the "Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests". A further feasibility study on the measurement of total fallout exposure was requested in 1998 and was carried out jointly by the CDC and NCI. The "Report on the Feasibility of a Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and other Nations" was published in 2005. The data employed here came from the I-131 deposition measures contained in the former report.

Deposition estimates exist for all tests from 1951 to 1970 with the exceptions of 3 tests in the Ranger series in 1951 and 6 tests from 1962 to 1970. These county level estimates are reported in terms of nano Curies per square meter (nCi). Much of the raw data came from national monitoring stations whose number varies across time, but never exceeded 100 stations. Figure 5 provides a map of national monitoring stations for 1953. The military also engaged in air monitoring and used city-county stations around the NTS to track the radiation cloud (National Cancer Institute, 1997). This raw data allowed researchers to track the position of the radiation cloud over time and understand how much radiation precipitated down under differing meteorological conditions. The NCI applied Kriging techniques to interpolate county level depositions for each test. Radiation would only be collected at monitoring stations when precipitation occurred. This means fallout would only land in a region if both the cloud of radioactive matter was overhead and it was raining. The NCI corrects for the efficacy of the monitoring technology used with regards to rainfall intensity. It is possible that the radioactive fallout would be positively correlated with rainfall, but there is a small window for radiation to rain out for each test. In my regressions I control for monthly precipitation and mean temperatures for the current and previous year, which controls for this potential correlation.

A key advantage of the NCI data relative to data used in the Norway or Sweden studies is that it tracks the position of the fallout cloud resulting from each originating nuclear test across time. Furthermore, the study accounts for the efficacies of monitoring technologies under different meteorological conditions. This information allowed researchers to understand not only the position of fallout clouds in the days following the test but also how much radioactive material would have been dispersed under various meteorological conditions. While the monitoring stations did not measure specific isotopes, the researchers were able to calculate the amount of radioactive material released from each test, initial yields of isotopes at detonation, and the fact that fallout particles precipitated together to back out I-131 deposition. These features make I-131 depositions measures make a suitable proxy for total radioactive fallout deposition.

4.2 Agricultural Data

Two sources of agricultural data are employed in this study. The first is yearly county level reports from the National Agricultural Statistical Service (National Agricultural Statistics Service, 2015) for the years 1940-1970. I restrict the annual sample to counties which are observed in 1950 in the NASS data to ensure that there is at least one year of observation prior to nuclear testing. The empirical analysis of the annual data examines the winter wheat and spring wheat. These crops have consistent reporting across years and a broad geographic scope. The state included in the spring wheat sample consist of ID, MT, ND, OR, SD, and WY. The states included in the winter wheat analyses consist of CA, CO, DE, ID, KS, MD, MT, OK, SD, WV, and WY. In Appendix A I examine the effects of radiation deposition on animals. Annual counts of total sheep inventories are available for NE and SD. Annual counts of sheep withheld for breeding purposes are available for IL, MN, MT, and ND. Milk per cow is available for SD and MN.

These annual data have a limited scope and only provide information on total crop output, yields, acres harvested and acres planted at the county level. I do not have annual county level counts of farms, so all outcomes in the study are aggregated to the county level. The primary use of this data is to identify the direct output reductions resulting from fallout dispersal. Price Fishback and Alex Hollingsworth provided additional data, including monthly temperature and precipitation data, interest rates, and crop prices (National Oceanic and

Atmospheric Administration, 2015).

In Appendix B I use agricultural data from the Historical U.S. Agricultural Censuses for the years 1940 to 2007 (Haines, Fishback, and Rhode 2015). This Census data come from the most comprehensive surveys of agriculture in the United States that ranges back to 1840. Starting in 1920, the Agricultural Census started conducting bidecennial surveys. I use this data to explore the effects on radioactive fallout deposition on long run outcomes and agricultural development at a national level. I examine the number of farms engaged in agriculture, allocation of farmland, and land value. I employ this information to investigate the long run adaptive responses of farmers in exposed counties. None of the Census years occurred simultaneously with nuclear testing dates at the NTS. As a result, within year effects upon investment and production decisions cannot be identified in Census records. Additional Census controls from the 1940 Census come from Haines (2010).

5 Empirical Model

The first aim of the empirical section is to identify whether radioactive matter generated from nuclear testing altered agricultural output. The second aim is to establish whether farmers responded to these output shocks. The final portion of the empirical analysis seeks to explain whether agricultural adjustments following fallout exposure were driven by agricultural policy constraints. I use the previous year's yields serve as a signal for the next year's growing conditions. I then test to see how the past year's yields affect this year's planting decision. In this analysis, I use two sources of exogenous variation in output, weather conditions and radioactive fallout deposition. Weather patterns are observable and correlated over time and variation in output from these events should differ from output changes where the underlying cause is unobserved.

The identification strategy of this paper relies upon using within county variation in fallout patterns across time. There are a number of potential challenges to this identification strategy. There is the possibility that the radiation measures could be correlated with local weather patterns. Most of the fallout deposition resulting from the tests came down as wet precipitate. This means that radiation would come down in a region if it was both raining and the radiation cloud was overhead. To control for any potential correlations with weather patterns I included monthly temperature averages and monthly precipitation totals for the current and previous year. Another challenge could be measurement error in the deposition measure. My fallout treatment variable is only positive during test years but global fallout from nuclear testing in the USSR and Pacific could be depositing in the U.S.. This global fallout would be much smaller in magnitude and diffuse relative to the NTS fallout. If global fallout were an issue it would introduce attenuation bias and bias the treatment effect of the exposure variable towards zero.

5.1 Testing Fallout Effects using Annual Data

$$\begin{split} ln(Y_{it}) = \alpha_i + \beta_0 * exposure_{it} + \beta_1 * exposure_{it-1} + \beta_2 * \Sigma_{k=2}^{5} \frac{exposure_{it-k}}{4} + \\ \beta_3 * \Sigma_{k=6}^{10} \frac{exposure_{it-k}}{5} + \chi_{it} * \theta + \gamma_t + \lambda_{it} * \phi + Trend_{it} + \epsilon_{it} \end{split} \tag{1}$$

Equation 1 represents the full specification of the regressions employed to measure how fallout from nuclear tests altered agricultural productivity. Y_{it} denotes the outcome of interest such as the bushels produced per acre planted or harvested in county i at time t for each acre planted. The main variable of interest is $exposure_{it}$. This variable measures the total I-131 deposition in County i in Year t, as thousands of nCi per square meter. I exploit variation within counties across time to identify the effects of radiation deposition upon yields. The exposure measure proxies for total fallout deposition resulting from each nuclear test series. I include deposition in the current year, previous year, average deposition between two to five years ago, and average deposition between six to ten years ago. The averaged exposure measures medium to long term effects of fallout exposure. χit denotes a vector of 12 monthly precipitation levels and 12 monthly temperature averages for county i in years t and t-1. I include lagged values of these controls since the previous year's weather can affect current year's production. λ_{it} denotes a number of controls including acres planted, state specific crop prices and 1940's demographic and county characteristic controls interacted with year indicators.[4] In the yield per acre regressions, I include log acres of wheat planted to control for possible scale effects. $Trend_{it}$ denotes state specific time trends and controls for any underlying trends in productivity or technology within states. Year fixed effects and county fixed effects are represented by γ_t and α_i respectively. ϵ_{it} denotes the heteroskedastic error term which is not observed by the researcher. Errors are clustered at the county level.

While the location of the site was not random, as it was chosen for its remote location and proximity to government labs, the tests themselves are exogenous events from the perspective of farmers. The precipitation of fallout across much of the United States can be treated as a

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[4] These controls consist of percent white, percent households with electricity, percent urban, percent of the labor force in agriculture, and percent of land as cropland. Population density, median education measures, farms per capita, and per capita retail sales are also included. Per farm controls of capital value, crop values, and farm value are also included.

quasi exogenous shock because the United States government, Atomic Energy Commission and U.S. military provided little public information regarding the tests. Persons living far away from the site would not have knowledge of where a fallout cloud might be traveling or the exact date of nuclear tests. While test planners did avoid meteorological conditions that could result in fallout in the immediate area around the base, they would have been unable to adjust test schedules for weather conditions far outside the region (NCI 1997). Public knowledge of the dangers associated with nuclear testing were fairly under developed early in the testing period at NTS. Persons living in the few counties downwind of the test site might have suspected the tests caused illness and been harmful to the environment as they could visibly link tests with radioactive dust blows. These counties are few in number in my sample. Furthermore the U.S. Department of Energy, Atomic Energy Commission and Public Health Service actively spread disinformation and covered up illnesses and animal deaths associated with radiation poisoning (US Government Printing Office 1980). It was not until the late 1970's did the public at large become aware of how dangerous atmospheric tests at the NTS were (Ball, 1986; LeBaron, 1998; Fradkin, 2004). It is unlikely that people living hundreds of miles from the test site would have been able to adequately anticipate the dangers of fallout from tests, the position of fallout clouds, or possess knowledge of how fallout precipitates down under various meteorological conditions. Farmers and ranchers whose animals resided in fields also would have been unaware of these risks to their animals. Radiation threats cannot be seen, smelled, or tasted. In order to engage in avoidance behaviors, farmers would have needed an understanding of fallout dispersal that was contemporaneously being developed by researchers. Even if the exposure variable is correlated with rainfall, the monthly precipitation and temperature controls should account for this correlative effect. Therefore $exposure_{it}$ should be orthogonal with ϵ_{it}. Appendix C presents a placebo tests to establish this orthogonality.

