Measuring Policy's Role in Mediating Responses to Agricultural Productivity Shocks

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Job Market Paper

Current Version

October 27, 2017

Abstract

As the effects of climate change become more pronounced, policy's role in shaping producer responses to adverse shocks becomes more relevant. Contemporary agricultural policies such as crop insurance are often tied to farmers' production histories. Using changes in agricultural productivity caused by radioactive fallout from nuclear testing between 1951 to 1958, I find such "use-it or lose-it" policies can encourage producers to divert resources toward rather than away from adversely affected crops. Treating policy as a fixed factor may obscure the role policies play in shaping producer behavior and can lead to misestimation of the social costs associated with disruptive events. Government policies that regulated production based on producer history encouraged farmers to "double down" on adversely affected crops, and led producers to plant an additional 2.6 million acres of wheat in the years following fallout exposure.

JEL N42, N52, Q18, Q53, Q58; Keywords: Nuclear testing, radioactive fallout, agricultural policy, producer behavior

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*This material is based in part upon work supported by the National Science Foundation under Grant Number SES 1658749. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Additional funding and support was provided by the Economic History Association. Thanks to Price Fishback, Ashley Langer, Jessamyn Schaller, Derek Lemoine, and Cihan Artunc for feedback, data and support. Additional thanks to Andre Bouville, Steven Simon and the National Cancer Institute for their help providing fallout deposition records.

Disruptive events such as natural disasters, disease outbreaks, and extreme temperatures often alter the production environment. A growing body of research focuses on extreme temperature events to draw insight about the social costs of climate change. Weather conditions are often observable and shocks can be serially correlated over time. People might take actions in anticipation of future shocks and these actions may reduce the measured effect of the productivity shock. This complication potentially obscures the role government policy plays in shaping responses to changes in productivity. To draw insight about how policy and productivity interact, I study how farmers adjusted their planting decisions in response to unanticipated agricultural productivity shocks caused by radioactive fallout from nuclear testing between 1951 and 1958. The unique characteristics of radioactive fallout provide an attractive context in which to study how policy affects producers' responses to changes in productivity.

Nuclear testing occurred in an environment where U.S. agricultural policy heavily regulated agricultural production. During the 1950s, the USDA regulated the amount of cropland farmers could harvest. In my analysis, I focus specifically on two regulated crops, corn and winter wheat, which both had wide geographic distribution in production and differences in regulations. Farm level regulations on corn acreage were not tied to a farmer's past production history. Conversely, farm level regulations on wheat acreage were specifically tied to a farmer's past production history and agricultural productivity. This created a "use-it or lose-it" scenario for wheat farmers where adverse productivity shocks from fallout could have negatively affected their wheat acreage and thus income in future years.

Typically, if an agricultural producer experiences an adverse productivity shock specific to one crop, they will reduce planting of that crop in the next year if they treat shocks as serially correlated across time. I find that U.S. agricultural policy for wheat promoted the opposite response to a productivity shock. The policies that alloted wheat acreage to farmers were based on multi-year average of past acres harvested. Thus, when disasters cut acres harvested, wheat producers had an incentive to increase their planting to ensure that their average did not fall below their allotment. In this case, allotment policies caused wheat farmers to "double-down" on the adversely affected crop and divert land from other uses towards wheat production. Corn producers, who were not subject to such policies, treated fallout-induced productivity shocks as transitory and did not alter their planting decisions. The results of this paper reveal that policy can interact with productivity in perverse ways that alter the effects of a productivity shock. Overlooking the role policy plays in shaping producer behavior may misattribute the effects of policy to a disruptive event and inaccurately measure the social costs of these events.

Contemporary crop insurance programs in the United States include similar "use-it or lose-it" provisions akin to those in the 1950s. Federal crop insurance payments are a function of a farm's past crop specific production history.[1] These policies distort farmers' incentives, and researchers find the crop insurance program encourages the cultivation of marginal land, reductions in crop rotation, continuous corn planting, and causes soil erosion (Goodwin and Smith, 2013; Glauber, 2013; Miao et al., 2016; Claassen et al., 2017).[2] These policies likely also encourage maladaptation. Government policy can incentivize agricultural producers to invest and specialize in crops and production methods that will increase their exposure to climate change. Evidence from Annan and Schlenker (2015) suggests that temperature affects corn and soy yields with greater intensity in counties with greater crop insurance coverage. Understanding how policy affects producers' responses to productivity shocks is of increasing importance as the effects of climate change intensify, but the research studying policy's role in shaping adaptive responses is relatively sparse.

Radiation from nuclear testing provides a particularly effective way of identifying productivity shocks and measuring how policy affects producer behaviors. Nuclear testing at the Nevada Test Site (NTS) from 1951 to 1963 generated enormous quantities of radioactive matter. Much of this invisible pollution deposited on agricultural fields hundreds to thousands of miles from the original test site and negatively affected agricultural productivity. NTS fallout reduced corn output by more than 2.5 billion bushels and winter wheat output by over 300 million bushels from 1951 to 1967 (Meyers, 2017b). The same regions produced on average 900 million bushels of corn and 400 million bushels of wheat per year between 1945 and 1950. The value of this lost product exceeds over $30 billion in 2016$.

[1] The 2014 Farm Bill determines insurance payments on up to ten years of farm production information and requires minimum of four years of crop specific production information. Years of low production traditionally reduces payments, though now farmers can exclude low performing years due to a 2014 policy change under certain conditions. If a farmer has few years of data, then their insurance coverage faces greater exposure risk to adverse years. For additional information see `https://www.rma.usda.gov/news/currentissues/aphye/`

[2] Continuous corn denotes cultivation of corn year after year.

If agents anticipate productivity shocks they might make adjustments that partially mitigate the observed effect of the shock. Serial correlation in weather across time may induce people to make investments that are correlated with future weather. For example, the purchase of a combine harvester could have increased yields through more efficient harvesting and enabled the farmer to harvest (and thus plant) more arable land. A farmer might have made such an investment if they anticipated favorable growing conditions in the future. If shocks are anticipated, then the investments that are often unobservable to the econometrician can bias the estimated welfare impact of future shocks. One method to avoid such mitigating actions is to use variation from unexpected events (Moretti and Neidell, 2011). To circumvent the challenges posed by unobserved adaptive actions, I use unanticipated radioactive fallout dispersal patterns generated by atmospheric nuclear testing at the NTS.

During the period of testing, information regarding nuclear testing and contamination caused by radioactive fallout was classified information.[3] The full geographic extent of radioactive contamination from NTS testing became known many decades after atmospheric testing had ended (National Cancer Institute, 1997; Center for Disease Control, 2006). Farmers living hundreds to thousands of miles from the NTS would have neither anticipated productivity shocks caused by radioactive fallout nor would they have been able to observe the cause of the decreased productivity. Given the nature of fallout deposition, this pollutant is plausibly uncorrelated with farmers' underlying production decisions that affect both productivity in one year and planting the next.

Increases in global temperatures caused by climate change have the potential to drastically alter agricultural production in the coming decades. A growing body of research measuring the social costs of climate change studies how the agricultural sector responds to short run variation in temperatures (Deschênes and Greenstone, 2007, 2012; Schlenker and Roberts, 2009; Burke and Emerick, 2016). These studies indirectly measure adaptation by studying the effects of extreme temperatures on agricultural land values and crop yields. Apart from Annan and Schlenker (2015), these studies generally abstract away from the role government policy plays in shaping responses to extreme temperatures. As extreme temperatures become

[3] A Freedom of Information Act request in 1978 revealed to the public that the Atomic Energy Commission (AEC), Public Health Service (PHS), Department of Defense (DOD), and federal government hid both the dangers of nuclear testing from the public and the scope of the radioactive contamination. See US Government Printing Office (1980); Ball (1986); LeBaron (1998) and Fradkin (2004) for additional information.

more frequent, policies that encourage producers to specialize in crops vulnerable to climate change may magnify the cost of adaptation. Failing to account for the role policy plays in shaping producer behavior may misstate the direct costs of climate change.

1 Background and Related Literature

Economists interested in measuring the potential disruptive costs of climate change have long studied agriculture. The agricultural sector is directly affected by climatic conditions and likely would be the economic sector most vulnerable to climate change. Mendelsohn et al. (1994) introduce Ricardian analysis and measure the effect of climatic variables upon agricultural land values using a cross sectional approach. Schlenker et al. (2005) reveal that irrigation plays a key role in climatic sensitivity, and Schlenker et al. (2006) introduce agronomic measures of growing degree days as cumulative measures of agricultural temperature exposure. Deschênes and Greenstone (2007) pioneer the use of panel data methods and short run variation in weather to measure the effects of temperature on agricultural productivity and land values. Schlenker and Roberts (2009) find that corn and soybean yields are becoming more sensitive to increasing temperatures over time. Burke and Emerick (2016) corroborate this finding using long-differences between two cross sections of data. They find that yield sensitivities to extreme heat are not decreasing over time and suggest that the agricultural sector has not adapted to increasing temperatures.

As the climate and agriculture literature has moved towards using short run weather variation, it becomes increasing plausible that farmers are making adaptive investments that are correlated with the weather treatment variables of interest. I add to this research by using radioactive fallout to address this issue of unobserved adaptive investments made in anticipation of productivity shocks. Using radioactive fallout to instrument for productivity allows me to explore how farmers adjust their planting decisions in response to adverse productivity shocks. Finally, government policy is an aspect often treated as fixed in the climate change and agricultural literature. The unique variation in agricultural productivity fallout provides and agricultural policy environment during the period of atmospheric nuclear testing allow me to analyze how policy can interact with productivity shocks.

