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The stock market speaks: How Dr. Alchian learned to build the bomb

Joseph Michael Newhard *

John E. Walker Department of Economics, Clemson University, 109 College St. Apt 9, Clemson, SC 29631, United States

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ABSTRACT

At RAND in 1954, Armen A. Alchian conducted the world's first event study to infer the fuel material used in the manufacturing of the newly-developed hydrogen bomb. Successfully identifying lithium as the fusion fuel using only publicly available financial data, the paper was seen as a threat to national security and was immediately confiscated and destroyed. The bomb's construction being secret at the time but having since been partially declassified, the nuclear tests of the early 1950s provide an opportunity to observe market efficiency through the dissemination of private information as it becomes public. I replicate Alchian's event study of capital market reactions to the Operation Castle series of nuclear detonations in the Marshall Islands, beginning with the Bravo shot on March 1, 1954 at Bikini Atoll which remains the largest nuclear detonation in US history, confirming Alchian's results. The Operation Castle tests pioneered the use of lithium deuteride dry fuel which paved the way for the development of high yield nuclear weapons deliverable by aircraft. I find significant upward movement in the price of Lithium Corp. relative to the other corporations and to DJIA in March 1954; within three weeks of Castle Bravo the stock was up 48% before settling down to a monthly return of 28% despite secrecy, scientific uncertainty, and public confusion surrounding the test; the company saw a return of 461% for the year.

1. Introduction

Fifteen years before Fama conducted "the original event study" in 1969 (Fama, 1991 pg. 1599), Armen A. Alchian was pioneering financial event studies in his spare time. In this paper I reconstruct a confiscated and destroyed event study of the Castle Bravo nuclear test conducted by Alchian at RAND in 1954. This event is chosen because of the historical importance it holds as one of the world's earliest event studies, and due to the subsequent declassification of top secret information surrounding the test it also provides an excellent case study of market efficiency. Realizing that positive developments in the testing and mass production of the two-stage thermonuclear (hydrogen) bomb would boost future cash flows and thus market capitalizations of the relevant companies, Alchian used stock prices of publicly traded industrial corporations to infer the secret fuel component in the device in a paper titled "The Stock Market Speaks." Alchian (2000) relates the story in an interview:

> We knew they were developing this H-bomb, but we wanted to know, what's in it? What's the fissile material? Well there's thorium, thallium, beryllium, and something else, and we asked Herman Kahn and he said, 'Can't tell you'… I said, 'I'll find out', so I went down to the RAND library and had them get for me the US Government's Dept. of Commerce Yearbook which has items on every industry by product, so I went through and looked up thorium, who makes it, looked up beryllium, who makes it, looked them all up, took me about 10 minutes to do it, and got them. There were about five companies, five of these things, and then I

* Tel.: +1 614 747 1403.
E-mail address: JMNewhard@Gmail.com.

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> called Dean Witter… they had the names of the companies also making these things, 'Look up for me the price of these companies…' and here were these four or five stocks going like this, and then about, I think it was September, this was now around October, one of them started to go like that, from $2 to around $10, the rest were going like this, so I thought 'Well, that's interesting'… I wrote it up and distributed it around the social science group the next day. I got a phone call from the head of RAND calling me in, nice guy, knew him well, he said 'Armen, we've got to suppress this'… I said 'Yes, sir', and I took it and put it away, and that was the first event study. Anyway, it made my reputation among a lot of the engineers at RAND.

Alchian's study using only public information to successfully identify the fuel material of a secret US nuclear bomb test provides powerful evidence in favor of market efficiency; it was public information that the US was conducting atomic bomb tests, but it was not publicly known at the time how the bombs were constructed and even for top scientists working on the bomb, it was purely speculative what the best fusion fuel for hydrogen bombs would turn out to be. A timeline of notable dates in the secret development of lithium fuel as well as public information on lithium appearing in the media is found in Table 1. This original event study is a testament to Alchian's great contributions to economic thought; unfortunately, his work was so insightful that the paper was suppressed and is now lost and largely forgotten. Alchian (2006, pg. xxv–xxvi) provides some additional information on the relevant test:

> The year before the H-bomb was successfully created, we in the economics division at RAND were curious as to what the essential metal was—lithium, beryllium, thorium, or some other… For the last six months of the year prior to the successful test of the bomb, I traced the stock prices of those firms. I used no inside information. Lo and behold! *One* firm's stock price rose, as best I can recall, from about $2 or $3 per share in August to about $13 per share in December. It was the Lithium Corp of America. In January I wrote and circulated [the memorandum]. Two days later I was told to withdraw it. The bomb was tested successfully in February, and thereafter the stock price stabilized.

The first hydrogen bomb test, Mike shot of Operation Ivy on November 1, 1952, used liquid deuterium as its fuel. The purpose of Operation Ivy was to upgrade the US nuclear arsenal from atomic bombs to much more powerful hydrogen bombs. After Operation Ivy which involved a total of two tests, both in November 1952, Operation Upshot–Knothole followed with eleven detonations in Nevada between March and June 1953. The purpose of these tests was hydrogen bomb component development, measuring the effects of fallout and radiation, and the testing of the effects of nuclear artillery. Shot Ruth, the third of eleven tests in Upshot–Knothole, was detonated on March 31 and tested a bomb made with uranium hydride — it fizzled. The fifth test, Shot Ray, tested a device made of uranium deuteride on April 11 and also fizzled. The failures of both Ruth and Ray demonstrate the difficulties engineers faced in the development and testing of nuclear weaponry, especially in the early days with the uncertainty regarding the effectiveness of various radioactive materials available. The last, Shot Climax, was detonated on June 4, 1953 and tested the MK 7 primary detonator to be used in the two-stage weapons of Operation Castle. Climax was followed by Operation Castle – the first series of hydrogen bomb tests to make use of lithium fuel – with seven detonations from March 1 (February 28, local time) to April 22, 1954 in the Marshall Islands. At the time, scientists had only publicly speculated on the usefulness of lithium in the development of the hydrogen bomb; the Castle tests were the first to experiment with what were only theoretical uses of lithium fuel, though the public was not aware of this

Table 1
Timeline of major events.