6 Empirical Results

Summary statistics for the regressions are available in Table 2. The NASS data exploit annual variation in radioactive fallout within counties to measure distortions caused by nuclear testing. For winter and spring wheat I test whether fallout reduced crop yields. Since these are yields per acre planted, if fallout damaged crops it is likely that farmers would have abandoned planted acreage. I then test to whether fallout reduced harvesting of cultivated acres. Then, I test to see if these damages induced farmers to alter their planting behavior in subsequent years. In Appendix A I explore the potential effects fallout may have had upon grazing animals. The scientific literature suggests that animals grazing I-131 irradiated grass experience stunted grown, reduced fertility, and decreased lactation. If radiation poisoning killed sheep or reduced offspring viability, then the effects might appear in aggregate data as decreased total populations or as increased numbers of sheep reported as withheld for breeding purposes.[5] Using data on the log number of sheep withheld for breeding purposes explores whether farmers attempted to offset the negative effects radiation had upon their herds.[6] Starting in 1954 SD began reporting pounds of milk produced at the county level and in 1955 MN followed suite. The scientific literature suggested that I-131 in sheep reduced lactation and I test whether or not this poisoning would have an effect on milk produced per dairy cow in SD and MT.

6.1 Direct NASS Annual Crop Effects

The results for wheat yields, acres harvested and acres planted are available in Tables 3 to 8 with a variety of specifications. In the discussion, I emphasize specification six, which includes the full set of controls. Radiation depositions from these tests are proxied for using the cumulative deposition of I-131 measured in nCi per m^2. The time dimension of fallout's effects are measured using the deposition in the current year, deposition in the previous year, average deposition per year between two and five years prior, and average deposition per year between six and ten years prior. The yield regressions measure reductions in plant performance and retardations in growth that might appear as a result of radioactive contamination. The log acres harvested conditioned on log acres planted regression tests whether or not reduced performance in crops led farmers to leave more crop unharvested.[7] The log acres planted regression tests whether or not farmers reduced planting of wheats in the subsequent years following fallout deposition.

Fallout from nuclear tests reduced winter wheat yields across the continental U.S.. Specification 6 in Table 3 shows that an additional 1000 nCi of I-131 deposition in the current year directly reduced yield per acre planted by a statistically significant 6.1%. This direct reduction in bushels per acre is driven in part by increased land abandonment by wheat farmers. This effect persists into the subsequent year with lagged deposition of 1000 nCi

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[5] While cattle might have been affected by fallout ingestion, the scientific literature suggests that the levels of exposure would have to be many times greater than that for sheep. I find little evidence that radioactive fallout deposition affected cattle populations.

[6] Only a few states in the 1950's reported annual county level counts of livestock. This limits the geographic scope of the animal regressions to IL, MN, ND and MT.

[7] This regression specification is equivalent to running a regression on the log share of planted acres harvested.

causing a statistically significant reduction in yields by 2.9%. In Table 4 an additional 1000 nCi of I-131 deposition in the current year and prior year increased the percentage of planted acres left unharvested by 3.4% and 2.1% respectively. The direct effects of radiation upon spring wheat yields is much weaker than for winter wheat. Specification 6 in Table 6 reports the effect of fallout deposition in a county upon spring wheat yields. An additional 1000 nCi of I-131 deposition in the current year reduced yield per acre planted by 1.7% but the effect is not statistically significant. I do find that radiation did cause a statistically significant increase in abandoned spring wheat acreage. In specification 6 in Table 7, I find that a 1000 nCi deposition would increase crop abandonment by 1.4%.

6.2 Response to Output Shocks in NASS Annual Data

In Table 5, I find that fallout deposition in the previous year had consistently positive effect upon winter wheat planting in the current year. The statistical significance of this effect attenuates with the inclusion of regional controls interacted with year indicators. This increase in cultivated acreage ranges from an insignificant 2.5% to a statistically significant 7.4% for a 1000 nCi deposition. The coefficients for average exposure two to five years ago and six to ten years ago are consistently negative and insignificant. This results suggests that farmers attempted to counteract the negative effect of wheat failure in the previous year by increasing the amount of acreage cultivated in the subsequent year. Farmers could both be hedging against possible crop failure in the future and trying to counter act the effect of the policy constraint. If the farmer believes that wheat failure might persist into the future then over planting wheat becomes more salient given the policy constraints. In Table 8 I report the effects of fallout exposure upon spring wheat planting. An average of 1000 nCi of I-131 deposition in the previous year, between two and five years prior, and between six and ten years prior would lead to statistically significant reductions of spring wheat acreage planted by 6.6%, 16.6%, and 11% respectively. These results suggest that irradiated counties reduced spring wheat planting rather than winter wheat. This results could point to a possible liquidity constraint and might suggest that as wheat allotments become more restrictive farmers in irradiated counties opted to plant wheat varieties that allowed them greater flexibility under farm regulation.

In irradiated counties, farmers tended to decrease the amount of cultivated wheat that they abandoned following fallout exposure events. This behavior increased yields per acre planted in the years following fallout exposure. These results could also suggest that farmers are moving marginal acreage out of wheat production as the policy constraint binds more tightly. For winter wheat these effects might be the result of adaptive responses to damage by farmers, but the results are sensitive to the inclusion of state specific time trends. For winter wheat an average of 1000 nCi of exposure between two and five years before, and between six and ten years before increased yields per acre by 9.3% and 6.9%. This increase in yield can in part be explained by decreases in abandoned winter wheat acreage. An average of 1000 nCi of exposure between two and five years prior, and between six and ten years prior increased harvesting of planted acreage 4.7% and 3.4% respectively. Only the latter effect is statistically significant and the statistical significance of exposure on winter wheat yields and harvesting behaviors two to ten years in the future is sensitive to the inclusion of state specific time trends. A similar result appears with spring wheat but only in response to radiation damage from the previous year. Specification 6 in Table 6 reports the effect of fallout deposition in a county upon spring wheat yields. An additional 1000 nCi of fallout in the previous year increase yields by 4.9% and is robust across specifications. This results is consistent with the scenario that wheat farmers attempted to counteract the effects wheat abandonment due to radioactive fallout. By harvesting more acreage in the years following the crop failure event, farmers are attempting to maintain (or expand) their base acreage. For spring wheat, there is some evidence of increased yields six to ten year following exposure with 1000 nCi causing a 5.1% increase in yields. These result is in part driven by reductions in spring wheat acreage and increases in acres harvested. Unlike winter wheat, spring wheat yields also appear sensitive to acreage planted. A 10% decrease in spring wheat acreage increasing yields by 0.9%. Specification 6 in Table 7 shows farmers increased acres harvested in response to fallout exposure previous year, between two and five years prior, and between six and ten years prior. An average 1000 nCi of I-131 deposition caused a statistically significant increase in acres harvested by 3.3%, 5.7%, and 2.8% in each period.

6.3 Effect of Yields on Future Winter Wheat Planting

In this section I study how farmers adjust their planting decisions in response to wheat yields. In this section, I perform 2SLS and instrument for winter wheat yields using weather variables and radiation deposition. Both weather conditions and radioactive fallout affect winter wheat productivity. Variation in wheat productivity due to weather affects both farm income and provides the farmer information about future growing conditions. Furthermore, farm policy took into account weather conditions when determining acreage allotments (Cochrane and Ryan, 1976). Radioactive fallout affects output but is an unobservable variable to the farmer.

$$ln(YPA_{it-1}) = \theta_0 * Z_{it-1} + X_{it-1}\beta + \alpha_i + \gamma_t + \epsilon_{it-1} \tag{2}$$

In the first stage of the regression the exogenous instrument Z_{it-1} represents weather variables or radiation deposition. County and year fixed effects are denoted by α_i and γ_t. Control variables of wheat prices, acreage planted in the previous year, and state specific time trends are denoted by X_{it-1}.

$$ln(Acres_{it}) = \phi_0 * ln(YPA_{it-1}) + X_{it-1}\beta + \alpha_i + \gamma_t + \mu_{it} \tag{3}$$

The second stage reports the effect of yields in the previous year upon acres of winter wheat planted. Table 9 reports the results of a panel regression, 2SLS using weather instruments, and 2SLS using radiation exposure. There is a statistically significant relationship between yield per acre planted and acres planted in the subsequent year. When I instrument for yields using variation in weather, a similar result appears. This is an intuitive result if weather and wheat productivity is correlated across years. Variation in winter wheat yields from radioactive fallout deposition has the opposite effect on wheat acreage in the subsequent year. This result suggests that if wheat yields decrease, acreage increases in the subsequent year. This evidence suggests that wheat farmers respond differently to a pure output shock when it is separated from an informative signal. This particular response in planted acreage happens for winter wheat due to policy constraints that regulate base acreage. If a farmer abandons damaged acreage in one year and it is not due to weather, his or her future stream of income might suffer and thus counteracting this negative shock becomes more salient.