Economists also study historical episodes where large events affected productivity and the adjustments agents made in response to these shocks. Lange et al. (2009) analyze how cotton farmers responded to the anticipated arrival of the Boll Weevil and find that cotton farmers tried to squeeze out one last large harvest before the arrival of the pest. They also find that following the pest's arrival, farmers moved away from cotton production. Hornbeck (2012) measures the long run adaptation made by farmers following Dust Bowl erosion. He finds long run out migration and shifts away from wheat production in more eroded counties. Boustan et al. (2012) study migratory responses to tornadoes and floods. Their results show that government expenditures on flood control following disasters induced in-migration. Hornbeck and Naidu (2014) measure agricultural and migratory responses to the 1927 Mississippi flood. Out migration in more flooded areas caused agricultural production to become more capital intensive. This paper adds to this historical literature by measuring the short run adaptive responses agricultural producers made in response to damage from nuclear testing.

This paper belongs to a set of concurrent research papers studying the consequences and adverse effects of domestic nuclear testing conducted at the Nevada Test Site (NTS) in Nye County, Nevada. Meyers (2017b) finds that fallout depositing across much of the Great Plains and Midwest adversely affected agricultural output. Radioactive pollution from NTS tests resulted in farmers leaving millions of planted acres of cropland unharvested and decreased agricultural output by billions of dollars. Over 331 million fewer bushels of wheat and 2.5 billion bushels of corn were produced as a result of NTS testing. The total cost of this damage exceeded \$30 billion (2016\$). Meyers (2017a) studies the health effects of this radioactive pollution using annual vital statistics records and finds that nuclear testing contributed to hundreds of thousands of deaths in the twenty-year period following testing. The areas most affected by the pollution were in the Midwest and Great Plains and far beyond the regions studied in the medical literature. These results suggest that in addition to affecting agriculture, NTS nuclear tests likely affected public health and worker productivity. Prenatal exposure to radioactive pollution is associated with decreases in human capital. Almond et al. (2009) and Black et al. (2013) show that fetal exposure to low doses of ionizing radiation negatively affects educational attainment and income of exposed cohorts in Scandinavia.

Atmospheric nuclear testing was a deliberate and destructive policy conducted for the purpose of national defense. From 1945 to 1993 the U.S government detonated 1,030 nuclear weapons (US Department of Energy, 2000). Of these tests, 100 atmospheric tests occurred at the NTS during the 1951-1963 time period. Atmospheric nuclear testing by the U.S. effectively ended in 1963 with the signing of the Partial Nuclear Test Ban Treaty, though from 1958 to 1961 there was a testing moratorium between the U.S. and USSR that led to a secession of atmospheric testing. Over 12 billion curies of radioactive material was released into the environment by these atmospheric tests in the U.S.. In comparison, the worst nuclear disaster in human history, the partial meltdown at Chernobyl, released approximately 80 million Curies of radioactive material into the environment (LeBaron, 1998).[4] The public at large did not know about the harm caused by nuclear testing until 1978. This knowledge environment changed when a Freedom of Information Act request revealed the environmental and public health dangers NTS activities had for populations living near the test site (Ball, 1986; LeBaron, 1998; Fradkin, 2004). This revelation prompted Congressional investigations (US Government Printing Office, 1980) and a government inquiry into the public health risks posed by nuclear testing (National Cancer Institute, 1997; Center for Disease Control, 2006). As such, it is unlikely that farmers residing in areas hundreds to thousand of miles from the NTS would have known that their crops were being exposed to fallout from nuclear tests in Nevada.

2 Model and U.S. Agricultural Policy

To illustrate the effects of farm policy and how it interacts with fallout-induced productivity shocks, I expand upon a model developed by Hornbeck (2012). Hornbeck's model describes how farmers responded to permanent soil degradation resulting from Dust Bowl erosion. I adapt this model to study how farmers adjust their short-run planting decisions in the year following an adverse productivity shock. This paper's model describes the mechanisms through which an agricultural productivity shock can affect a farmer's planting decision in the subsequent year. There are several potential mechanisms to examine. The baseline scenario involves a farmer who is an unconstrained maximizer and faces productivity shocks

[4]These measures relate to the amount of radioactive debris created and not radioactive gases such as tritium that were released by these events. Such radioactive gases would not deposit on the surface of the earth. Fukashima released less radioactive material than Chernobyl due to differences in reactor design.

are treated as completely transitory. Under this scenario, a productivity shock in the past would not affect acreage planted.

The next three cases describe mechanisms through which a transitory shock may have persistent effects on planting decisions. The beliefs scenario describes a case where the agent farmer is an unconstrained maximizer and believes the fallout shock will be persistent across years. The resource constraint scenario involves an adverse productivity shock in the previous year that causes a resource constraint to bind. In both the second and third cases, productivity shocks and acreage are positively related. The policy scenario involves a wheat specific policy constraint that restricts the amount of acreage a farmer can harvest in the future based on his or her past production history. This policy creates an acreage target for farmers. Since fallout caused farmers to abandon cultivated acreage in the previous year, this could cause the regulators to restrict the amount of land farmers could harvest in future years. Producers could potentially partially offset this regulation and insure themselves against another year of reduced harvest by increasing the amount of land they planted as wheat in the year following the shock. This policy makes it possible for productivity shocks and cultivated acreage to be negatively related. Table 1 describes the empirical predictions of the model.

2.1 Baseline Model

In this model there are two different production technologies and a single unit of land that can be divided between them. Both technologies have concave and twice differentiable profit functions denoted by $f(\cdot)$ and $g(\cdot)$. In the context of agriculture, let $f(\cdot)$ denote the profit the farmer receives from alternative land uses and $g(\cdot)$ denote the profit the farmer receives from producing wheat. In each year the farmer must decide how to divide his or her unit of land between the two technologies. Let θ_t denote the division of this single unit of land between $f(\cdot)$ and $g(\cdot)$.

Equation (1) describes the unconstrained maximization problem the farmer faces. If the farmer is an unconstrained maximizer, then by the concavity of the profit function she allocates land such that at θ_t the marginal profit of land for the two technologies are equal. The first order conditions for equation (1) appear in equation (2) and describe the optimal allocation decision.

$$\max_{\theta_t \ \epsilon[0,1]} g(\theta_t) + f(1 - \theta_t) \tag{1}$$

$$g'(\theta_t) - f'(1 - \theta_t) = 0 \tag{2}$$

This static one-period model also describes the optimal land division when productivity shocks are transitory. A transitory shock will affect realized profits in one year, but will not affect the farmers' optimal planting decision in subsequent year. That is the optimal θ_t equals the optimal θ_{t-1}. For productivity shocks to show persistence in this model they need to either affect agents' beliefs, agents' available resources, or interact with policy.

2.2 Beliefs in persistent damages

Productivity shocks in the previous year might affect farmers' beliefs about growing conditions in the next year and these beliefs might make them adjust their planting decisions in subsequent years. For example, suppose weather shocks are serially correlated across multiple years. Then if a given year has little rainfall, the agent farmer might believe the subsequent year will be drier than average and thus allocate less land toward water intensive crops. Suppose there is an anticipated damage function denoted by $\delta(\cdot)$ that is between zero and one. This damage variable is an increasing function of fallout-induced damage in the previous year, η_{t-1}. Assume the agent believes this damage function affects only the productivity of technology g. If the productivity shock is treated as persistent, then the farmer's profit maximization problem becomes:

$$\max_{\theta_t \ \epsilon[0,1]} \delta(\eta_{t-1}) g(\theta_t) + f(1 - \theta_t) \tag{3}$$

The value $\delta(\cdot)$ decreases the perceived profitability of wheat relative to alternative land uses. The non-wheat productivity is unaffected by fallout shocks, while wheat crop productivity is affected. In the empirical analysis, such a belief mechanism would imply a positive relationship between prior productivity and the share of current acreage planted in wheat. The first order condition in (4) shows the effect of beliefs in persistent damages on the optimal land allocation. The optimal allocation when there is no productivity shock is $\theta_t = \theta_{t-1}$, but this value no longer equates the two marginal profits.

$$\delta(\eta_{t-1})g'(\theta_t) - f'(1-\theta_t) = 0 \tag{4}$$

If $\delta(\eta_{t-1})g'(\theta_t) < f'(1-\theta_t)$ when $\theta_t = \theta_{t-1}$, then by the concavity of $f(\cdot)$ and $g(\cdot)$ the optimal θ_t must decrease. As with Hornbeck (2012), this scenario leads the farmer to reallocate land away from crop production towards alternative uses. This mechanism reveals that farmers will reallocate resources from wheat towards alternative uses as the effect of the productivity shock is treated as persistent. This result means that farmers would reduce the amount of wheat cultivated in the subsequent year if they believe adverse productivity shocks to be persistent. Thus θ_t is smaller relative to the previously optimal allocation of θ_{t-1}.