Date	Private information	Public information
June 17, 1951	AEC agrees to begin producing lithium for possible use in the hydrogen bomb.	
August 1952		*Popular Science* speculates that lithium may be used in the hydrogen bomb due to its use in producing tritium.
March 18, 1953		"Much about the new development is secret. But what is known is this: the new device uses only three-quarters as much fissionable material as the bombs that destroyed the Japanese cities".
March 1, 1954	Castle Bravo, the first US test of a lithium fuel hydrogen bomb exceeds expected yield. Navy and Japanese fishing ships are dusted with radioactive fallout.	
March 2, 1954		"'Joint Task Force Seven has detonated an atomic device at the A.E.C.'s Pacific proving ground in the Marshall Islands. This detonation was the first in a series of tests.' The statement did not make clear whether the 'atomic device' was of the fission or thermonuclear (hydrogen) type."—NYT
March 14, 1954		"A high government official indicated today that the United States has set off the most powerful hydrogen blast yet achieved… a few days ago."—NYT
March 26, 1954	MK-21 bomb based on Castle Bravo test begins production.	

This table shows major public and private events reported in the New York Times and the Wall Street Journal regarding the Castle Bravo test. This is an abridged version of the full table in Appendix A.

experimentation due to the secrecy surrounding nuclear development. The first of these tests, Castle Bravo, was the first American test of a dry fuel thermonuclear bomb, using lithium deuteride instead of the cryogenic liquid fuel of previous tests. It was a great success and remains the largest detonation in US history, yielding 15 megatons, about 1000x the power of Little Boy or Fat Man. The lithium deuteride fuel generated an unexpected boost to the yield and Castle Bravo exceeded the predicted energy output by 150%, paving the way for powerful yet practical aircraft-deliverable weapons. It was so unexpectedly powerful that U.S. servicemen and Japanese fishermen who were thought to be at a safe distance from the test were dusted with fallout. The press reported on the destructive power of the bomb after a lag of several days, but mistakenly reported that it was an atomic rather than hydrogen bomb, illustrating the secrecy and lack of public information that surrounded the tests. The Bravo test was followed by Romeo on March 26 with fusion fuel composed of 7.5% lithium. It exceeded its expected energy by a factor of 3, yielding 11 megatons. Shot Echo, which had been scheduled for March 29, was canceled after the success of Bravo rendered cryogenic fuel bombs obsolete. The next shot, codenamed Koon, was run on April 6 but fizzled due to a design defect, and was followed by Union on April 25. Union used highly enriched lithium fuel and was a success, yielding 6.9 megatons. This was followed by Yankee II on May 5 with 40% partially enriched lithium fuel, doubling expected yield with 13.5 megatons, the second most powerful test in US history. Operation Castle concluded with Nectar on May 3 consisting of uranium and plutonium with a lithium booster. Given its importance, its timing, and its fuel source, Castle Bravo is the most likely subject of Alchian's suppressed paper. The following batch of tests called Operation Teapot were run from Feb 18 to May 15, 1955 and included 14 small 1 to 30 kiloton tests, but their purpose was to improve nuclear battlefield tactics, not bomb manufacturing.

The efficient market hypothesis holds that prices are "accurate," that they reflect all available information (Fama et al., 1969). As a test of market efficiency, several questions must be addressed surrounding Castle Bravo. First, to what extent was the Operation Castle test series kept secret before and after the tests, and how quickly and in what manner was the information surrounding the tests disseminated to the public? French and Roll (1986) observe that most information falls in a continuum between public and private, and Maloney and Mulherin (2003) and Maloney and Mitchell (1989) provide evidence that the stock market reflects secret or unknown information in the price discovery process. Operation Castle clearly entailed both public and private information components. Second, to what extent did the public understand the importance of lithium fuel in advancing the development of small high-yield thermonuclear weapons? Were there any unexpected positive developments regarding the use of lithium for commercial purposes that could have driven Lithium Corp.'s price upward in the time immediately preceding and subsequent to the successful Castle tests? As I demonstrate below, while stories mentioning lithium appearing in the New York Times or Wall Street Journal throughout 1953–1954 were consistent with a positive outlook for the lithium market, there were no sudden positive changes that alone would seem to explain very large increases in the valuation of Lithium Corp. in the months surrounding Operation Castle.

Using daily closing bids of major publicly traded manufacturers of fuel producers I find significant upward movement in the price of Lithium Corp. stock relative to other metal-producing corporations and to the Dow Jones Industrial Average (DJIA) in March 1954; within three weeks of Castle Bravo the stock was up 48% before settling down to a monthly return of 28% despite secrecy and public confusion surrounding the test. This greatly outperformed the other stock returns for the same month and the DJIA which saw an increase of 2.3% for the month. The price of Lithium Corp. continued to rise for the remainder of 1954 and saw a return of 461% for the year, some of which was gained in the two months leading up to the test despite little price movement in the twelve months prior. Lithium Corp. was seemingly singled out not only in the lead-up to the test, suggesting insider information, but after the successful test as well, suggesting successful dissemination of information relevant to the value of Lithium Corp. in the weeks and months following Operation Castle's success.

The paper proceeds as follows. I briefly describe the development of lithium fusion fuel in hydrogen bomb production as well as the market for radioactive metals generally in the early 1950s in Section 2; I observe price reactions of these manufacturers leading up to and after Castle Bravo in Section 3, and make some generalizations about the results in Section 4, with concluding comments in Section 5.