6.4 Quantifying the Magnitude of the Effects

In this section I calculate the magnitude of the effects that appeared in the previous section using back of the envelope calculations. I take the relevant coefficients from specification 6 in the regressions and multiply them by the I-131 exposure to get a causal treatment effect. I created county level planting and yield per acre planted counterfactuals for each county. These values are the average of the available data between 1940 and 1950. Some counties do have data for that entire decade so the average is constructed from what data was available. I then added up changes across counties across years. Yearly real state level prices in 2016$ for crops were used to place a value on the damages and distortions. In my samples in 1950, 5.3 million acres of barley were planted and 124 million bushels produced. For corn in 1950, 25 million acres of were planted and 925 million bushels of corn produced. For spring wheat in 1950, 14 million acres were planted and 211 million bushels were produced. For winter wheat in 1950, 27 million acres were planted and 332 million bushels produced.

Equation 4 describes how I calculated the direct reductions in output. Equation 5 calculates how much radioactive pollution altered land allocations. Using the coefficients from the most restrictive specifications, specification 6 in the regression tables, I calculated the direct and indirect effects of radioactive fallout in the NASS samples for the years 1950 to 1970. Below are a number of equations explaining how I calculated my back of the envelope estimates regarding output and planting changes.

$$\begin{aligned} &DirectOutputReduction = \Sigma_i \Sigma_t \\ &(1 - exp(\beta_{exposure})) * Exposure_{it} * Y\bar{P}A_i * AcresPlanted_{it} \end{aligned} \tag{4}$$

$$\begin{aligned} &EffectonAcresPlanted = \Sigma_i \Sigma_t ((1 - exp(\beta_{1,exposure})) + \\ &(1 - exp(\beta_{2,exposure})) * AvgExposure_{it-2,it-5}) * Acres\bar{P}lanted_i \end{aligned} \tag{5}$$

I took the coefficients from specification 6 of the equations of interest, multiplied them by the exposure measure for each county year observation and summed up the effect over all the counties and sample years. $Y\bar{P}A$ and $Acres\bar{p}lanted$ are the average values for yields per acre planted and acres planted in each county for years 1940 to 1950. Using this method I find that radiation exposure in the current year directly led to a reduction of 71 million bushels of winter wheat, which would have been worth $1.3 billion in 2016$. The cumulative effect of fallout upon winter wheat production in the subsequent year suggests that radiation reduced wheat production by 35 million bushels and led to 25 million acres to be abandoned. This lost output would be valued at $606 million in 2016$. In irradiated counties farmers planted 13 million fewer acres of spring wheat. My results also suggest that farmers boosted yields of spring wheat and winter wheat in the years following fallout damage. This rebound effect is in part due to increased harvesting of cultivated acreage following fallout exposure and would imply a increase in output of 170 million bushels of winter wheat and 42 million bushels of spring wheat in the years following radiation damage. The rebound effect for winter wheat is based on coefficients that are sensitive to state specific time trends but the effect for spring wheat is robust across specifications.

7 Conclusion

Nuclear testing appears to have had broader economic consequences than previously known. Economic damages materialized in a sample that was substantially further away from the test site than what would be typically considered downwind and back of the envelope calculations suggest that these damages were in the hundreds of millions of dollars. Radiation exposure proxied for by I-131 depositions suggest sizable reductions in bushels of wheat harvested for each acre planted, resulted in greater field abandonment, and led farmers to reduce spring wheat planting. U.S. farm policy guided the responses made by farmers to fallout induced damage. Farmers responded to changes in wheat output due to fallout differently than when output changes were due to weather. By disentangling the effect of output from potential informative signals regarding future weather conditions, I show that U.S. farm regulations guided adjustments made by farmers. Farmers cultivated more winter wheat acreage to offset the negative effect of crop abandonment in the previous year.

Employing a unique dataset I have explored some adaptive responses to negative productivity shocks where the threat is unanticipated and unobservable. This adds to the current research into the resilience of the agricultural sector and has implication for climate change adaptation. Previous research has shown that adaptation plays a limited role in economic adjustment when there is a permanent decline in land productivity. In this paper, I examined a transitory shock to agricultural productivity and show that farmers adjust their behavior in response to damage caused by an unobservable factor. I find evidence that unlike weather shocks

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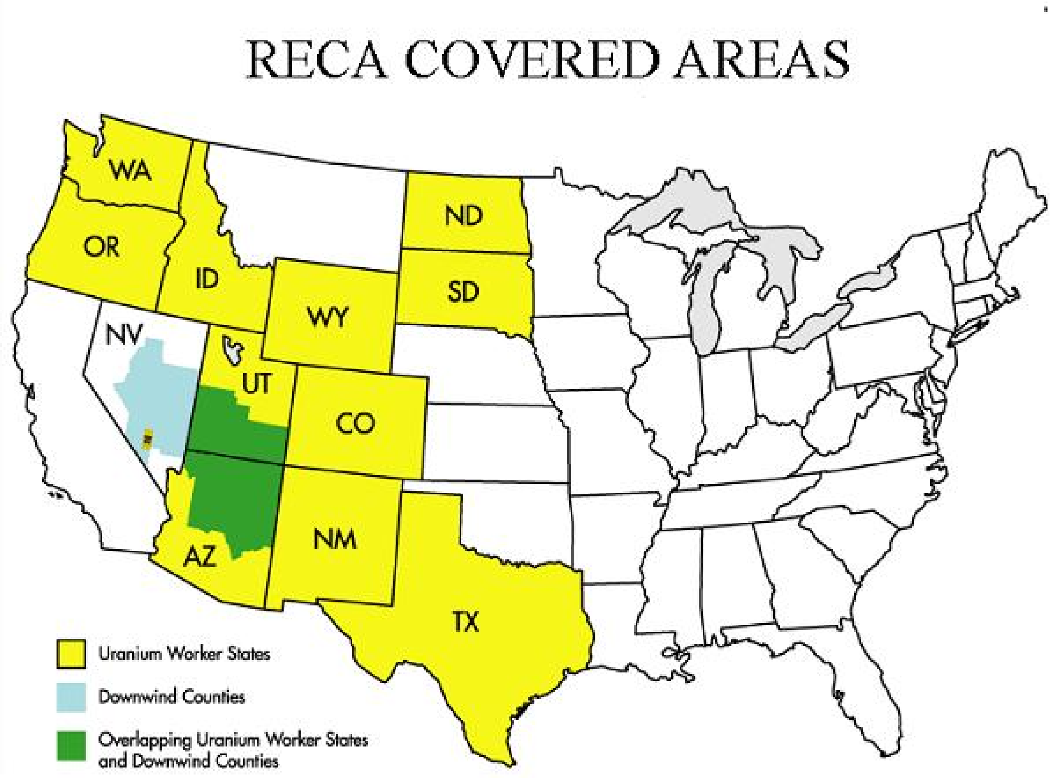
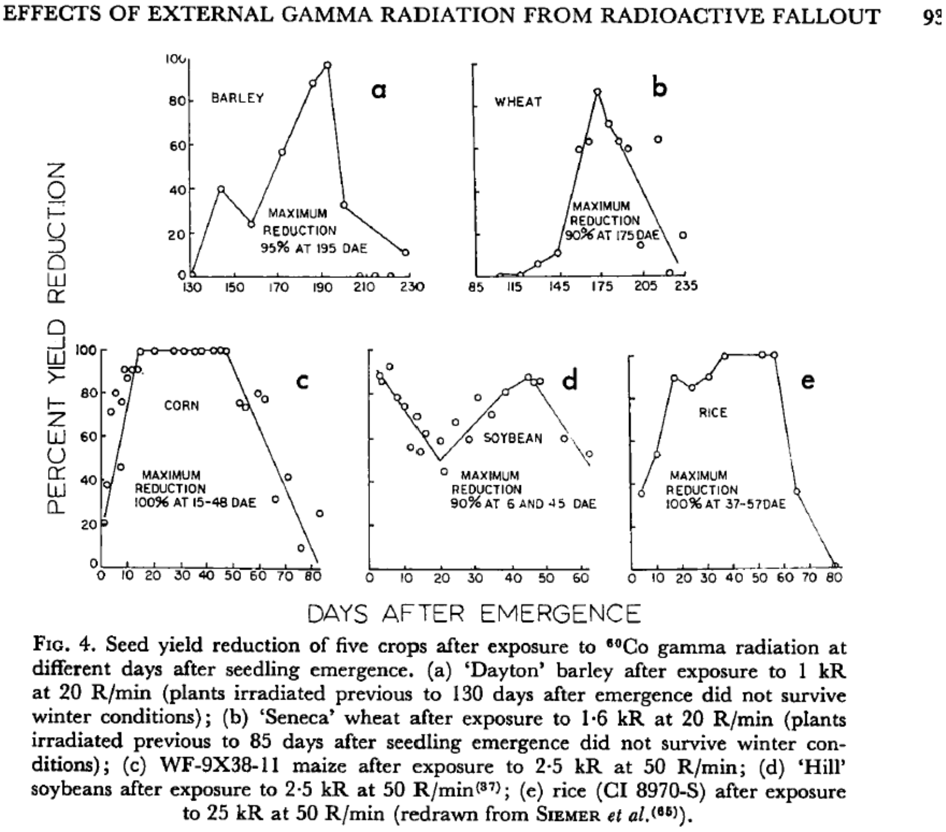


Figure 1: Radiation Exposure Compensation Act compensated areas.