2.3 Resource constraint mechanism

If the adverse productivity shock from fallout in the previous year is large enough, then the negative income shock may reduce the feasible amount of land the farmer can dedicate towards wheat production in the subsequent year. Fallout from nuclear testing caused substantial yield reductions and losses in agricultural output. If farmers faced imperfect capital markets, then they might not be able to afford to plant as much wheat as they were planning to following a fallout shock. Let $Y(\eta_{t-1})$ denote the amount of income the farmer received in the year fallout deposited across his fields. Y is decreasing in fallout damage from the previous year, Let the cost, C, of planting wheat be an increasing function of θ_t. If the negative productivity shock is large enough, then the amount of resources the farmer has to plant this year at $\theta_t = \theta_{t-1}$ is less than the cost (i.e.: $Y(\eta_{t-1}) < C(\theta_{t-1})$). Therefore, the unconstrained maximization problem becomes a constrained problem as in equation (5).

$$\max_{\theta_t \ \epsilon[0,1]} g(\theta_t) + f(1-\theta_t) \ s.t. \ 0 \leq C(\theta_t) \leq Y(\eta_{t-1}) \tag{5}$$

When the maximization problem is unconstrained, the cost of production C must be less than or equal to Y. If the damage is great enough in the previous year such that the constraint binds, then the previously optimal allocation, θ_{t-1}, is no longer feasible.

$$g'(\theta_t) - f'(1-\theta_t) - \lambda C'(\theta_t) \leq 0 \tag{6}$$

If the budget constraint binds, then $\lambda C'(\theta_t) > 0$ and ensures the inequality (6) holds when θ_t is less that θ_{t-1}. Therefore, decreasing the amount of land allocated towards wheat at time t satisfies the resource constraint. In the econometric analysis, I test whether farmers are liquidity constrained by comparing OLS and two-stage least squares estimates. The liquidity constraint mechanism suggests a positive relationship between agricultural productivity and acreage.

2.4 Agricultural Policy Mechanism

The federal government has intervened in the agricultural sector since 1933 and it played an active role in regulating agricultural production during the period of atmospheric nuclear testing. The U.S. Department of Agriculture supported prices of major commodities through price support loans and regulated production through restrictions on cultivate acreage and quotas on marketed commodities. Both corn and wheat were subject to acreage restrictions in the 1950s, but the structure of the restrictions differed at the farm level for the two crops.

When the USDA subsidized crop prices using price support programs, these programs distorted incentives and increased agricultural production. This would in turn place additional downward pressures on the prices of agricultural commodities. The government regulated the amount of acreage farmers could harvest to prevent such production responses. Farmers were given a base acreage which then adjusted acreage allotments annually according to a government multiplier (Cochrane and Ryan, 1976; Burt and Worthington, 1988). When the government held large excess supplies of crops or when it expected production to be greater than the government's production target, this multiplier would determine the acreage allotment and regulated the number of planted acres a farmer could harvest.

For corn producers, these base acreage values were a function of a farm's fixed characteristics such as a farm's tillable acreage, crop rotation practices, soil quality, and topography (U.S. Department of Agriculture, 1950; U.S. Congress, 1954; Bailey et al., 2016; U.S. Department of Agriculture, 1956; Cochrane and Ryan, 1976). Corn producers' base acreage for corn was not a function of their production histories. As such corn producers' base acreage would be fixed.

In contrast, wheat producers' base acreage adjusted in response to farmers' harvesting decisions and wheat production histories. A farm's wheat base was generally a function of the farm's past harvested acreage from between two and five years prior (U.S. Department of Agriculture, 1950; U.S. Congress, 1954; Bailey et al., 2016; U.S. Department of Agriculture, 1956; Cochrane and Ryan, 1976). This regulation gave county agricultural boards the authority to reallocate base acreage from farmers who did not use their allotments and other wheat producers. This policy also provided wheat producers a harvested acreage target. While exceptions for drought to other weather-related damage were made at the state and national level, if a farmer failed to harvest their acreage allotment regulators could then reduce his base acreage. Such an event could adversely affect a farmers' future income.[5]

The enforcement mechanisms of the regulations also differed between wheat and corn. Regulators made price support for both wheat and corn conditional on farmers meeting their allotment restrictions. Corn producers would receive a lower price subsidy if they exceeded their allocation. Wheat producers who exceeded their allotments not only lost eligibility for price supports but also faced additional punishments such as fines and reductions in acreage allotments (Cochrane and Ryan, 1976; Burt and Worthington, 1988). An additional policy of marketing quotas tied wheat producers' incomes to their base acreage and regulated how many bushels of wheat farmers could markets based off their acreage allotment.

The incentive structure created by wheat regulations formed a "use it or lose it" scenario for wheat producers, while such a policy was not present for corn producers (U.S. Congress, 1938, 1948, 1949; Cochrane and Ryan, 1976). Wheat farmers could petition for allotment increases but these allotment requests in total could not exceed 3% of the county's cumulative allotment restriction. Some accommodations were made in response to known adverse weather events such as drought or flooding, but these exceptions were probably not made in response to an unexplained productivity shock from radiation. The regulatory incentive

[5] For example, in June 1950 the USDA notified farmers that their 1951 allotments would be a function of acreage seeded for harvest for the years 1946 to 1949 for the western U.S. and 1947 to 1949 for the eastern U.S. (USDA, 1950B) These restrictions were lifted after farmers seeded winter wheat acreage in the fall of 1950 due to Korean War demands.

structure made reducing cultivated wheat acreage in response to unknown adverse productivity shocks less attractive to farmers. This policy would punish farmers more if crop failure caused by radioactive fallout forced them to abandon cultivated acreage. In cases where cultivated land went unharvested due to failure, farmers faced reductions in the future acreage they could plant.[6]

Winter wheat producers planted in the fall and would receive notification regarding acreage restrictions for the subsequent season in late spring or early summer of the current growing season (USDA, 1950B; and USDA, 1956). Let the fallout shock be denoted by η_{t-1}. Suppose this fallout event caused farmers to abandon acreage in year $t-1$, then this decrease in harvested acreage would affect their wheat acreage allotment at year $t+1$ as the acreage allotments for the subsequent year were determined prior to the realized damage. This timing potentially provides wheat farmers a one year window to respond to the productivity shock before the policy might affect their planting. If farmers planted more acreage in the following year, then they have the option to harvest more acreage and offset the allotment constraint (regulations allowed farmers to place excess output in storage for sale at a later date.)

I incorporate this allotment constraint into a two-period model where the farmer responds to a fallout-induced productivity shock, η_{t-1}, that will cause the allotment constraint to bind in subsequent years. For simplicity, assume that harvested acreage equals planted acreage, that the farmer has one year where they can freely respond to the productivity shock, and that in every year following this one year adjustment period the allotment constraint restricts the farmer's planting decision. Let $A(\cdot)$ denote the allotment function that restricts wheat acreage in all subsequent years, i.e.: $\theta_{t+1} = A(\cdot)$. Let the allotment function be a function of η_{t-1}, the fallout event, and harvested acreage in year t.[7] Increases in fallout exposure caused farmers to harvest fewer acres of planted wheat acreage and this action will reduce the value of the average acreage in the farmer's future allotment unless he increases the average in year t. Equation (7) describes the two-period model. The discounted stream of future profits is denoted by the concave function $V(\theta_{t+1})$ and is discounted by $\beta \; \epsilon \; [0,1]$.[8]

[6] In 1955, farm regulators switched from using acreage planted for the intent of harvest to using only harvested acreage in their allotment calculations (Cochrane and Ryan, 1976). Policy makers believed using acreage "planted for harvest" discouraged hedging by wheat farmers. By switching to acreage harvested, regulators would not punish farmers who increased planted acreage to hedge against crop failure.

[7] I assume that the policy binds for all subsequent years to simplify the model.

[8] I collapse the second period profit function into a single function to simplify notation. $V(\cdot)$ denotes the value of a discounted an infinite geometric sum, $\Sigma_{k=1}^{\infty}\beta^k(g(A(\eta, h(\theta_t)) + f(1 - A(\eta_{t-1}, h(\theta_t))))$.

$$\max_{\theta_t \ \epsilon[0,1]} g(\theta_t) + f(1-\theta_t) + \beta V(A(\eta_{t-1}, \theta_t)) \tag{7}$$

Taking the derivative with respect to θ_t and rearranging the values results in expression (8).

$$\beta \frac{\delta A}{\delta \theta_t} V'(A(\eta_{t-1}, \theta_t)) \leq f'(1-\theta_t) - g'(\theta_t) \tag{8}$$

The first order conditions show that the marginal discounted value of future profits must equal net marginal profit in the current year. At $\theta_t = \theta_{t-1}$ the left-hand side of the expression is larger than the right-hand side (by concavity of $V(\cdot)$ and because of η_{t-1}). When the fallout shock occurs, the farmer will increase the amount of land allocated towards wheat in year t to an amount greater than θ_{t-1}. By the concavity of f, g, and V, this will decrease the left-hand side of the inequality and increase the value of the right-hand side of the inequality until both terms are equated.

3 Empirical Strategy and 2SLS Model

To isolate how farmers respond to exogenous variation in productivity, I perform Two-Stage Least Squares (2SLS) regressions and instrument for crop yields using radiation deposition. Both weather conditions and radioactive fallout affect crop productivity. Variation in productivity due to weather affects farm income and plausibly provides the farmer information about future growing conditions. Furthermore, farm policy considered weather conditions when determining acreage allotments (Cochrane and Ryan, 1976). Fallout induced changes in productivity, by contrast, only affected income as farmers would have little information regarding the cause of the productivity shock.[9]

$$ln(Acres_{it}) = \delta ln(YPA_{it-1}) + \boldsymbol{\lambda_{it-1}}\beta + \boldsymbol{\alpha_i} + \boldsymbol{\gamma_t} + \tau_{st} + \mu_{it} \tag{9}$$

The second stage regression denoted by equation (9) reports the effect of a crop yield shock in the previous year upon acres planted of that crop in the next year. The empirical model includes a set of fixed effects to control for time invariant county specific factors and common

[9] Radioactive fallout is relatively uncorrelated with cumulative precipitation during the growing season.

annual shocks that affected farmers' planting behavior. County and year fixed effects are denoted by $\boldsymbol{\alpha_i}$ and $\boldsymbol{\gamma_t}$. A vector of crop specific monthly precipitation and temperature controls for the previous growing season are denoted by $\boldsymbol{\lambda_{it-1}}$. τ_{st} denotes state specific time trends that control for common state specific trends in crop acreage. The heteroskedastic standard errors ϵ_{it-1} and μ_{it} are clustered at the county level.