2. The market for lithium

In late 1948, Soviet scientists proposed using lithium deuteride instead of deuterium and tritium in nuclear bombs. By early 1949, they were told to develop a bomb using lithium. But "at the time, this was just another theory … and would not be revisited for five years" (DeGroot, 2005 pg. 168). Working in parallel in the United States, Edward Teller proposed exploring the use of lithium deuteride in bombs as an alternative fuel to liquid deuterium; being a solid at room temperature, it would not require being kept several hundred degrees below zero inside the bomb, although its high rate of radiation, nine times that of hydrogen isotopes, appeared much more difficult to ignite. "Assuming the ignition problem could be overcome, Teller thought that hundreds of kilograms of Li^6D might need to be produced" (Rhodes, 1996 pg. 306). In June 1951 Edward Teller wrote a memo noting the advantages of using lithium deuteride and "the AEC agreed to begin producing lithium deuteride as a possible fuel for both the equilibrium thermonuclear and a radiation-imploded Alarm clock" device (Rhodes, 1996 pg. 476). However, the usefulness of lithium fuel was still highly speculative, and in the lead-up to the first hydrogen bomb test as Ivy Mike, lithium fuel was regarded as too complicated and was put on the back-burner (Rhodes, 1996 pg. 483–484):

> One early and important decision concerned which thermonuclear fuel to use. Lithium deuteride was one choice. Deuterated ammonia was another. Liquid deuterium was a third. Each had its advantages and disadvantages. Lithium deuteride—LiD—would be the simplest material to engineer because it was a solid at room temperature, but breeding tritium within a bomb from lithium required a complex chain of thermonuclear reactions that involved only one of lithium's several isotopes, Li^6. "We were very much aware of lithium deuteride," Hans Bethe comments. "We were not totally sure how well it would work."… [They] soon settled on liquid deuterium despite its engineering challenges… primarily

> because it would give the cleanest physics… The description of the [thermonuclear] burning process of pure deuterium is much simpler than the description of the burning process with either Li^6 or normal lithium deuteride… To avoid discussing the lithium seemed like a virtue. Every departure from the simplest picture seemed like something to avoid.

Despite the secrecy surrounding nuclear development, the September 1952 issue of *Popular Science* suggested that lithium may come to be used in hydrogen bombs due to its use in producing tritium, leading to an increase in demand for lithium in the coming years: "For lithium, there seems good reason to believe, may be called 'the H Bomb metal.' It is expected to play a key part in making the hydrogen bomb, the most awesome military weapon ever projected… In addition, although this is pure speculation, lithium itself might actually be put into H-Bombs." In addition to being a source for tritium, the article noted that "Fusion-type atomic reactions between hydrogen and lithium are among those that could yield enormous energy [and] the purely mechanical problem of squeezing as much hydrogen as possible into a bomb might favor using lithium hydride—a solid lithium–hydrogen compound" (Armagnac, 1952 pg. 111–112). But the author makes it clear that this is all pure speculation. However, the scientists did come around to the use of lithium fuel despite earlier objections, and "by August 1953, Los Alamos was actively preparing to test (in 1954) a lighter, lithium-deuteride-fueled successor to Mike that could be weaponized quickly for delivery by air" (Rhodes, 1996 pg. 525).

Even though lithium was viewed as a possible component for hydrogen bombs leading up to the Castle Bravo test, it is clear that the theoretical possibility still required successful design of a bomb that wouldn't fizzle. The Soviets had a parallel research plan that also was considering lithium deuteride and in August 1953, the Soviets successfully tested a bomb using lithium deuteride and uranium, their first hydrogen bomb (Miller, 1986). Although lithium deuteride was known secretly by American scientists to be a possible contributor to a workable H bomb, it was not until the successful March 1954 Castle Bravo test which used lithium deuteride instead of deuterium that its usefulness was substantiated; "This explosion was twice as large as expected and 40 times more powerful than [the soviet bomb]" (DeGroot, 2005 pg. 192–193).

According to Alchian's interview, the fuel materials that he suspected of being used in the hydrogen bomb at the time of Operation Castle included beryllium, thallium, thorium, and lithium. To recreate the event study, I record stock prices of publicly traded manufacturers of the possible fuel components of early two-stage thermonuclear weapons from 1953 to 1954. Using the "Minerals Yearbook Metals and Minerals (Except Fuels) 1954" from the now-defunct US Bureau of Mines, I obtain information on radioactive materials including which firms produced them. (In Tables 2 and 3 I also include producers of radioactive material other than the four Alchian specifies.) I then determined which of these were publicly traded. Of these, I tracked down their daily closing bid prices for 1953–1954 in the Wall Street Journal archives on ProQuest. Table 2 lists radioactive material producers, and Table 3 identifies publicly traded ones.

Of the lithium producers, Foote Mineral Co. produced only lithium carbonate up to this time (used for glasses, adhesives, and batteries) and spent 1953–1954 expanding its lithium production capacity. American Potash & Chemical was also expanding into lithium at this time, and produced such a diverse range of chemicals that the stock price response to developments in the lithium

Table 2
Major producers of radioactive metals.