EFFECTS OF EXTERNAL GAMMA RADIATION FROM RADIOACTIVE FALLOUT 9

Fig. 4. Seed yield reduction of five crops after exposure to ^{60}Co gamma radiation at different days after seedling emergence. (a) 'Dayton' barley after exposure to 1 kR at 20 R/min (plants irradiated previous to 130 days after emergence did not survive winter conditions); (b) 'Seneca' wheat after exposure to 1·6 kR at 20 R/min (plants irradiated previous to 85 days after seedling emergence did not survive winter conditions); (c) WF-9X38-11 maize after exposure to 2·5 kR at 50 R/min(87); (d) 'Hill' soybeans after exposure to 2·5 kR at 50 R/min(87); (e) rice (CI 8970-S) after exposure to 25 kR at 50 R/min (redrawn from Siemer *et al.*(65)).

Figure 2: Gamma Radiation Exposure and Crop Yields. Sparrow, Schwemmer, and Bottino (1971)

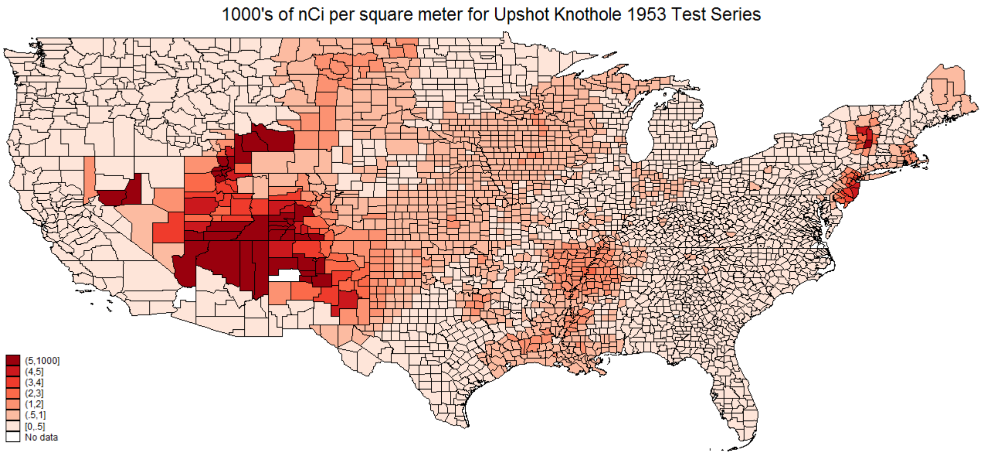


Figure 3: Thousands of nanoCuries of I-131

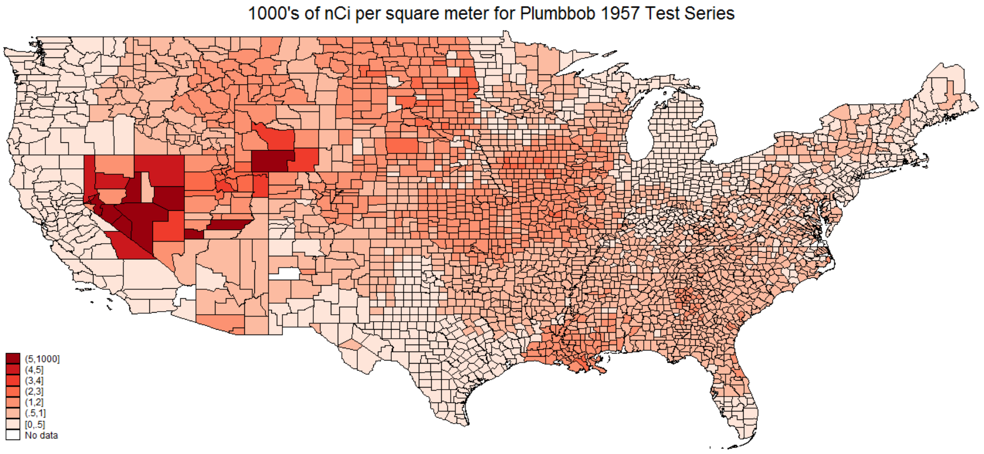


Figure 4: Thousands of nanoCuries of I-131

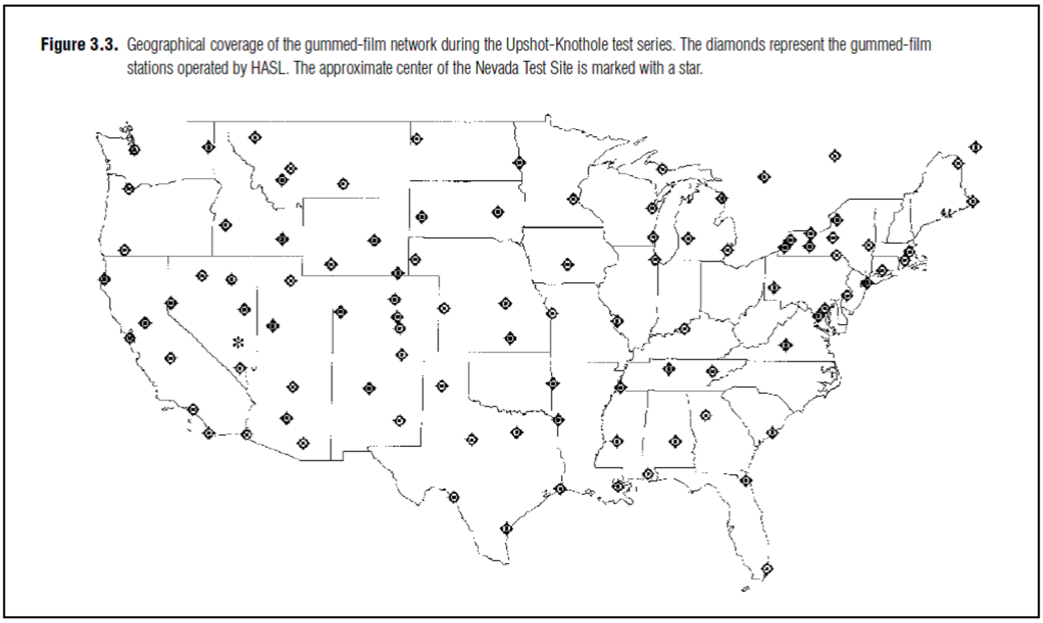


Figure 3.3. Geographical coverage of the gummed-film network during the Upshot-Knothole test series. The diamonds represent the gummed-film stations operated by HASL. The approximate center of the Nevada Test Site is marked with a star.

Figure 5: Map of National Radiation Monitoring Stations 1953. NCI (1997)

Table 1: Scientific and Theoretical Predictions

Scientific Predictions	
Barley	- acute irradiation might decrease yields. - Barley sown in spring is less vulnerable to damage than barley sown in fall. - NASS sample includes only spring sown barley.
Spring Wheat	- acute irradiation might decrease yields, wheat sown in spring is less vulnerable to damage.
Winter Wheat	- acute irradiation might decrease yields, wheat sown in fall is more vulnerable to damage. - Frost and cold damage coupled with irradiation might increase the chance of crop failure.
Sheep Populations	- Ingestion of I-131 contaminated grass can decrease fertility, stunt growth, and offspring viability - Increased I-131 presence might decrease flock size and cause farmers to withhold sheep from market
Milk Production	- I-131 poisoning in sheep decreased lactation and led to trouble with animal nursing - I-131 might decrease dairy cow productivity

Theoretic Model of Short Run Land Allocation Predictions	
No Policy Constraint	**Policy Constraint on Conditional on planting/harvesting**
Farmers do not adjust planting of wheat or other crops	Farmers temporarily increase planting of wheat, farmers increase harvesting of wheat.