YPA_{it-1} denotes yield per acre planted in the past year and is a measure of agricultural productivity. It is plausible that this variable is correlated with unobserved factors that affect both productivity in the previous year and a farmers' planting decisions in the next year. Instrumenting for productivity using weather variation would require weather to only affect farmers' planting decisions through its effects on productivity in the previous year. It is plausible that observable shocks such as weather influence farmers' decisions by changing their expectations about future weather conditions in addition to weather's effect on productivity in the prior year. As such, weather variation would not make a good candidate to instrument for productivity, because it would directly affect planting decisions in year t. Therefore, I use plausibly exogenous variation in radioactive fallout to instrument for agricultural productivity.

$$ln(YPA_{it-1}) = \theta Z_{it-1} + \boldsymbol{\lambda_{it-1}}\phi + \boldsymbol{\alpha_i} + \boldsymbol{\gamma_t} + \tau_{st} + \epsilon_{it-1} \tag{10}$$

I instrument for agricultural productivity using radioactive fallout from nuclear testing. Equation (10) denotes the first stage regression where the exogenous instrument Z_{it-1} represents radiation deposition. Z_{it-1} reports the average amount of fallout depositing on a square meter of land in a given county and year. This measure is reported in thousands of nanoCuries of iodine-131 and is indicative of cumulative fallout deposition. Radioactive fallout would have been uncorrelated with farmer's investment decisions that would both affect the productivity and planting relationship, because the farmer did not know of his fallout exposure.

The only way fallout can affect a farmer's planting decision is through its effects on productivity. Fallout provides an unanticipated productivity shock and this quality makes it an ideal instrument for crop productivity. A positive δ would imply that productivity in one year is positively related to planting in the subsequent year. A positive coefficient would be consistent with the model's predictions suggesting that fallout-induced productivity shocks either limited farmers' resources or that farmers' believed damage caused by unobserved fallout would continue into the next year. A negative δ would imply that a negative productivity shock in the previous year caused farmers to increase planting in the subsequent year. This result would be consistent with the model associated with a "use-it or lose-it" wheat policy. Such a response would be driven by farmers trying to offset the drop in average output that would have reduced the farmer's future allotment. If damage from fallout caused farmers to abandon planted acreage, then it is plausible that government regulations on land allocation became tighter in response to these abandonment decisions.

4 Data

This paper combines annual county level agricultural production measures with historic weather records and a new dataset measuring radioactive fallout dispersal at the county level. The sample is an unbalanced panel from 1939 to 1970. This range of data includes years before atmospheric nuclear testing and years after the cession of nuclear testing in 1963 (NTS atmospheric testing concluded in 1958 apart from a few small tactical tests in 1962.) States in the winter wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, MT, ND, NE, SD and WI. Summary statistics for each sample are reported in Table 2.

National Agricultural Statistics Service (2015) provides annual county level information on winter wheat and corn output, yields, harvesting, and planting. Since the counties that report crop production information might change over time, I restrict the sample to counties where acres planted are observed continuously from 1945 to 1958. This restriction ensures that counties that were exposed to radioactive fallout are observed before, during, and after atmospheric testing. Several states started reporting information on wheat and corn in the mid-1940s and many more states started reporting crop production information at later dates.[10] Figure 1 reports counties that are include in the winter wheat and corn samples.

County level fallout deposition records for each atmospheric nuclear test conducted at the Nevada Test Site are provided by the National Cancer Institute (1997). These variables

[10]CA reports winter wheat starting in 1945. WY is missing wheat data for 1963. MT starts reporting corn planting in 1944. WI stops reporting corn planting in 1967.

cover each test conducted from 1951 to 1958.[11] The NTS is located just northwest of Las Vegas in Nye County, Nevada. There were major test series in 1951, 1952, 1953, 1955, and 1957. A series of small atmospheric tests occurred in 1958 right before the U.S. entered a testing moratorium in 1958. In 1961 the moratorium broke down and a set of small atmospheric tests with a cumulative yield less than two kilotons occurred in 1962 before the enactment of the Partial Nuclear Test Ban Treaty in 1963 (US Department of Energy, 2000). The treaty ended all atmospheric nuclear tests by the U.S. and USSR after 1963. Most tests occurred between the months of March and July. Fallout dispersal maps for the 1953 Upshot Knothole and 1957 Plumbbob test series are presented in Figures 2 and 3. These measures report cumulative iodine-131 dispersal per meter squared. This measure is highly correlated with cumulative fallout deposition since the deposition is occurring in the days following each test and therefor it makes an appropriate proxy for cumulative radiation exposure (National Cancer Institute, 1997). I aggregate each of these measures up to the year level. County level data on monthly temperature averages and monthly precipitation totals come from the Global Historical Climatology Network version 3 and were created by Lawrimore et al. (2011). These records control for the effects of weather on agricultural productivity and potential information provided to farmers about future weather conditions.

5 Empirical results

5.1 Main empirical results

Table 3 presents the OLS regression estimates of the relationship between agricultural yield in the previous year and acres planted. The relationship between productivity and planting in the subsequent year are subject to potential upward bias in the OLS models because of unobserved investments and potential belief effects. To address these endogeniety issues, I measure responses to fallout-induced productivity shocks. These results are captured in the 2SLS regressions in Table 4. I run three different model specifications for each crop. Specifications (1) and (4) include only year and county fixed effects and provide a baseline for comparison to other specifications. In specifications (2) and (5), I add crop specific monthly temperature and precipitation controls. These specifications control for potential correlations between fallout deposition and weather conditions that affect agricultural productivity.

[11]Note, deposition measures for the first three tests conducted in 1951 are not available as the radiation monitoring station network was not yet set up.

Specifications (3) and (6) add state specific linear time trends to control for potential underlying trends that are shared across counties within the same state. All coefficients discussed in this section refer to the specifications (3) and (6) and are statistically significant at least at the 5% level unless otherwise noted. Finally, I present additional evidence to further establish the credibility of the estimates through a series of robustness checks.

The OLS regression results find a positive and statistically significant relationship between yield per acre planted in the previous year and acres planted in the subsequent year for both wheat and corn. A 1% decrease in yields in year t results in wheat farmers decreasing wheat acreage by approximately 0.13% and corn acreage by 0.03% in year $t + 1$. Wheat farmers appear to respond more to yield shocks than corn planters. These OLS results are consistent with either farmers treating productivity shocks as serially correlated or a resource constraint scenario. The 2SLS results differ substantially from these OLS results for both wheat and corn.

The 2SLS estimates are reported in Table 4. The first stage effects of fallout on yields are negative and statistically significant. The Kleibergen-Paap Wald rk F statistics suggest the instrument is sufficiently strong. A one standard deviation increase in fallout exposure caused winter wheat yields to drop approximately 3.4% and corn yields to drop approximately 3.1%. These reductions in yields and agricultural productivity resulted from farmers abandoning planted acreage. Fallout induced productivity shocks caused farmers to reduce acre harvested in year year of these shock, and this crop abandonment is what would decrease future wheat allotments to farmers. Decreases in harvested acreage by corn producers would not affect their future allotments. To show this, I regress harvested acreage on acres planted and on the fallout exposure variable.

Table 5 reports the effects of fallout deposition on how much planted acreage farmers harvested. This measure approximates the extent to which fallout caused crop abandonment. Farmers abandoned cultivated wheat and corn in response to fallout deposition. A one standard deviation increase in fallout exposure caused wheat farmers to abandon approximately 1.7% more planted acreage. Corn producers exhibited greater sensitivity to fallout exposure and a one standard deviation increase in fallout caused them to abandon approximately 3.7% more planted acreage. Fallout exposure reduced both wheat and corn productivity, but the harvesting actions of wheat producers in response to the shocks caused future allotments to decrease.

In the second stage of the 2SLS regression, I analyze how agricultural producers adjusted their planting behavior in response to unanticipated productivity shocks from fallout. Wheat producers increased the amount of wheat acreage they planted following a negative productivity shock. These responses to fallout-induced productivity shocks were shaped by government policy constraints that tied their productivity histories to their future streams of income. Fallout caused farmers to harvest fewer acres of planted wheat and this action could adversely affect their future wheat allotments and thus their future income. By planting more, farmers created the option to harvest more and offset the tightening policy constraint. A 1% fallout-induced decrease in winter wheat yield per acre planted in the previous year would have caused wheat producers to plant 0.73% additional acres the subsequent year. Corn producers, who were not subject to a regulatory constraint tied to agricultural production, did not adjust their planting in response to fallout-induced productivity shocks. The only information producers had regarding the fallout-induced productivity shock were the observable changes in productivity. Since radioactive fallout was invisible, they would have been unable to identify the specific cause of the diminished productivity.