Element	Major producers
Uranium	– Anaconda Copper Mining Co.
	– Homestake Mining Co.
	– Kerr-McGee Oil Industries, Inc.
	– United States Vanadium Co.
	– Canadian Radium & Uranium Corp.
Radium	– Canadian Radium & Uranium Corp.
Thorium	– Lindsay Chemical Co.
	– Maywood Chemical Works
	– Rare Earths, Inc.
	– Westinghouse
	– Metal Hydrides, Inc.
Polonium	– Monsanto Chemical Co.
	– Mound Laboratories
Plutonium	– DuPont Company
Beryllium	– Beryllium Corp.
	– Beryl Ores Co.
	– Brush Beryllium Co.
Bismuth	– American Smelting & Refining Co.
	– Anaconda Copper Mining Co.
	– US Smelting Lead Refining Inc.
Thallium	– American Smelting & Refining Co.
Lithium	– Lithium Corp. of America
	– Foote Mineral Co.
	– American Potash & Chemical

This table shows major producers of radioactive metals in 1954. Source: Bureau of Mines, Minerals yearbook metals and minerals (except fuels) 1954, Year 1954, Volume I United States Government Printing Office, 1958.

market would be diluted. As such I use Lithium Corp. to represent lithium production, as Alchian did. The New York Stock Exchange-traded companies Westinghouse, Monsanto, and DuPont are all too large and diversified to expect any significant price response based solely on their radioactive metal interests. American Smelting (ASARCO) is also a large producer but is included as the sole publicly traded producer of thallium. All companies included in the event study are listed in bold in Table 3. (Lithium Corp. went on to merge with Gulf Resources in 1967).

3. Market reaction to the Castle Bravo detonation

3.1. The Operation Castle tests

Operation Castle was part of the effort to develop powerful weapons that were small enough to be delivered by aircraft, a drive requiring innovative bomb designs. The relatively weak bomb at Nagasaki was only 17% efficient as measured by percent of material fissioned, while the Hiroshima bomb was only 1.4% efficient, yielding about 20 and 15 kt each, respectively (see Nuclear Weapon Archive, 2007). Such pure fission atomic weapons used uranium or plutonium fuel. These were followed by the development of boosted fission atomic weapons which more than doubled the energy output of pure fission weapons. These in turn were replaced by a third design, the Teller–Ulam configuration, a radical innovation that greatly increased the efficiency of nuclear weapons utilizing a two-stage design with a primary fission trigger that compressed a fusion fuel capsule. Commonly called a hydrogen bomb, it was first tested at Ivy Mike in November 1952, resulting in a yield of 12,000 Mt and was an important step in developing small, extremely powerful nuclear weapons.

In addition to the new design, other approaches for boosting the energy output of nuclear weapons were tested. "One of the new approaches – the use of non-cryogenic "dry" (lithium deuteride) fuel – was a spectacular (and disastrous) success with a yield far exceeding expectations" (Nuclear Weapon Archive, 2007). Castle Bravo was the first "dry" (solid fuel) H-bomb the US detonated, using lithium deuteride in a natural uranium tamper. It was the basis for the MK-21 bomb which went into further development beginning on March 26; by December 1955, mass production began and 275 units were built through July 1956. In late 1957 it was upgraded to the MK-36 design (Nuclear Weapon Archive, 2007). Yet just a few years earlier, the development of the hydrogen bomb had stalled prior to the 1951 development of the Teller–Ulam design and no plans were made to produce lithium enriched in Li^6. As such, "it became a race to get a large lithium enrichment plant into production" once the working hydrogen bomb design was developed (Nuclear Weapon Archive, 2007). Due to the lack of lithium-6, some of the Operation Castle tests used partially enriched or unenriched lithium instead. The second test, Castle Romeo used lithium deuteride fusion fuel consisting of cheap and abundant unenriched lithium. It was unknown ex ante whether unenriched natural lithium would be effective fuel; "In fact as late as October 1953, Los Alamos was considering not even testing this device. The decision to include it was thought to be a crap-shoot to see if this cheap fusion fuel would be useful" (Nuclear Weapon Archive, 2007). Despite this concern, it produced the 4th largest nuclear detonation in US history. Romeo was a test of the MK-17 bomb which was deployed months later after the test was successful. Once the effectiveness of lithium dry fuel was demonstrated in the first of the Castle tests, the Castle Jughead test of cryogenic (liquid deuterium) fuel was seen as obsolete and was canceled. Four more Castle tests followed, concluding with Castle Nectar on May 14, 1954.

3.2. Lead-up to the test

Nuclear testing was shrouded in secrecy. Bomb design and even test schedule and location were classified. The article "Wide Open Secrecy" appearing in the Wall Street Journal on June 20, 1958 discusses how some information surrounding the tests was disseminated beyond the military:

> While the Atomic Energy Commission keeps secret the timing of its series of atomic blasts now going on in the Pacific, another government agency is busy broadcasting warnings to planes telling pilots to keep out of the area. The Civil Aeronautics Administration has been sending unclassified, uncoded messages to everybody who wants to listen telling

Table 3
Publicly traded manufacturers.

Metal	Company	Exchange	Pricing source
Beryllium	**Beryllium Corp.**	OTC	WSJ OTC Industrials
Beryllium	Brush Beryllium	NYSE[a]	WSJ New York Stock Exchange Transactions
Thallium	**American Smelting & Refining Co.**	NYSE[b]	WSJ New York Stock Exchange Transactions
Thorium	Westinghouse Electric Co.	NYSE	WSJ New York Stock Exchange Transactions
Thorium	**Metal Hydrides Inc.**	OTC	WSJ OTC Weekly List
Polonium	Monsanto Chemical Corp.	London	WSJ London Stock Averages
Plutonium	DuPont	NYSE	WSJ New York Stock Exchange Transactions
Lithium	**Lithium Corp. of America**	OTC	WSJ OTC Industrials
Lithium	Foote Mineral Co.	OTC	WSJ OTC Industrials
Lithium	American Potash & Chemical Co.	NYSE	WSJ New York Stock Exchange Transactions

This table shows all publicly-traded producers of metals from Table 2. The ones in bold are the focus of this paper.
[a] After 1956.
[b] In DJIA 1901–1958.

> pilots of specific periods of time when the test areas will be hazardous to airplanes. A spokesman for the A.E.C. condones the C.A.A. on the ground that "telling people they ought to stay out of an area is not the same as saying a test has occurred."