Table 2: Summary Statistics: NASS Crop Samples

Winter Wheat Sample Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
I-131 Exposure	14476.00	0.10	0.38	0.00	6.58
Avg Exp. 2-5 Yrs Prior	14476.00	0.10	0.22	0.00	2.94
Avg Exp. 6-10 Yrs Prior	14476.00	0.10	0.20	0.00	2.35
Yield Per Acre, bu	14476.00	19.49	10.20	0.16	86.00
Acres Planted	14476.00	52527.60	77460.32	10.00	615000.00
Acres Harvested	14476.00	45456.19	68430.79	10.00	586000.00

Spring Wheat Sample Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
I-131 Exposure	9242.00	0.11	0.45	0.00	7.84
Avg Exp. 2-5 Yrs Prior	9242.00	0.11	0.25	0.00	2.94
Avg Exp. 6-10 Yrs Prior	9242.00	0.11	0.23	0.00	2.35
Yield Per Acre, bu	9242.00	19.37	10.37	0.30	75.11
Acres Planted	9242.00	38840.27	62950.33	10.00	418600.00
Acres Harvested	9242.00	37197.41	60962.20	10.00	410200.00

I-131 Exposure is measured as 1000 nCi deposited per m^2

Table 3: Log Yield Per Acre Planted, bu Winter Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	-0.000000772	-0.000687	0.00959	0.00513	0.00588	0.00249
	(0.0105)	(0.0100)	(0.00975)	(0.00912)	(0.00912)	(0.00877)
Exposure	-0.113***	-0.0953***	-0.0643***	-0.0477***	-0.0732***	-0.0627***
	(0.0184)	(0.0174)	(0.0165)	(0.0160)	(0.0173)	(0.0168)
Exposure Last yr	-0.0154	-0.00281	-0.0455***	-0.0368***	-0.0342**	-0.0295**
	(0.0139)	(0.0140)	(0.0136)	(0.0132)	(0.0149)	(0.0146)
Avg Exp 2-5 yrs prior	-0.00803	0.0648**	-0.00297	0.0689**	0.0363	0.0895***
	(0.0284)	(0.0305)	(0.0265)	(0.0273)	(0.0299)	(0.0314)
Avg Exp 6-10 yrs prior	-0.170***	-0.0579*	-0.0609*	0.0606**	-0.00377	0.0672**
	(0.0315)	(0.0306)	(0.0321)	(0.0306)	(0.0324)	(0.0317)
Wheat Price Last yr	-0.00116	-0.00606***	0.000608	-0.00637***	0.000557	-0.00617***
	(0.000799)	(0.000983)	(0.000805)	(0.000952)	(0.00106)	(0.00122)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	14476	14476	14463	14463	14463	14463
Adjusted r^2	0.264	0.287	0.373	0.395	0.461	0.475

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Log Acres Harvested, Winter Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	0.987***	0.979***	0.989***	0.983***	0.987***	0.983***
	(0.00611)	(0.00571)	(0.00580)	(0.00535)	(0.00553)	(0.00526)
Exposure	-0.0522***	-0.0486***	-0.0261***	-0.0227**	-0.0375***	-0.0342***
	(0.0105)	(0.0102)	(0.00953)	(0.00939)	(0.00979)	(0.00979)
Exposure Last Yr	-0.00829	-0.00560	-0.0217***	-0.0213***	-0.0239***	-0.0215***
	(0.00618)	(0.00624)	(0.00617)	(0.00625)	(0.00731)	(0.00734)
Avg Exp 2-5 yrs prior	-0.00792	0.00876	0.000851	0.0240*	0.00542	0.0260
	(0.0132)	(0.0141)	(0.0133)	(0.0138)	(0.0167)	(0.0170)
Avg Exp 6-10 yrs prior	0.000121	0.0277**	0.0157	0.0462***	0.0173	0.0341**
	(0.0128)	(0.0134)	(0.0128)	(0.0136)	(0.0155)	(0.0160)
Wheat Price Last yr	-0.00120***	-0.00236***	-0.00170***	-0.00303***	-0.00119**	-0.00266***
	(0.000375)	(0.000492)	(0.000402)	(0.000476)	(0.000553)	(0.000621)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	14476	14476	14463	14463	14463	14463
Adjusted r^2	0.874	0.876	0.884	0.886	0.894	0.895

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Log Acres Planted, Winter Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	0.0532**	0.0577***	0.0712***	0.0601***	0.0266	0.0248
	(0.0206)	(0.0210)	(0.0215)	(0.0217)	(0.0202)	(0.0198)
Avg Exp 2-5 yrs prior	-0.00632	0.0168	-0.0491	-0.00990	-0.148**	-0.0845
	(0.0648)	(0.0660)	(0.0645)	(0.0658)	(0.0649)	(0.0641)
Avg Exp 6-10 yrs prior	-0.134	-0.139	-0.101	-0.127	-0.113	-0.0728
	(0.0886)	(0.0851)	(0.0919)	(0.0879)	(0.0924)	(0.0864)
Wheat Price Last yr	0.0173***	0.00765***	0.0186***	0.00616***	0.0178***	0.00653***
	(0.00192)	(0.00104)	(0.00215)	(0.00119)	(0.00251)	(0.00145)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	14476	14476	14463	14463	14463	14463
Adjusted r^2	0.0783	0.147	0.0944	0.157	0.181	0.215

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Log Yield Per Acre Planted, bu Spring Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	-0.0273***	-0.0561***	-0.0614***	-0.0732***	-0.0775***	-0.0853***
	(0.00997)	(0.0109)	(0.00943)	(0.0102)	(0.00978)	(0.0100)
Exposure	-0.00658	0.00442	-0.000631	0.000295	-0.0175	-0.0167
	(0.0145)	(0.0137)	(0.0134)	(0.0135)	(0.0136)	(0.0137)
L.Exposure	0.0412***	0.0448***	0.0560***	0.0563***	0.0489***	0.0475***
	(0.0111)	(0.0110)	(0.0114)	(0.0114)	(0.0133)	(0.0135)
Avg Exp 2-5 yrs prior	0.0188	0.0356	0.0319	0.0303	0.0218	0.0148
	(0.0321)	(0.0307)	(0.0315)	(0.0308)	(0.0294)	(0.0297)
Avg Exp 6-10 yrs prior	0.0639**	0.0597**	0.111***	0.119***	0.0666**	0.0493*
	(0.0268)	(0.0256)	(0.0277)	(0.0277)	(0.0278)	(0.0279)
Wheat Price Last yr	-0.00210*	-0.00852***	0.000431	-0.00347***	0.000123	-0.00344**
	(0.00108)	(0.00140)	(0.00111)	(0.00132)	(0.00121)	(0.00136)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	9242	9242	9229	9229	9229	9229
Adjusted r^2	0.281	0.306	0.458	0.462	0.540	0.543

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Log Acres Harvested, Spring Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	0.988^{***}	0.975^{***}	0.977^{***}	0.971^{***}	0.970^{***}	0.965^{***}
	(0.00480)	(0.00547)	(0.00473)	(0.00523)	(0.00509)	(0.00540)
Exposure	-0.0208^{***}	-0.0157^{**}	-0.00792	-0.00693	-0.0142^{**}	-0.0140^{**}
	(0.00780)	(0.00746)	(0.00687)	(0.00679)	(0.00683)	(0.00678)
Exposure Last Yr	0.00923^{**}	0.0113^{**}	0.0271^{***}	0.0259^{***}	0.0334^{***}	0.0322^{***}
	(0.00460)	(0.00466)	(0.00503)	(0.00494)	(0.00649)	(0.00648)
Avg Exp 2-5 yrs prior	0.0379^{***}	0.0519^{***}	0.0545^{***}	0.0670^{***}	0.0509^{***}	0.0553^{***}
	(0.0103)	(0.0111)	(0.0112)	(0.0123)	(0.0143)	(0.0150)
Avg Exp 6-10 yrs prior	0.0126	0.0295^{***}	0.0320^{***}	0.0511^{***}	0.0230	0.0272^{*}
	(0.00978)	(0.0105)	(0.0107)	(0.0118)	(0.0142)	(0.0148)
Wheat Price Last yr	-0.00257^{***}	-0.00572^{***}	-0.00117^{**}	-0.00332^{***}	-0.00134^{**}	-0.00369^{***}
	(0.000556)	(0.000825)	(0.000550)	(0.000736)	(0.000611)	(0.000789)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	9242	9242	9229	9229	9229	9229
Adjusted r^2	0.961	0.962	0.966	0.966	0.969	0.969

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Log Acres Planted, Spring Wheat

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	-0.0614***	-0.0521**	-0.0398*	-0.0484**	-0.0615**	-0.0685***
	(0.0222)	(0.0217)	(0.0234)	(0.0225)	(0.0248)	(0.0231)
Avg Exp 2-5 yrs prior	-0.136**	-0.0587	-0.120*	-0.0573	-0.223***	-0.182***
	(0.0656)	(0.0664)	(0.0639)	(0.0645)	(0.0663)	(0.0628)
Avg Exp 6-10 yrs prior	-0.215***	-0.0830	-0.203***	-0.0424	-0.185***	-0.117*
	(0.0687)	(0.0639)	(0.0704)	(0.0660)	(0.0707)	(0.0683)
Wheat Price Last yr	0.00987***	-0.00630***	0.0121***	-0.00156	0.0189***	0.000468
	(0.00242)	(0.00160)	(0.00256)	(0.00167)	(0.00338)	(0.00237)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	9242	9242	9229	9229	9229	9229
Adjusted r^2	0.449	0.511	0.468	0.520	0.528	0.566