Producers' responses to fallout-induced productivity shocks differed across both corn and wheat. Assuming the covariance between the corn and wheat models is zero, I find that producer responses to fallout-induced productivity shocks differ statistically.[12] Between specifications (1) and (4), the difference is statistically significant at the 10% level. For specifications (2) and (5) and specifications (3) and (6) the difference is statistically significant at the 5% level.

5.2 Placebo falsification tests

In order to test the robustness of the 2SLS estimates and the exogenous nature of the fallout instrument, I report two different falsification tests. Tables 6 and 7 report the results

[12]Estimating the covariance between two different regression specifications usually employs Seemingly Unrelated Regressions and OLS. OLS estimates substituting fallout for yield per acre suggest the covariance factor for fallout between the two models is positive and thus assuming the covariance measure between the 2SLS models as zero likely understates statistical difference between the corn and wheat coefficients. 2SLS with different samples requires a custom three-stage-least-squares estimator to estimate the covariance matrix between the two regressions.

showing the validity of the fallout instrument. The first test reassigns fallout exposure to a period fifteen years earlier so that deposition is artificially assigned to the years between 1936 and 1943. This tests for underlying unobserved prior aspects of farmers that might be geographically correlated with fallout that might bias econometric estimates. The second test randomly reassigns fallout exposure within each year of occurrence, i.e. fallout exposure in 1951 is randomly shifted to another sample county in 1951. This reassignment tests for potential unobserved variables that are temporally correlated with the fallout variable. For both corn and wheat, I test for a potentially spurious relationship between fallout exposure and the variables of interest. These variables include log acres planted, log yield per acre planted, and log yield per acre harvested. Each regression only includes county and year fixed effects and the samples consists of counties included in the main analysis. In either placebo test, I find small statistically insignificant relationships between fallout exposure and the variables of interest. The results suggest that the instrument is uncorrelated with potentially unobserved factors that might affect farmers' planting and harvesting decisions.

6 Discussion

Radioactive fallout shocks interacted with U.S. agricultural policy and added to the damage directly caused by nuclear testing at the NTS. In the sample, the average amount of land in winter wheat production between 1945 and 1950 was 17.4 million acres. To understand the size of this policy induced distortion, I calculated the marginal effect of each year's fallout deposition on wheat yields in the first stage regressions, multiplied this effect by the coefficient for log yields from Table 4 specification (3), and multiplied this marginal effect by the average amount of land planted for wheat between 1945 and 1950. This "back-of-the-envelop" calculation suggest that on average fallout reduced winter wheat yields by 4.7% (with a 6.4% standard deviation) in the years of deposition. These fallout-induced productivity shocks caused winter wheat producers to plant an additional 2.6 million acres of winter wheat. The average sample county increased winter wheat acreage by approximately 960 acres (with a 3,160 acre standard deviation) in the years following these shocks.

One portion of the cost of this policy induced behavior was the increased seed cost for the additional acreage. U.S. Agricultural Statistics volumes report the per bushel prices for wheat, high quality wheat seeds, and average sowing rates per acre. From this information

I estimate the additional seed cost for sowing this land was between \$43.4 million and \$63 million (2016\$).[13] The total cost of this additional planting is likely many times greater than these estimates.

Corn producers were not subject to policy constraints that penalized them for abandoning acreage in response to fallout-induced crop damage. Their responses to these unanticipated productivity shocks were to treat it as a transitory event. These farmers did not adjust their planting behavior and this result suggests that producers' budget constraints did not alter their planting decisions. Wheat farmers engaged in costly actions in response to negative productivity shocks. Producers who were constrained by a tightened budget would not have been able to make such a response. These two results suggest that liquidity constraints are not the mechanism behind the OLS relationship between productivity and planting.

7 Conclusion

Policy incentives can fundamentally alter the responses producers make to productivity shocks. Government has the potential to magnify or mitigate the costs of adverse shocks. Many times it is empirically difficult to isolate the mechanisms that contribute to the overall measured effect of a shock. A confluence of factors can disguise the costs of policy mechanisms. I model these mechanisms using a framework Hornbeck (2012) developed and employ a unique source of variation to isolate the direct effect of a productivity shock to agriculture.

In the empirical analysis, I instrument for agricultural productivity using radioactive fallout from nuclear testing. Radioactive fallout differs fundamentally from typical productivity shocks and OLS productivity shocks. Unlike weather, fallout provides an unanticipated productivity shock. Since weather conditions tend to be correlated over time, weather shocks can potentially provide information about future growing conditions and affect producer responses though channels other than productivity. Corn farmers treated fallout-induced productivity shocks as transitory and did not adjust their planting in response to these shocks. Wheat farmers' reactions to fallout were shaped by policy restrictions that tied future farm income to their harvesting history.

[13] I used nominal prices in January 1959 and the Bureau of Labor statistics CPI calculator to convert these values to January 2016\$.

This paper reveals that government policy can interact with productivity shocks and shape responses to such shocks. From regulating pollution to subsidizing wages through the Earned Income Tax Credit to mandating health insurance coverage, governments intervene in many areas of economic life. The potential costs of these policies are likely obscured by other mechanisms in empirical analyses of disruptive events. As the effects of climate change become more pronounced, measuring the social costs associated with such temperature shifts becomes more relevant. One dimensions of these costs are the social costs attributable to government policy. Policies such as crop insurance and ethanol mandates push farmers towards practices that likely increase their exposure to climate change. Treating policy as a fixed factor can overlook its role in shaping adaptation and may misstate the estimated effects of climate change.

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Table 1: Model predictions on 2SLS effects

Mechanism	Effect of fallout induced productivity shock on planting	
	Wheat	Corn
Transitory Shock	(0)	(0)
Resource Constraint	(-)	(-)
Beliefs in Persistent Shock	(-)	(-)
Policy Constraint	(+)	(0)

Table 2: Summary Statistics

Summary statistics winter wheat, CA CO ID KS MT OK OR SD WY				
	mean	sd	min	max
Yield Per Acre Planted	19.0	9.89	0.16	86
Acres planted, W.Wheat	57,456.5	79,535.6	10	615,000
Exposure, t	0.10	0.37	0	6.58
Observations	13,400			

Summary statistics corn, IA MT ND NE SD WI				
	mean	sd	min	max
Yield Per Acre Planted	33.6	23.3	0.013	120.3
Acres planted, Corn	63,757.1	50,709.4	30	292,660
Exposure, t	0.090	0.29	0	3.09
Observations	11,852			

Table 3: OLS effects of yield shock on acres planted next year, 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
		Log wheat acres			Log corn acres	
Log Yield, t	0.127***	0.135***	0.126***	0.035***	0.027**	0.027**
	(0.019)	(0.021)	(0.018)	(0.012)	(0.012)	(0.014)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	No	Yes	Yes
State Time Trends	No	No	Yes	No	No	Yes
N	13,400	13,400	13,400	11,852	11,852	11,852
$Adj.r^2$	0.932	0.933	0.940	0.950	0.952	0.958

All yields are yield per acre planted for their respective crop. Standard Errors in parentheses are clustered by County. States in the winter wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, MT, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1945 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.

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

Table 4: 2SLS effects of yield shock on acres planted next year, fallout instrument, 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
		Log wheat acres			Log corn acres	
Log Yield, t	-0.437***	-0.520**	-0.729***	-0.054	0.013	-0.045
	(0.156)	(0.238)	(0.252)	(0.109)	(0.104)	(0.158)
			First stage IV coefficients			
Exposure, t	-0.124***	-0.091***	-0.093***	-0.156***	-0.167***	-0.108***
	(0.019)	(0.020)	(0.019)	(0.035)	(0.036)	(0.030)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	No	Yes	Yes
State Time Trends	No	No	Yes	No	No	Yes
Kleiberger-Paap Wald rk F-stat	40.60	21.60	23.11	19.47	21.04	12.79
N	13,400	13,400	13,400	11,852	11,852	11,852

All yields are yield per acre planted for their respective crop. Standard Errors in parentheses are clustered by County. States in the winter wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, MT, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1945 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.

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

Table 5: Log acres harvested conditioned on log acres planted: 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
		Log wheat acres			Log corn acres	
exposure	-0.060***	-0.046***	-0.047***	-0.193***	-0.166***	-0.128***
	(0.012)	(0.012)	(0.012)	(0.032)	(0.032)	(0.026)
Log acres planted	0.989***	0.990***	0.985***	1.201***	1.142***	1.038***
	(0.006)	(0.006)	(0.006)	(0.064)	(0.056)	(0.040)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	No	Yes	Yes
State Time Trends	No	No	Yes	No	No	Yes
N	13,871	13,871	13,871	12,224	12,224	12,224
r2_a	0.989	0.990	0.990	0.901	0.913	0.948

All yields are yield per acre planted for their respective crop. Standard Errors in parentheses are clustered by County. States in the winter wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, MT, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1945 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Placebo test, fallout exposure shifted forward 15 years : 1939-1950

	(1)	(2)	(3)	(4)	(5)	(6)
	Log acres planted		Log yield per acre planted		Log yield per acre harvested	
	Wheat	Corn	Wheat	Corn	Wheat	Corn
Placebo, t-1	0.021	0.012	-0.023	-0.039	-0.014	-0.021
	(0.022)	(0.011)	(0.028)	(0.032)	(0.019)	(0.028)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	No	No	No	No
State Time Trends	No	No	No	No	No	No
N	4,939	4,615	4,942	4,615	4,942	4,615
$Adj.r^2$	0.953	0.978	0.470	0.770	0.549	0.757

Fallout deposition was reassigned to the same counties but 15 year before nuclear testing started at the NTS. Standard Errors in parentheses are clustered by County. States in wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in corn sample include IA, MT, ND, NE, SD, and WI. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather Controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather Controls for corn consist of month temperature averages and precipitation totals for the months January to August in the current year.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Randomized placebo treatment, fallout for each test randomly reassigned to county within same test year: 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
	Log acres planted		Log yield per acre planted		Log yield per acre harvested	
	Wheat	Corn	Wheat	Corn	Wheat	Corn
Placebo	0.022	-0.008	0.029	-0.019	0.018	0.003
	(0.019)	(0.007)	(0.019)	(0.021)	(0.011)	(0.010)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	No	No	No	No	No
State Time Trends	No	No	No	No	No	No
N	12,933	11,418	13,400	11,852	13,400	11,852
$Adj.r^2$	0.932	0.952	0.490	0.586	0.582	0.780

Fallout deposition was randomly reassigned to counties within the sample within the same year of the test. Standard Errors in parentheses are clustered by County. States in wheat sample include CA, CO, ID, KS, MT, OK, OR, SD, and WY. States in corn sample include IA, MT, ND, NE, SD, and WI. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather Controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather Controls for corn consist of month temperature averages and precipitation totals for the months January to August in the current year.