The article also notes that despite the secrecy surrounding tests, the Tokyo Meteorological Board detects the shock waves that nuclear tests generate at Bikini Atoll, 2424 miles away. The article "Ally for Peace" of March 18, 1953 discusses some unknowns regarding the new hydrogen bomb first tested 4 months earlier as Ivy Mike:

> Much about the new development is secret. But what is known is this: the new device uses only three-quarters as much fissionable material as the bombs that destroyed the Japanese cities; when finally it is perfected it will be small enough to be carried to its target by a jet plane, yet it is the equivalent of 15,000 tons of TNT.

Operation Castle itself was mysterious and its timing and the nature of the tests were not clear to the public. The public was only informed about upcoming tests with a cryptic and brief statement from the military ("Atom Blast Opens Test in Pacific; No Hint of Hydrogen Plans Given," New York Times, March 2, 1954):

> The only prior announcement was made Jan. 8. When the Atomic Energy Commission said that "men and materials" were being transported to the proving ground "to carry out a further phase of a continuing series of weapons tests of all categories."

This seems to have been the extent to which the public was informed of any specific upcoming nuclear testing by the US prior to Castle Bravo.

3.3. Dissemination of information following the detonation

The Castle Bravo test was detonated on Monday, March 1, 1954 at 06:45 EST (February 28, 18:45 GMT) at Bikini Atoll. It was a surface burst producing a yield of 15 Mt, 150% more powerful than the 6 Mt that was expected and producing a crater 2 miles wide. On March 1, 1954, the US detonated its first lithium-deuteride-fueled thermonuclear weapon called Shrimp, code-named Castle Bravo (Rhodes, 1996, pg. 542). "The room-temperature Shrimp device used lithium enriched to 40% lithium6; it weighed a relatively portable 23,500 lbs and had been designed to fit the bomb bay of a B-47 when it was weaponized. It was expected to yield about five megatons, but the group at Los Alamos that had measured lithium fusion cross sections had used a technique that missed an important fusion reaction in lithium7, the other 60% of the Shrimp lithium fuel component. "They really didn't know," Harold Agnew explains, "that with lithium7 there was an n, 2n reaction [i.e., one neutron entering a lithium nucleus knocked two neutrons out]. They missed it entirely. That's why Shrimp went like gangbusters." Bravo exploded with a yield of fifteen megatons, the largest-yield thermonuclear device the US ever tested. "When the two neutrons come out," says Agnew, "then you have lithium6 and it went like regular lithium6. Shrimp was so much bigger than it was supposed to be because we were wrong about the cross section"" (Rhodes, 1996, pg. 541).

The test is also one of the worst radiological disasters in U.S. history. The unexpectedly large yield combined with unfavorable weather patterns resulted in contamination of several inhabited islands including one where U.S. servicemen were stationed; evacuations were conducted only after victims received significant exposure to radiation. U.S. Navy ships and at least one Japanese fishing vessel were also dusted with fallout. "The US offered radiation specialists to treat the fishermen but refused to reveal fallout content for fear the Soviets would learn that the Shrimp had been fueled with lithium deuteride" (Rhodes, 1996, pg. 542). The next day, the New York Times reported on a statement from the Atomic Energy Commission which the paper noted was not clear on whether an atomic or hydrogen weapon had been tested:

> "Joint Task Force Seven has detonated an atomic device at the A.E.C.'s Pacific proving ground in the Marshall Islands. This detonation was the first in a series of tests." The language of Admiral Strauss' statement did not make clear whether the "atomic device" was of the fission or thermonuclear (hydrogen) type. There have been unofficial indications, however, that a variety of hydrogen weapons or devices will be tested during the next several weeks. The most powerful of these is expected to be an actual hydrogen bomb with perhaps twice the explosive power of the experimental device that disintegrated an island of Eniwetok Atoll on Nov. 1, 1952.

On March 7 and again on March 11 it was reported that a hydrogen bomb test was imminent. On March 12 it was announced that recent testing had resulted in radiation exposure to US servicemen and island natives. Not until March 14 was it reported that the test conducted in early March was a hydrogen bomb. Following the great success of the lithium fuel in Bravo, "the Castle tests continued with tests of an unenriched lithium-deuteride device… 'The results of Operation Castle,' Raemer Schreiber writes, 'left me with the unpleasant job of negotiating the closeout of a sizeable cryogenic hardware contract.' Future US thermonuclear weapons would be fueled with lithium deuteride" (Rhodes, 1996, pg. 542–543).

3.4. Price reaction

The pre-event period saw a run-up on the price of Lithium Corp. that was not seen by the other stocks. The January preceding Castle Bravo, the price of Lithium Corp. began rising following a year where the stock didn't see much change in price. On January

2, 1953 it was priced at $5.25 and ended the year at $5.125, having hit a low of $3.50 in mid-September. Yet in the 2 months leading up to Castle Bravo, Lithium Corp. of America rose from $5.125 on December 31, 1953 to $8.875 on February 26, 1954, the last trading day before the detonation. Charts 1 and 2 begin on this date and show the changes in stock prices for March for each day relative to February 28th. While there was no immediate price reaction to the successful test in any of the stocks, by March 5th all had gone up slightly but Lithium Corp. had overtaken the rest in return, a position it never relinquished. On March 8th, Lithium Corp. was up 12.7% to $10.00. It hit $11.00 on March 12th, jumped from 11 7/8 to 12 3/8 on March 19th, and was up over 48% to $13 1/8 on March 23, just over three weeks after the detonation, before settling down to $11.375 on March 31 for a monthly return of 28%. By comparison the Dow Jones Industrial Average (DJIA) had only risen 2.3% in March from 294.54 to 303.51. ASARCO and Metal Hydrides (MHI) saw very high growth relative to both the Dow and to their own prior 3 month averages, but rose much less than Lithium Corp., rising 16% and 19.6%, respectively. This would have presented strong circumstantial evidence to Alchian that lithium was the fuel used in Castle Bravo. Additionally, only in the case of Lithium Corp. did the price rise seen in March represent the continuation of high returns in previous months, a lead-up that Alchian referenced in his memories of the study. Returns surrounding the tests are given in Table 4.