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Effect of Log Yields on Log Acres Planted , Winter Wheat

	(1) Log Acres	(2) Log Acres	(3) Log Acres
L.Log Acres	0.702***	0.702***	0.704***
	(0.0136)	(0.00592)	(0.00644)
L.Log YPA	0.137***	0.152***	-0.228*
	(0.0110)	(0.0228)	(0.135)
Year_FE	Yes	Yes	Yes
County_FE	Yes	Yes	Yes
Weather_Controls			
State_Time_Trends	Yes	Yes	Yes
Weather_Instruments	No	Yes	No
Fallout_Instrument	No	No	Yes
N	14323	14310	14323

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A I-131 Fallout's Effects on Sheep Populations and Dairy Productions

Populations of grazing animals likely suffered due to direct exposure to radioactive isotopes. Scientists have shown that fairly low levels of radioactive iodine exposure can retard growth and development of sheep, lower animal fertility and reduce the viability of offspring. The annual NASS data for sheep covers states that did not receive many large depositions, so the effects of radiation poisoning would likely be less pronounced. Regression results for sheep herds are in Tables 11 and 12. The inclusion of robust controls removes much of the statistical significance for these regression but the patterns across specifications are consistent. Nevertheless, changes in total sheep populations in NE and SD counties observed in response to radiation depositions are consistently negative across all measures of lagged exposure. In specification 6, an average of 1000 nCi of deposition last year ago would reduce sheep populations but 5.4% in the county. Similarly, radiation induced farmers to increase the number of sheep withheld for breeding purposes. 1000 nCi of deposition in the previous year would increase the number of sheep withheld for breeding by 3.5%. If dairy cows grazed irradiated milk in MN and SD then it might have reduced dairy production. Specifications 1 to 4 show that increased radiation deposition caused statistically significant reductions of lbs. of milk produced per dairy cow. The effect attenuates with the inclusion of regional controls to an insignificant reduction in dairy output per cow of 1.3%. These results support the scenario that relatively modest levels of I-131 stunted the growth of sheep, reduced fertility, or offspring viability. Farmers withheld sheep from market as an adaptive response to fallout. There is also evidence that radiation deposition had direct effects upon dairy production, which was a particularly important I-131 exposure channel for humans.

Table 10: Summary Statistics: NASS Animal Samples

Sheep Inventory Sample NE & SD

Variable	Obs	Mean	Std. Dev.	Min	Max
I-131 Exposure	4929.00	0.09	0.28	0.00	3.09
Avg Exp. 2-5 Yrs Prior	4930.00	0.09	0.16	0.00	0.99
Avg Exp. 6-10 Yrs Prior	4930.00	0.09	0.15	0.00	0.80
Number of Sheep	4930.00	14448.30	29479.41	10.00	393000.00

Sheepwithheld for Breeding Sample, IL, MN, MT, ND

Variable	Obs	Mean	Std. Dev.	Min	Max
I-131 Exposure	2481.00	0.06	0.26	0.00	2.26
Avg Exp. 2-5 Yrs Prior	2481.00	0.13	0.16	0.00	0.99
Avg Exp. 6-10 Yrs Prior	2481.00	0.13	0.14	0.00	0.80
Lbs Milk Per Cow	2481.00	6285.79	1821.30	1333.33	13835.62

Dairy Production Sample, MN & SD

Variable	Obs	Mean	Std. Dev.	Min	Max
I-131 Exposure	8704.00	0.08	0.26	0.00	3.14
Avg Exp. 2-5 Yrs Prior	8704.00	0.08	0.14	0.00	0.81
Avg Exp. 6-10 Yrs Prior	8704.00	0.08	0.13	0.00	0.76
N. Sheep Held For Breeding	8704.00	12500.09	20727.05	100.00	217000.00

I-131 Exposure is measured as 1000 nCi deposited per m^2

Table 11: Log Number of Sheep in Inventory, NE & SD

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	-0.0977**	-0.0957**	-0.0831**	-0.0849**	-0.0588	-0.0552
	(0.0387)	(0.0386)	(0.0388)	(0.0389)	(0.0432)	(0.0426)
Avg Exp 2-5 yrs prior	-0.375**	-0.365**	-0.264*	-0.266*	-0.231	-0.227
	(0.145)	(0.148)	(0.152)	(0.153)	(0.162)	(0.162)
Avg Exp 6-10 yrs prior	-0.294	-0.278	-0.180	-0.188	-0.208	-0.195
	(0.202)	(0.205)	(0.215)	(0.218)	(0.204)	(0.206)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
N	4930	4930	4930	4930	4930	4930
Adjusted r^2	0.357	0.357	0.362	0.362	0.454	0.455

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Log Number of Sheep withheld for Breeding, IL, MN, MT, & ND

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	0.0677***	0.0649***	0.0733***	0.0677***	0.0429**	0.0348*
	(0.0191)	(0.0187)	(0.0199)	(0.0193)	(0.0193)	(0.0187)
Avg Exp 2-5 yrs prior	0.0243	0.0264	-0.0520	-0.0354	-0.0711	-0.122
	(0.101)	(0.102)	(0.100)	(0.0999)	(0.110)	(0.107)
Avg Exp 6-10 yrs prior	0.00713	0.0419	-0.00314	0.0145	-0.0343	-0.123
	(0.114)	(0.112)	(0.111)	(0.110)	(0.115)	(0.113)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
N	8704	8704	8703	8703	8703	8703
Adjusted r^2	0.508	0.537	0.529	0.553	0.634	0.643

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Log lbs Milk Per Dairy Cow, MN & SD

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	-0.0671***	-0.0526***	-0.0556**	-0.0482**	-0.0318	-0.0133
	(0.0208)	(0.0202)	(0.0217)	(0.0218)	(0.0248)	(0.0243)
Avg Exp 2-5 yrs prior	-0.244***	-0.207**	-0.126	-0.114	-0.0148	-0.0227
	(0.0833)	(0.0812)	(0.0774)	(0.0761)	(0.0757)	(0.0759)
Avg Exp 6-10 yrs prior	-0.0522	-0.0564	0.00461	-0.00831	0.164*	0.113
	(0.0794)	(0.0802)	(0.0914)	(0.0939)	(0.0933)	(0.0958)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
N	2481	2481	2481	2481	2481	2481
Adjusted r^2	0.663	0.665	0.682	0.682	0.739	0.748

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B Agricultural Census Panel Regressions

B.1 Testing Fallout Effects Using Census Data

$$ln(Y_{it}) = \alpha_i + \Sigma_{j=0}^{J}\beta_j * CumulativeExposure_{it-j} + \gamma_t + Trend_{it} + \chi_{it} * \theta + \epsilon_{it} \tag{6}$$

Equation 6 seeks to measure changes in long run agricultural production using a panel constructed from U.S. Agricultural Census data for the years 1940 to 2007. It is a distributed lag model with J lags and time and county fixed effects. $CumulativeExposure_{it}$ measures the total cumulative deposition of I-131 for the five year periods between Census years. In the analysis I show the impact of deposition for the half decades from 0-5, 6-10, 11-15, 16-20, 21-25, 21-25, and 26-30 years earlier. χ_{it} denotes county specific 1940 Census characteristics interacted with Census year indicators. [8] Additional weather controls include monthly temperature and precipitation averages between Censuses. $Trend_{it}$ denotes state specific time trends. α_i and γ_t, denote county and Census year fixed effects. ϵ_{it} is the heteroskedastic error term clustered at the county level. The outcomes of interest tested, Y_{it} for county i in Census year t include the average size of farm, number of farms, land value per acre, share of agricultural land used as cropland, and share of agricultural land as pastured cropland.

B.2 Census Regression Results

It is possible that these disruptions to output, though temporary, altered the production and investment decisions of farmers. Hornbeck (2012) showed that erosion during the Dust Bowl permanently lowered agricultural productivity in much of the Plains States. This decreased productivity manifested in permanently lowered land values and shifts in agricultural land from crop production towards pasture. In this section I report changes in agriculture using a Census Panel from 1940 to 2007. I use a fixed effects framework with four distributed lags for cumulative I-131 deposited between Censuses to measure whether or not radiation deposition resulting directly from the Nevada Test Site caused permanent changes in agricultural production in the West. I test whether cumulative radiation deposition from tests reduced land values, led to farm closures, changed the size of remaining farms, and altered the allocation of farmland. The results in this section cover more states than the NASS samples.

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[8] These controls consist of percent white, percent households with electricity, percent urban,and percent of the labor force in agriculture. Population density, median education measures, and per capita retail sales are also included. Per farm controls of capital value and crop values are also included.