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

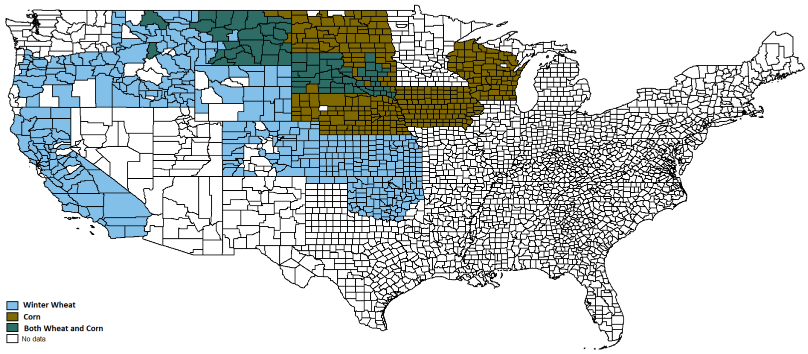

Figure 1: Empirical Sample of Corn and Wheat Producing Counties

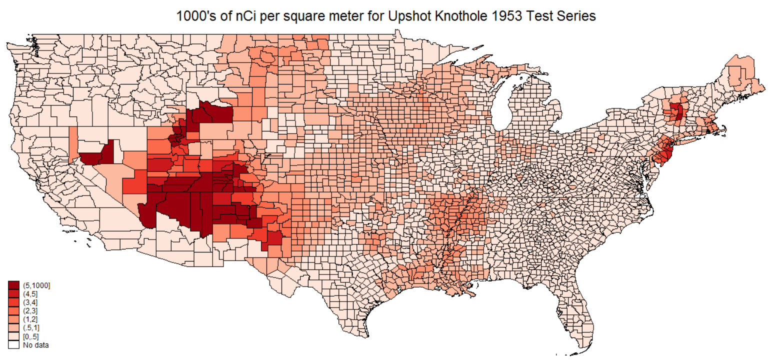

Figure 2: Cumulative I-131 Deposition in 1953

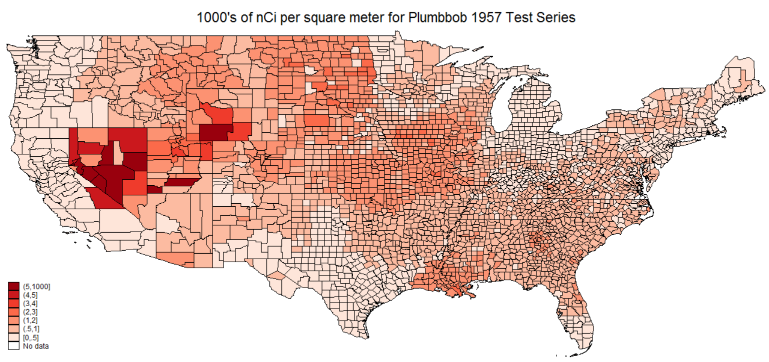

Figure 3: Cumulative I-131 Deposition in 1957

A Additional Robustness Checks

A.1 Learning responses following fallout events

Farmers might observe fallout-induced productivity shocks and develop beliefs about future growing conditions. Bayesian learning suggests that fallout-induced productivity shocks would be more informative in areas where there is low variability in agricultural yields. The intuition behind this prediction is that agricultural producers would be better able to discern that something is damaging crops from underlying noise in production when variance in productivity is low. If underlying productivity is highly variable, then it becomes more difficult for producers to discern whether fallout-induced productivity shocks from random variation productivity.

Suppose that agricultural yields, denoted by Y_t are distributed normally with known variance σ and unknown mean μ_t, i.e. $Y_t \sim N(\mu_t, \sigma)$. The farmer has prior beliefs regarding the distribution of μ_t where $\mu_t \sim N(\mu_0, \tau)$. After experiencing a realized level of agricultural productivity the farmer adjusts her beliefs regarding future agricultural productivity for period $t+1$. This updated expectation is the weighted average of the observed Y_t and the prior beliefs the farmer holds. Equation (11) describes how the farmer updates their value of μ_{t+1}.

$$\mu_{t+1} = \frac{\sigma^2 * \mu_0}{\sigma^2 + \tau^2} + \frac{\tau^2 * Y_t}{\sigma^2 + \tau^2} \tag{11}$$

As underlying variance in crop productivity, σ, increases the farmer weights the released yields in year t, Y_t, less and weights the prior beliefs relatively more. I test this Bayesian prediction by interacting the fallout exposure variable with the inverse of county specific yield variances from 1939 to 1950 in an OLS regression. The inverse variance variable increases as variation in yields decreases. If farmers learn from fallout and adjust their behavior in response to fallout-induced shocks, then areas with lower variability should decrease acreage in response to fallout shocks. Table A1 reports information regarding the inverse yield variance measures. The OLS results are reported in Table A4. I find that the the fallout exposure variable interacted with inverse yields has a consistently negative coefficient for both wheat and corn. Only specifications (2) and (3) for wheat find statistically significant effects at the 5% and 10% levels respectively. A one standard deviation increase in the inverse variance measure offsets the increase in planted acreage by approximately 2.2%.

These results suggest that farmers in areas with less variability in productivity were more likely to treat fallout-induced productivity shocks as persistent events and that this learning offsets the policy induced planting behavior estimated in the 2SLS analysis.

Table A1: Summary statistics of yield variance measures

Winter Wheat Sample					
Variable	Obs	Mean	Std. Dev.	Min	Max
Inverse Yield Variance	33,744	0.06	0.04	0.01	0.26
Interaction	33,744	0.00	0.02	0.00	0.81
Corn Sample					
Inverse Yield Variance	34,732	0.04	0.10	0.01	1.52
Interaction	34,732	0.00	0.01	0.00	0.82

Table A2: OLS effects of fallout and underlying yield variability: 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
	Log wheat acres			Log corn acres		
Exposure, t-1	0.064***	0.093***	0.086***	0.015	0.008	0.017
	(0.025)	(0.025)	(0.025)	(0.014)	(0.014)	(0.014)
Exposure, t-1 X	-0.258	-0.727**	-0.549*	-0.183	-0.233	-0.277
Inv. Yield Var.	(0.305)	(0.335)	(0.315)	(0.190)	(0.190)	(0.202)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	No	Yes	Yes
State Time Trends	No	No	Yes	No	No	Yes
N	12,113	12,113	12,113	11,280	11,280	11,280
adj r^2	0.927	0.929	0.933	0.947	0.948	0.956

Standard Errors in parentheses are clustered by County. Inverse yield variances for each . States in the winter wheat sample include CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1939 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.2 The effect of a binding policy constraint

From 1939 to 1949, the government did not restrict the amount of acreage farmers could harvest but it did collect the information to determine farmers' base acreages. In 1950, the government enforced acreage allotments on both wheat and corn. These were lifted due to the Korean War between 1951 and 1953 and reinstated in 1954 (Cochrane and Ryan, 1976). I interact my fallout variable with an indicator variable for years after 1954 in an OLS framework to test whether farmers reacted differently to fallout once the government started regulating farmers. It is plausible that farmers reacted more to government policy when the government was actively restricting allotments.

Since I do no have multiple instruments, I run the interaction directly in OLS with fallout replacing yield per acre planted. Table A3 reports farmers' responses once policy became binding. Corn producers who's productivity was not tied to acreage allotments did not adjust their planting in response to fallout shocks. The interaction term for wheat producers suggests that farmers started to increase cultivated acreage after the policy imposition.