Chart 2 graphs only Lithium Corp. stock for March, with key dates. At (1), Castle Bravo is successfully tested. The test remains secret, and the stock price is unaffected. At (2), the New York Times reports that Joint Task Force Seven announces the detonation of an "atomic device" in the Pacific. At this point, as far as the public knows only an atom bomb has been tested, and nothing extraordinary is reported. On March 3, the stock price dips to $8 3/4 before rebounding and steadily climbing to $10 on March 8, the day after the New York Times reports that "The United States detonated last week its forty-sixth nuclear device and prepared to test in the next couple of weeks its first operating model of a hydrogen bomb," appearing on Chart 2 as (3). At this point the press still believes that the March 1 device was atomic, but the stock price continues to climb. On March 11 – (4) on Chart 2 – the New York Times repeats the same error: "A hydrogen bomb designed for combat may produce history's greatest man-made blast in the Marshall Islands between March 16 and 28… The first blast in the current series of tests was March 1. The commission announced that an atomic device had been detonated, indicating that the hydrogen bomb was yet to come since hydrogen bombs are usually referred to as thermonuclear."

At (5) on Chart 2, March 12, 11 days after the test, the Wall Street Journal reports that "Twenty-eight Americans and 236 natives were "unexpectedly exposed to some radiation" during recent atomic tests in the Marshall Islands." This is followed by a decline of 25 cents in the stock price. Over the weekend on March 14, (6) on Chart 2, the New York Times reports, "A high government official indicated today that the United States has set off the most powerful hydrogen blast yet achieved… a few days ago." Then the stock price really begins to take off. On March 15 the stock price is at $10 3/4 but climbs up to $11 7/8 on March 18, the day when the New York Times reports, "Shattering power hundreds of times greater than any previous man-made explosion was unleashed when the US set off its hydrogen explosion No. 2," seen at (7) on Chart 2. The stock price continues up through a March 22 Wall Street Journal article reporting, "Commentators and some congressmen are busily telling us that the horrors implied by the latest explosion are beyond belief," marked at (8) on Chart 2. The price hits a new high of $13 1/8 on March 23. At this point the stock begins to come back down. On March 25, (9) on Chart 2, the Wall Street Journal reports, "All fish brought into Japanese and West Coast ports are being checked for radioactivity." On this date the stock price hits $11 7/8. The next day, at (10), the stock price drops to $11 1/2 as the Wall Street Journal reports, "Atomic Energy Commission reported plans to step up US production of hydrogen and other atomic weapons." On Saturday, March 27, (11) on Chart 2, Castle Romeo is successfully tested

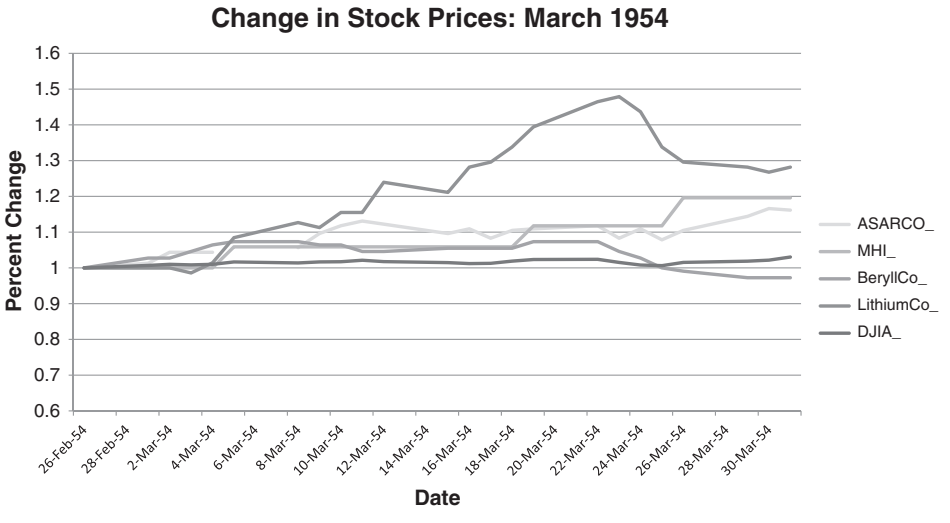

Chart 1. Stock prices, March 1954. Castle Bravo detonated on March 1. February 26 is last trading day prior.

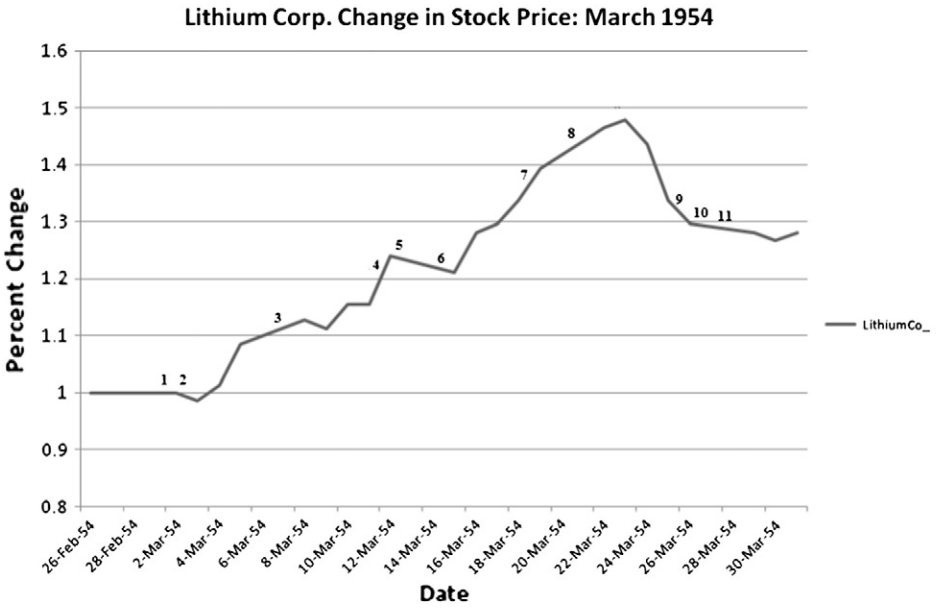

Chart 2. Stock prices, March 1954, Lithium Corp. Only with key dates.