The preferred specification for the Agricultural Censuses regressions are specification 6. The results of these regressions are provided in Tables 15 to 19. On a national scale, fallout from nuclear tests did not have a significant effect upon agricultural land values. The only exception is exposure ten to fifteen years prior appears to have a consistent and statistically significant effect. A 1000 nCi deposition would imply a reduction in land value per acre of 0.94%. There is also evidence that areas that experienced substantial radiation depositions had decreased numbers of farms relative to areas that did not experience fallout. These results attenuate with the inclusion of state specific time trends, nevertheless the coefficients are jointly significant. Exposure 0-5, 6-10, 11-15, 16-20, and 21-25 years prior suggest that 1000 nCi of deposition would decrease the number of farm operations by 0.45%, 0.21%, 0.40%, and 0.27%. The effect of fallout exposure 0-5 and 11-15 years ago statistically significant in specification 6. There is strong evidence that farms in irradiated counties became larger on average relative to farms in less irradiated counties. Exposure between 0-5, 6-10, 11-15, 16-20, and 21-25 years prior suggest that 1000 nCi of deposition would have caused an increase in average farm size of 0.9%, 1.2%, 1.6%, 1.4%, and 1.4%. If the income shocks from radiation induced damage caused some farmers chose to liquidate their farms, it is likely that the remaining farmers opted to purchase the agricultural land. I find that farmers dedicated less farmland toward crop production in irradiated counties with exposure between 0-5, 6-10, 11-15. and 21-25 years prior suggest fallout exposure led to statistically significant declines in the share of farmland allocated towards crops. A 1000 nCi deposition would imply declines in cropland shares of 1.46%, 1.9%, and 1.1%. Similarly, I find a consistently negative and statistically significant reduction in the share of arable pasture 16-20 and 21-25 year following fallout exposure. 1000 nCi of deposition would cause a reduction in the share of arable pasture of 1.1% and 2.1% respectively.

These two results suggest that irradiated counties moved away from producing crops in the decades following nuclear testing and radiation exposure. If the income shocks caused by radiation damage to crops were large enough, it is plausible that farmers would exit the agricultural sector. Throughout the 20th Century, there was a secular decline in the number of farms and individuals working in agriculture. If farmers in irradiated counties ceased working land it's quite plausible the arable land would not be in production in the long run as it's unlikely there would be new farmers coming into agricultural sector to put this land back into production.

Table 14: Summary Statistics: U.S. Agricultural Censuses 1940-2007

Variable	Obs	Mean	Std. Dev.	Min	Max
Number Farms	45393.00	1071.96	961.56	0.00	13114.00
Land Value Per Acre	45291.00	909.82	3691.10	0.00	457143.00
Avg Farm Size	45358.00	671.96	2204.72	0.00	131080.40
Share Pastured Cropland	45384.00	0.05	0.06	0.00	0.62
Share Cropland	45384.00	0.23	0.22	0.00	0.99
Cumulative I-131 Deposition Between Censuses	45391.00	0.16	0.60	0.00	43.96

I-131 Exposure is measured as 1000 nCi deposited per m^2

Table 15: Census Panel 1940-2007: log Number of Farms

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative I-131 Exposure, 0-5 yrs prior	-0.0437***	-0.00409*	-0.0229***	-0.00272	-0.0212***	-0.00450*
	(0.00814)	(0.00235)	(0.00524)	(0.00227)	(0.00446)	(0.00269)
Cumulative I-131 Exposure, 6-10 yrs prior	-0.0240***	0.000904	-0.0214***	-0.00160	-0.0188***	-0.00210
	(0.00449)	(0.00184)	(0.00423)	(0.00194)	(0.00337)	(0.00194)
Cumulative I-131 Exposure, 11-15 yrs prior	-0.0207***	0.00140	-0.0148***	-0.00156	-0.0156***	-0.00398*
	(0.00419)	(0.00194)	(0.00413)	(0.00207)	(0.00365)	(0.00240)
Cumulative I-131 Exposure, 16-20 yrs prior	-0.0149***	0.00124	-0.0187***	-0.00189	-0.0177***	-0.00271
	(0.00246)	(0.00277)	(0.00273)	(0.00266)	(0.00268)	(0.00247)
Cumulative I-131 Exposure, 21-25 yrs prior	-0.00638***	0.00693**	-0.00586***	0.000998	-0.00784***	0.000397
	(0.00221)	(0.00293)	(0.00218)	(0.00225)	(0.00194)	(0.00195)
Census_YR_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
State_Time_Trends	No	Yes	No	Yes	No	Yes
Weather_Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	41772	41772	41772	41772	41757	41757
r2_a	0.904	0.939	0.920	0.942	0.942	0.953
F_Stat	11.12	3.588	11.408	1.033	11.69	2.34
F_Test_Pvalue	0	0	0	.40	0	.04

All Standard Errors are Clustered by County

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 16: Census Panel 1940-2007: Log Land Value Per Acre

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative I-131 Exposure, 0-5 yrs prior	0.0158*	-0.000149	0.00589	-0.00277	0.00148	-0.00521
	(0.00923)	(0.00548)	(0.00777)	(0.00560)	(0.00682)	(0.00526)
Cumulative I-131 Exposure, 6-10 yrs prior	0.00852	-0.00124	0.00578	0.00510	-0.000830	0.00101
	(0.00687)	(0.00537)	(0.00650)	(0.00639)	(0.00528)	(0.00553)
Cumulative I-131 Exposure, 11-15 yrs prior	-0.00273	-0.0113***	-0.00940*	-0.0132***	-0.00662	-0.00941**
	(0.00556)	(0.00368)	(0.00537)	(0.00380)	(0.00572)	(0.00414)
Cumulative I-131 Exposure, 16-20 yrs prior	-0.000792	-0.00683**	0.00612	0.00295	0.00533	0.000236
	(0.00399)	(0.00300)	(0.00490)	(0.00418)	(0.00447)	(0.00367)
Cumulative I-131 Exposure, 21-25 yrs prior	0.00367	-0.000672	-0.00186	0.000906	0.00410	0.00457
	(0.00519)	(0.00401)	(0.00389)	(0.00422)	(0.00508)	(0.00494)
Census_YR_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
State_Time_Trends	No	Yes	No	Yes	No	Yes
Weather_Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	41693	41693	41693	41693	41683	41683
r2_a	0.964	0.973	0.968	0.973	0.974	0.978
F_Stat	4.39	5.21	7.10	7.43	4.48	5.04
F_Test_Pvalue	0	0	0	0	0	.0

All Standard Errors are Clustered by County

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 17: Census Panel 1940-2007: Log Average Farm Size

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative I-131 Exposure, 0-5 yrs prior	0.0215***	0.00920**	0.0134***	0.00847**	0.0110***	0.00869**
	(0.00429)	(0.00366)	(0.00410)	(0.00379)	(0.00423)	(0.00354)
Cumulative I-131 Exposure, 6-10 yrs prior	0.0209***	0.0129***	0.0227***	0.0108***	0.0207***	0.0117***
	(0.00371)	(0.00336)	(0.00364)	(0.00330)	(0.00338)	(0.00316)
Cumulative I-131 Exposure, 11-15 yrs prior	0.0201***	0.0127***	0.0168***	0.0119***	0.0193***	0.0155***
	(0.00331)	(0.00303)	(0.00331)	(0.00316)	(0.00328)	(0.00299)
Cumulative I-131 Exposure, 16-20 yrs prior	0.0174***	0.0118***	0.0185***	0.0121***	0.0196***	0.0143***
	(0.00318)	(0.00282)	(0.00323)	(0.00281)	(0.00303)	(0.00296)
Cumulative I-131 Exposure, 21-25 yrs prior	0.0146***	0.00924***	0.0174***	0.0128***	0.0181***	0.0143***
	(0.00327)	(0.00282)	(0.00345)	(0.00294)	(0.00302)	(0.00279)
Census_YR_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
State_Time_Trends	No	Yes	No	Yes	No	Yes
Weather_Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	41739	41739	41739	41739	41729	41729
r2_a	0.945	0.958	0.948	0.959	0.961	0.968
F_Stat	9.92	5.51	10.99	5.51	12.70	7.57
F_Test_Pvalue	0	0	0	0	0	0

All Standard Errors are Clustered by County

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 18: Census Panel 1940-2007: Log Share of Farmland as Cropland