Table A3: OLS effects of binding policy on harvested acreage: 1939-1970

	(1)	(2)	(3)	(4)	(5)	(6)
	Log wheat acres			Log corn acres		
Exposure, t	-0.001	-0.007	0.030	0.005	0.019	-0.019
	(0.023)	(0.024)	(0.024)	(0.032)	(0.037)	(0.035)
1[Year $\geq$ 1953]	0.132***	0.133***	0.093***	0.006	-0.033	0.036
X Exposure	(0.031)	(0.034)	(0.032)	(0.036)	(0.043)	(0.040)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	No	Yes	Yes
State Time Trends	No	No	Yes	No	No	Yes
N	13,400	13,400	13,400	11,852	11,852	11,852
adj r^2	0.931	0.933	0.939	0.950	0.951	0.957

Standard Errors in parentheses are clustered by County. Inverse yield variances for each . States in the winter wheat sample include CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1939 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B Measuring Weather Weather

B.1 Changes in planting in response to weather

Realized weather events likely affect farmers' planting decisions through weather's effects on agricultural productivity and through secondary belief channels. It is unlikely that farmers responses to weather events are wholly driven through weather's effects on productivity. Therefore, instrumenting for agricultural productivity using weather variables plausibly violates the exclusion restriction and the instrument is correlated with unobservable factors such as beliefs or adaptive investments. These unobserved factors would likely affect the estimated planting response farmers make towards productivity shocks in the previous year. Since a 2SLS analysis using weather shocks is not feasible due to violating exclusion restrictions, I use an OLS framework to measure weather's effects on corn and wheat yields. I then compare planting responses farmers make in the next year to these same weather measures. If farmers treat weather shocks as serially correlated across years, then a increases in temperatures associated with decreased crop productivity should decrease planting of that same crop next year and vice-versa. I pool temperature into three month average from January to December and aggregate precipitation to crop specific growing season totals to prevent a perfusion of coefficients. Temperature averages generally align with the growing season window used in the main analysis. [14] The results in Table **??** and for both corn and wheat. Increases in average temperatures that are associated with decreased corn or wheat yields result in farmers planting fewer acres of corn the next year. Warmer than average summers increase wheat yields and result in farmers planting more winter wheat for the subsequent growing year. A mild winter also increase planting but has no statistically significant effects on yields. These results suggest that agricultural producers responded to weather events in a manner consistent with a scenario where productivity shocks are serially correlated.

[14] The appendix reports correlations between these weather variables across years after the variables were demeaned of county and year fixed effects.

Table A4: OLS yield and planting responses to weather: 1939-1970

	(1)	(2)	(3)	(4)
	Corn		Wheat	
	ln yield, t-1	ln acres planted, t	ln yield, t-1	ln acres planted, t
Oct-Dec Avg Temp, t-2			0.006*	-0.004
			(0.003)	(0.004)
Jan-March Avg Temp, t-1			0.002	0.019***
			(0.002)	(0.002)
April-June Avg Temp, t-1	-0.023***	-0.011***	-0.042***	-0.013***
	(0.006)	(0.003)	(0.003)	(0.004)
July-Sept Avg Temp, t-1	-0.094***	-0.028***	0.020***	0.013***
	(0.007)	(0.004)	(0.003)	(0.004)
Growing Season Precip.	0.107***	-0.029***	0.035***	0.004
	(0.007)	(0.004)	(0.002)	(0.003)
Precip. Sq.	-0.002***	0.001***	-0.001***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
State Time Trends	Yes	Yes	Yes	Yes
N	11,852	11,852	13,400	13,400
adj r^2	0.772	0.957	0.533	0.939

Standard Errors in parentheses are clustered by County. Inverse yield variances for each . States in the winter wheat sample include CO, ID, KS, MT, OK, OR, SD, and WY. States in the corn sample include IA, ND, NE, SD and WI. Samples restricted to counties observed continuously from 1939 to 1958. Exposure is measured as thousand of nCi of I-131 depositing per square meter in a given year. Weather controls for wheat consist of month temperature averages and precipitation totals for the months January to August in the current year and months September to December of the previous year. Weather controls for corn consist of month temperature averages and precipitation totals for the months January to September in the current year.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C Data Appendix

C.1 Fallout Data Creation

When atomic bombs were detonated, a tremendous amount of energy which was released and caused splitting of the atoms in surrounding material. Atmospheric denotations conducted near the surface of the earth irradiated thousands of tons of material. This material was then drawn up into a mushroom cloud many kilometers up into the atmosphere. Figure A1 provides a diagram describing the 1953 Simon test shot. This figure describes how winds intercepted radioactive material. A portion of the radioactive material was intercepted by low altitude winds and deposited in the surrounding area as dry precipitate. In the downwind region, this radiation was carried as radioactive dust blows. Most of the material, however, was carried higher up and intercepted by high altitude winds. Figure A2 denotes where the resulting fallout debris clouds traveled in the days following the test. This radioactive material traveled vast distances and was deposited hundreds to thousands of miles from the test site as wet precipitate. In the days following the test, areas outside of the Downwind region experienced radioactive fallout only if it happened to be raining while the radiation cloud was over head. Rain scavenged radioactive dust from the cloud and delivered it to the ground. The agricultural regions studied in this paper would only experience fallout exposure through wet precipitate. As such, radioactive deposition from atomic testing can be treated as any exogenous event that would be uncorrelated with unmeasured aspects of farm production.

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. I use measures from 1951 to 1958 as these are the only tests which resulted in detectable depositions in my sample.[15] 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. The number of stations varies across time but never exceeded 100 stations.[16] Figure A3 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

[15] There was a testing moratorium from 1959 to 1961 and four low yield tactical nuclear tests at the NTS in 1962. The cumulative yield of these tests was less than two kilotons.

[16] The locations of the stations were not provided to me by the NCI.

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. Specific details regarding the techniques and calculations are available in National Cancer Institute (1997).

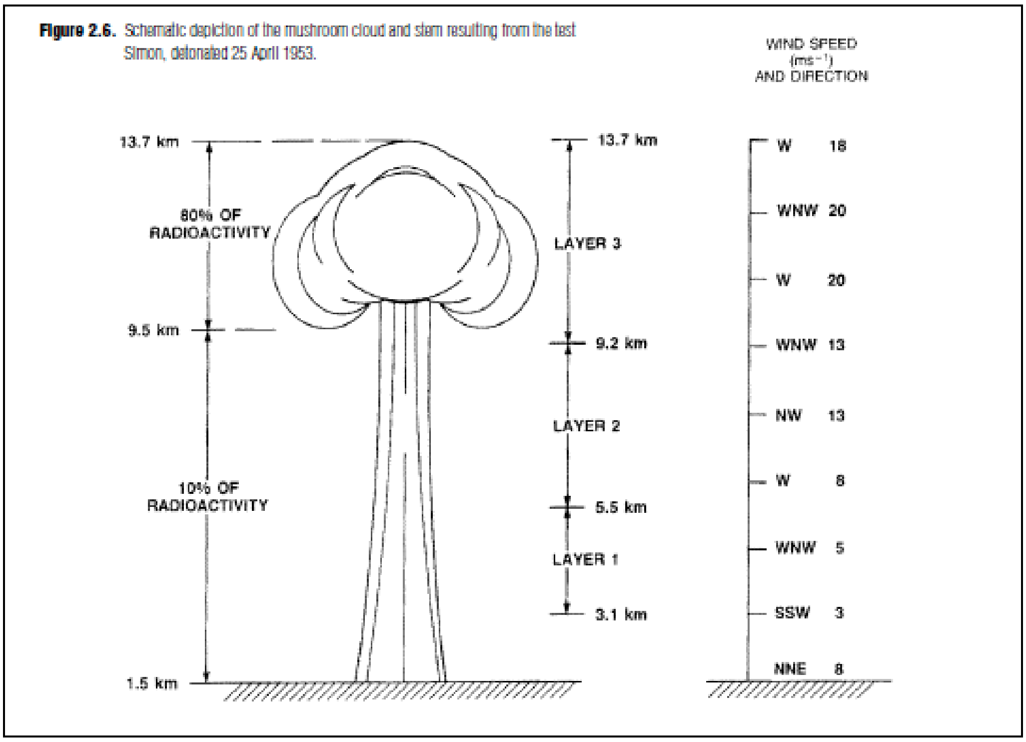

Figure A1: Mushroom Cloud and Wind Patterns, 1953 Simon Shot. Source: NCI 1997

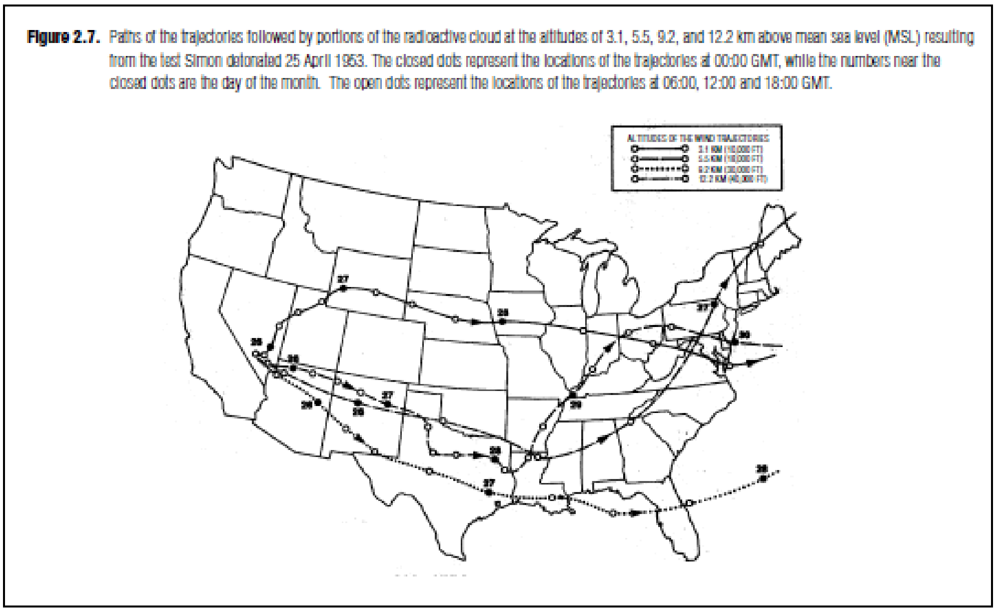

Figure A2: Trajectories of the 1953 Simon Shot's Radiation Clouds. Source: NCI (1997)