Table 4
Stock returns surrounding March 1 Castle Bravo test.

	Lithium Co.	Beryllium Co.	ASARCO	MHI	DJIA
March 1954					
March 1954 return	.282	−.054	.147	.196	.023
Prior 3 month average return	.170	.023	.007	−.048	.016
March 1954 st. dev	1.37	.93	1.24	.83	1.98
Prior 3 month's average st. dev	.54	.57	.75	.42	2.42
Post-test 1954 returns					
Feb 26 price	8.875	27.25	28.625	12.75	294.54
Dec 30 price	28.75	40.5	45	23.5	401.97
Return	224%	49%	57%	84%	36%
1954 returns					
Dec 31 53 price	5.125	24.75	28	14.5	280.90
Dec 30 54 price	28.75	40.5	45	23.5	401.97
Return	461%	64%	61%	62%	43%

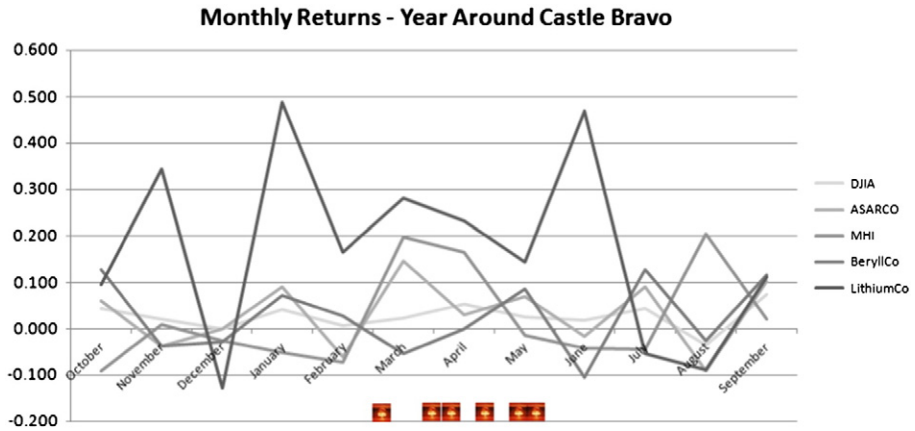

Chart 3. Monthly stock returns, year around Castle Bravo.

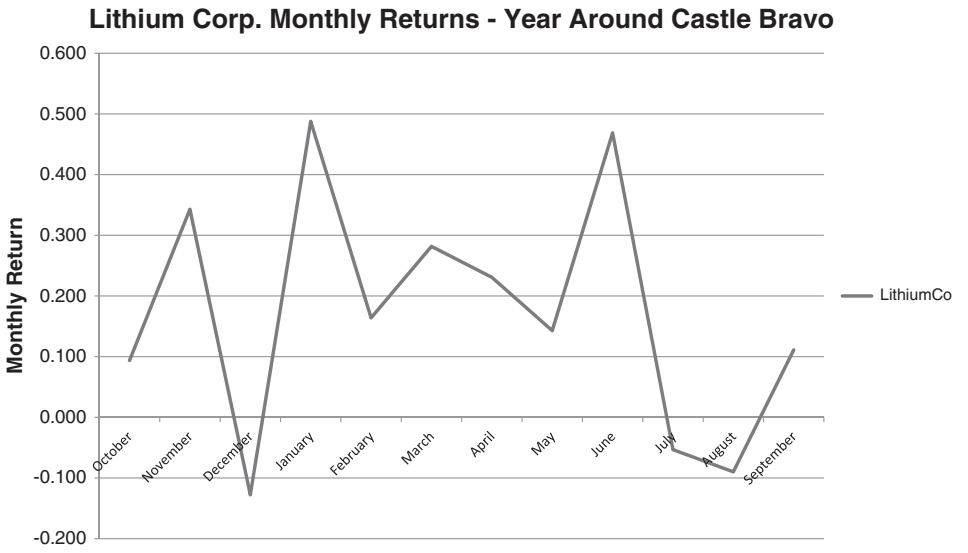

Chart 4. Monthly stock returns, year around Castle Bravo, Lithium Corp. only.

and the stock price drops to $11 3/8, closing at this price on March 31 two days later. Despite volatility in the stock price, it rose steadily throughout the month and would have indicated to Alchian that lithium was the likely fuel used in the Operation Castle devices.

Charts 3 and 4 plot monthly returns for the stocks and the Dow for the one-year period centered around the Castle series of tests. It shows that Lithium Corp. saw relatively high returns of 34.3% in November 1953, 48.8% in January 1954, 16.4% in February, 28.2% in March when the tests began, and then saw returns of 23.1%, 14.3%, and 46.9% in the following three months. From November 1953 through June 1954, Lithium Corp. beat the other stocks and the Dow in every month except December 1953 where it saw a negative return of −12.8%, two months prior to Castle Bravo. Comparing Lithium Corp., Beryllium Co., MHI, and ASARCO in the lead-up to and during the Castle tests, it is obvious which one would have stood out to Dr. Alchian or anyone else who knew to look to the stock market for information on the secret components of the hydrogen bomb.