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative I-131 Exposure, 0-5 yrs prior	0.000814	-0.0123**	-0.00530	-0.0151**	-0.00692	-0.0147**
	(0.00482)	(0.00542)	(0.00506)	(0.00627)	(0.00505)	(0.00595)
Cumulative I-131 Exposure, 6-10 yrs prior	-0.00546	-0.0136***	-0.0109***	-0.0181***	-0.0126***	-0.0196***
	(0.00369)	(0.00392)	(0.00366)	(0.00423)	(0.00380)	(0.00433)
Cumulative I-131 Exposure, 11-15 yrs prior	0.00256	-0.00456	0.000712	-0.00487	-0.00478	-0.00948***
	(0.00418)	(0.00358)	(0.00407)	(0.00359)	(0.00364)	(0.00359)
Cumulative I-131 Exposure, 16-20 yrs prior	0.00817***	0.00301	0.0104***	0.00197	0.00723**	-0.00103
	(0.00294)	(0.00313)	(0.00315)	(0.00323)	(0.00317)	(0.00356)
Cumulative I-131 Exposure, 21-25 yrs prior	-0.00666**	-0.0105***	-0.00821***	-0.0110***	-0.00715**	-0.0109***
	(0.00301)	(0.00335)	(0.00313)	(0.00336)	(0.00309)	(0.00347)
Census_YR_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
State_Time_Trends	No	Yes	No	Yes	No	Yes
Weather_Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	41467	41467	41467	41467	41461	41461
r2_a	0.933	0.939	0.935	0.941	0.940	0.945
F_Stat	9.12	10.46	11.48	10.34	10.19	9.54
F_Test_Pvalue	0	0	0	0	0	0

All Standard Errors are Clustered by County

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 19: Census Panel 1940-2007: Log Share of Farmland as Pastured Cropland

	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative I-131 Exposure, 0-5 yrs prior	-0.0138*	0.00931	-0.00445	0.00882	-0.00468	0.0104
	(0.00815)	(0.00874)	(0.00966)	(0.00928)	(0.00919)	(0.00888)
Cumulative I-131 Exposure, 6-10 yrs prior	-0.0119	0.00180	-0.00577	0.0124	-0.0102	0.0100
	(0.00750)	(0.00805)	(0.00759)	(0.00879)	(0.00787)	(0.00854)
Cumulative I-131 Exposure, 11-15 yrs prior	-0.00108	0.0105*	0.00330	0.0114*	-0.0000697	0.00985
	(0.00577)	(0.00630)	(0.00671)	(0.00680)	(0.00634)	(0.00633)
Cumulative I-131 Exposure, 16-20 yrs prior	-0.0191***	-0.0117**	-0.0249***	-0.00601	-0.0238***	-0.0113**
	(0.00502)	(0.00524)	(0.00512)	(0.00554)	(0.00489)	(0.00496)
Cumulative I-131 Exposure, 21-25 yrs prior	-0.0271***	-0.0221***	-0.0270***	-0.0213***	-0.0291***	-0.0217***
	(0.00488)	(0.00482)	(0.00528)	(0.00493)	(0.00476)	(0.00438)
Census_YR_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
State_Time_Trends	No	Yes	No	Yes	No	Yes
Weather_Controls	No	No	Yes	Yes	Yes	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	40109	40109	40109	40109	40104	40104
r2_a	0.739	0.796	0.756	0.800	0.788	0.826
F_Stat	9.95	6.01	9.55	5.23	10.57	6.75
F_Test_Pvalue	0	0	0	0	0	0

All Standard Errors are Clustered by County

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C NASS Wheat Regression Placebo Results

Table 20: Placebo Tests, Effects of Fallout Deposition on Wheat Production 15 Years Prior, Sample 1920 to 1940

	(1)	(2)	(3)	(4)	(5)	(6)
		Winter Wheat			Spring Wheat	
	Log YPA	Log Acres	Log Acres	Log YPA	Log Acres	Log Acres
Placebo Exposure	0.0305	0.00220	-0.0281	0.0103	-0.00200	0.00702
	(0.0250)	(0.0155)	(0.0358)	(0.0212)	(0.0137)	(0.0161)
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
County_FE	Yes	Yes	Yes	Yes	Yes	Yes
N	5875	5875	5875	3463	3463	3463

Standard Errors Clustered by County, samples restricted to counties observed in 1930

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

D Preliminary Regression Results For Corn

There is some evidence that radioactive fallout might have adversely affected corn production. Corn yields were increasing since the 1930's due to hybrids and fertilizers. In the 1950's chronic overproduction and high price supports led to enormous surpluses of corn. Base acreage for corn was not a function of the recent farm activity like wheat.

Table 21: Log Yield Per Acre Planted, bu Corn

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	0.0160	-0.0210	-0.0170	-0.0423	-0.00198	-0.0787*
	(0.0610)	(0.0451)	(0.0495)	(0.0418)	(0.0508)	(0.0447)
Exposure	-0.163***	-0.0549*	-0.127***	-0.0560*	-0.177***	-0.0616*
	(0.0412)	(0.0328)	(0.0384)	(0.0296)	(0.0396)	(0.0316)
Exposure Last Yr	-0.323***	-0.239***	-0.202***	-0.194***	-0.173***	-0.124***
	(0.0524)	(0.0455)	(0.0454)	(0.0425)	(0.0439)	(0.0409)
Avg Exp 2-5 yrs prior	-1.166***	-0.993***	-0.588***	-0.665***	-0.573***	-0.493***
	(0.210)	(0.161)	(0.162)	(0.144)	(0.172)	(0.149)
Avg Exp 6-10 yrs prior	0.112	0.328*	-0.264	0.0451	-0.350	0.0432
	(0.260)	(0.169)	(0.212)	(0.158)	(0.219)	(0.163)
Corn Price Last yr	-0.0279***	-0.00733***	-0.0173***	0.00161	-0.0223***	-0.000537
	(0.00348)	(0.00112)	(0.00312)	(0.00129)	(0.00337)	(0.00154)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	12827	12827	12827	12827	12827	12827
Adjusted r^2	0.115	0.433	0.293	0.527	0.434	0.588

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 22: Log Acres Harvested, Corn

	(1)	(2)	(3)	(4)	(5)	(6)
Log Acres Planted	1.158***	1.042***	1.118***	1.028***	1.065***	0.961***
	(0.0614)	(0.0420)	(0.0498)	(0.0381)	(0.0484)	(0.0404)
Exposure	-0.216***	-0.111***	-0.142***	-0.0966***	-0.178***	-0.0873***
	(0.0368)	(0.0277)	(0.0325)	(0.0251)	(0.0336)	(0.0268)
Exposure Last Yr	-0.266***	-0.185***	-0.152***	-0.160***	-0.159***	-0.127***
	(0.0471)	(0.0412)	(0.0399)	(0.0376)	(0.0391)	(0.0370)
Avg Exp 2-5 yrs prior	-0.903***	-0.735***	-0.393***	-0.502***	-0.400**	-0.369***
	(0.187)	(0.142)	(0.146)	(0.131)	(0.157)	(0.135)
Avg Exp 6-10 yrs prior	-0.124	0.0822	-0.322*	-0.0732	-0.320	-0.0216
	(0.241)	(0.155)	(0.192)	(0.147)	(0.201)	(0.148)
Corn Price Last yr	-0.0217***	-0.00262***	-0.0151***	0.00211*	-0.0183***	0.000561
	(0.00320)	(0.000979)	(0.00301)	(0.00115)	(0.00309)	(0.00131)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	12827	12827	12827	12827	12827	12827
Adjusted r^2	0.476	0.688	0.575	0.729	0.661	0.762

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 23: Log Acres Planted, Corn

	(1)	(2)	(3)	(4)	(5)	(6)
Exposure Last Yr	0.0129	0.0130	0.00370	-0.00123	0.0137	-0.00105
	(0.0175)	(0.0180)	(0.0184)	(0.0184)	(0.0204)	(0.0197)
Avg Exp 2-5 yrs prior	-0.0495	-0.0787	-0.0705	-0.0983*	0.0480	-0.0279
	(0.0563)	(0.0570)	(0.0568)	(0.0548)	(0.0626)	(0.0589)
Avg Exp 6-10 yrs prior	-0.183*	-0.237***	-0.196*	-0.266***	0.146	-0.0380
	(0.103)	(0.0885)	(0.103)	(0.0904)	(0.106)	(0.0932)
Corn Price Last yr	-0.00710***	-0.00356***	-0.00635***	-0.00241***	-0.00392**	-0.00242**
	(0.00113)	(0.000694)	(0.00139)	(0.000815)	(0.00157)	(0.000996)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	Yes	Yes	Yes	Yes
State Time Trends	No	Yes	No	Yes	No	Yes
1940 Census Controls	No	No	No	No	Yes	Yes
N	12827	12827	12827	12827	12827	12827
Adjusted r^2	0.164	0.271	0.181	0.280	0.326	0.382

All Standard Errors are Clustered by County. Exposure denotes 1000's nCi of I-131 per m2 .
Exposure measure cumulative I-131 deposition in a county over a year.
Samples is restricted to counties observed in the data in 1950.
Weather Controls denote monthly precipitation and average temperature measures.
These Regional controls consist 1940 county characteristics. These include: % white, % with electricity,
% urban, % of the labor force in agriculture, and % cropland.
Population density, median education measures, retail sales per capita, and farms per capita are also included.
Per farm controls of capital value, crop values, and farm value are also included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$