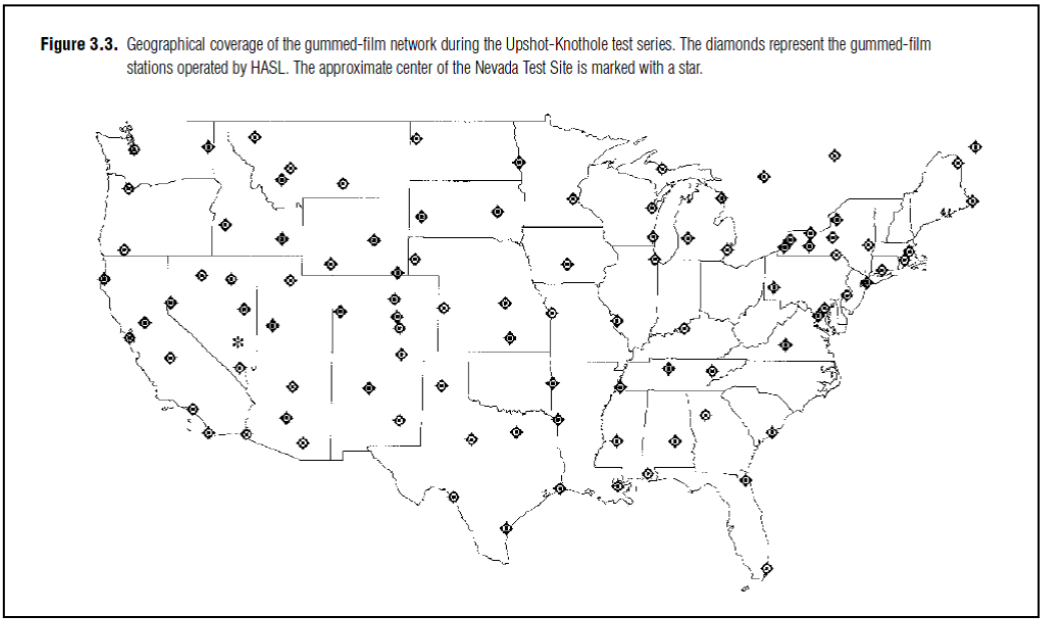

Figure A3: Map of National Radiation Monitoring Stations 1953. Source: NCI (1997)

Table A5: Atmospheric Nuclear Tests Conducted at Nevada from 1951-1953

Test Series	Date	Yield (kt)	Type	Height (m)
		Ranger: 1951		
Able	1/27/1951	1	Airdrop	320
Baker	1/28/1951	8	Airdrop	330
Easy	2/1/1951	1	Airdrop	330
Baker-2	2/2/1951	8	Airdrop	335
Fox	2/6/1951	22	Airdrop	340
		Buster-Jangle: 1951		
Able	10/22/1951	<0.1	Tower	100
Baker	10/28/1951	3.5	Airdrop	340
Charlie	10/30/1951	14	Airdrop	345
Dog	11/1/1951	21	Airdrop	430
Easy	11/5/1951	31	Airdrop	400
Sugar	11/19/1951	1.2	Surface	1
Uncle	11/29/1951	1.2	Crater	-5
		Tumbler-Snapper: 1952		
Able	4/1/1952	1	Airdrop	240
Baker	4/15/1952	15	Airdrop	320
Charlie	4/22/1952	31	Airdrop	1050
Dog	5/1/1952	19	Airdrop	320
Easy	5/7/1952	12	Tower	90
Fox	5/25/1952	11	Tower	90
George	6/1/1952	15	Tower	90
How	6/5/1952	14	Tower	90
		Upshot-Knothole: 1953		
Annie	3/17/1953	16	Tower	90
Nacy	3/24/1953	24	Tower	90
Ruth	3/31/1953	0.2	Tower	90
Dixie	4/6/1953	11	Airdrop	1835
Ray	4/11/1953	0.2	Tower	30
Badger	4/18/1953	23	Tower	90
Simon	4/25/1953	43	Tower	90
Encore	5/8/1953	27	Airdrop	740
Harry	5/19/1953	32	Tower	90
Grable	5/25/1953	15	Airburst	160
Climax	6/4/1953	61	Airdrop	400

Table A6: Atmospheric Nuclear Tests Conducted at Nevada from 1955-1957

Test Series	Date	Yield (kt)	Type	Height (m)
		Teapot: 1955		
Wasp	2/18/1956	1	Airdrop	230
Moth	2/22/1956	2	Tower	90
Telsa	3/1/1956	7	Tower	90
Turk	3/7/1956	43	Tower	150
Hornet	3/12/1955	4	Tower	90
Bee	3/22/1956	8	Tower	150
Ess	3/26/1956	1	Crater	-20
Apple-1	3/29/1956	14	Tower	150
Wasp Prime	3/29/1956	3	Airdrop	225
Ha	4/6/1956	3	Airdrop	11160
Post	4/9/1956	2	Tower	90
Met	4/15/1956	22	Tower	120
Apple-2	5/5/1956	29	Tower	150
Zucchini	5/15/1956	28	Tower	150
		Plumbbob: 1957		
Boltzmaan	5/28/1957	12	Tower	150
Franklin	6/2/1957	0.14	Tower	90
Lassen	6/5/1957	0.0005	Balloon	150
Wilson	6/18/1957	10	Balloon	150
Priscilla	6/24/1957	37	Balloon	210
Collumb-A	7/1/1957	0	Surface	0
Hood	7/5/1957	74	Balloon	460
Diablo	7/15/1957	17	Tower	150
John	7/19/1957	2	Rocket	6100
Kepler	7/24/1957	10	Tower	150
Omens	7/25/1957	10	Balloon	150
Pascal-A	7/26/1957	slight	Shaft	.
Stokes	8/7/1957	19	Balloon	460
Saturn	8/10/1957	0	Tunnel	.
Shasta	8/18/1957	17	Tower	150
Doppler	8/23/1957	11	Balloon	460
Pascal-B	8/27/1957	N.A.	Shaft	.
FranklinP	8/30/1957	4.7	Balloon	230
Smoky	8/31/1957	44	Tower	210
Galileo	9/2/1957	11	Tower	150
Wheeler	9/6/1957	0.2	Balloon	150
Collumb-B	9/6/1957	0.3	Surface	.
Laplace	9/8/1957	1	Balloon	460
Fizeaij	9/14/1957	11	Tower	150
Newton	9/16/1957	12	Balloon	460
Rainer	9/19/1957	1.7	Tunnel	-240
Whitney	9/23/1957	19	Tower	150
Charleston	9/28/1957	12	Balloon	460
Morgan	10/7/1957	8	Balloon	460

Table A7: Atmospheric Nuclear Tests Conducted at Nevada from 1958

Test Series	Date	Yield (kt)	Type	Height (m)
		Hardtack-Phase II: 1958		
Citero	9/12/1958	0.038	Shaft	-150
Bernalillo	9/17/1958	0.015	Shaft	-140
Eddy	9/19/1958	0.083	Balloon	150
Luna	9/21/1958	0.0015	Shaft	-150
Mercury	9/23/1958	slight	Tunnel	.
Valencia	9/26/1958	0.002	Shaft	-150
Mars	9/28/1958	0.013	Tunnel	.
Moria	9/28/1958	2	Balloon	460
Hildalgo	10/5/1958	0.077	Balloon	100
Colfax	10/5/1958	0.0055	Shaft	-110
Tamalpais	10/8/1958	0.072	Tunnel	-100
Oljay	10/10/1958	0.079	Tower	30
Lea	10/13/1958	1.4	Balloon	460
Neptune	10/14/1958	0.115	Tunnel	-30
Hamilton	10/15/1958	0.0012	Tower	15
Logan	10/16/1958	5	Tunnel	-250
Dona Ana	10/16/1958	0.037	Balloon	140
Vesta	10/17/1958	0.024	Surface	0
Rio Arriba	10/18/1958	0.09	Tower	22
San Juan	10/20/1958	0	Shaft	.
Socorro	10/22/1958	6	Balloon	440
Wrangell	10/22/1958	0.115	Balloon	460
Flushmore	10/22/1958	0.188	Balloon	150
Oberon	10/22/1958	0	Tower	.
Catron	10/24/1958	0.021	Tower	22
Juno	10/24/1958	0.0017	Surface	0
Ceres	10/26/1958	0.0007	Tower	10
Sanford	10/26/1958	4.9	Balloon	460
De Baca	10/26/1958	2.2	Balloon	460
Chavez	10/27/1958	0.0006	Tower	26
Evans	10/29/1958	0.055	Tunnel	-260
Humbolt	10/29/1958	0.0078	Tower	10
Mazama	10/29/1958	0	Tower	.
Santafe	10/30/1958	1.3	Balloon	460
Titanan	10/30/1958	0.0002	Tower	10
Blanca	10/30/1958	22	Tunnel	-250
Ganymede	10/30/1958	0	Surface	.

Table A8: Yearly correlation of I-131 fallout deposition

	t	t-1	t-2	t-3	t-4
t	1	-	-	-	-
t-1	0.0886	1	-	-	-
t-2	0.2009	0.0886	1	-	-
t-3	0.0311	0.2009	0.0886	1	-
t-4	0.1233	0.0311	0.2009	0.0886	1