Charts 5 and 6 graph the cumulative changes in stock prices and the value of the Dow from February 28, 1954 through December 30. The relative growth and volatility exhibited by Lithium Corp. following Castle Bravo is clear; after steadily climbing over 46% in 21 days, it dipped to a cumulative return of only 26.7% by March 30 before rebounding to a cumulative return of 71.8% on April 8th. By April 8th, ASARCO was up 21% and MHI was up 19.6%, both impressive in their own right. On this date the Dow was up 4.5% and Beryllium Co. was up less than 1%. By the end of the year, December 30, 1954, Lithium Corp. was at $28.75, a 224% return over the February 26 price, greatly exceeding the returns of the other companies as well as of the Dow, yet they all saw tremendous 10-month returns. Between the four companies, Beryllium Co. did the worst with only a 49% return by the end of

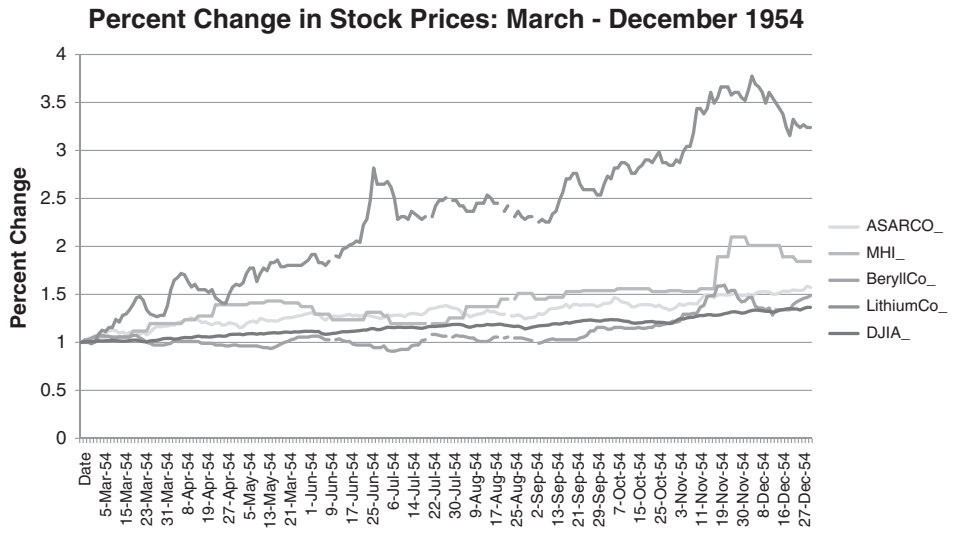

Chart 5. Percent change in stock prices, March–December 1954.

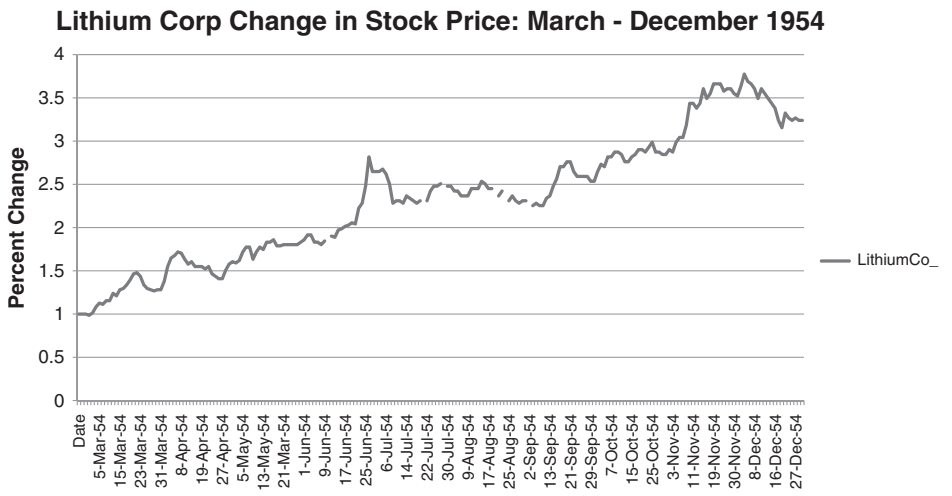

Chart 6. Percent change in stock prices, March–December 1954, Lithium Corp. only.

1954. Although at first the unusual price movements of Lithium Corp. in early 1954 may have been considered by a cautious skeptic to be a mere coincidence, if Alchian continued following the stocks through the end of the year his confidence in his findings undoubtedly grew.

Similarly, Chart 7 graphs cumulative changes in stock prices and the value of the Dow for the entire year, from December 31, 1953 through December 30, 1954. From the beginning of January, Lithium Corp. increased from $5.125 to $28.75, yielding a return of 461% for the year vs. 61%–64% for the other 3 companies and 43% for the Dow. Lastly, Charts 8 and 9 graph monthly returns of all four stocks and the Dow from January, 1953 through December, 1954. Relative to the other companies, Lithium Corp. was not unusual in its volatility and price movements for most of 1953. It enters a period of unusual volatility and unusually high returns only in the months immediately preceding, during, and after the Castle tests. This alone could have suggested to Alchian that lithium was likely the fuel used in the Castle series of nuclear devices, the high returns and volatility indicative of the dispersion of secret and increasingly certain knowledge favorable to the usefulness of lithium in hydrogen bombs.

3.5. Spot prices

The 1954 Minerals Yearbook on Lithium from the US Bureau of Mines specifically notes that lithium prices were not regularly quoted at the time. However, annual prices collected by the Geological Survey reveal that the price and production went up from 1953 to 1954, but that the 1954 price was below the 1952 real price. This suggests that the increased valuation of Lithium Corp. was not driven solely by a sudden increased spot price in lithium. American imports are listed as primarily originating from Southern Rhodesia, South West Africa, and Mozambique (Arundale and Marks, 1958 pg. 731). After the US, the largest importers

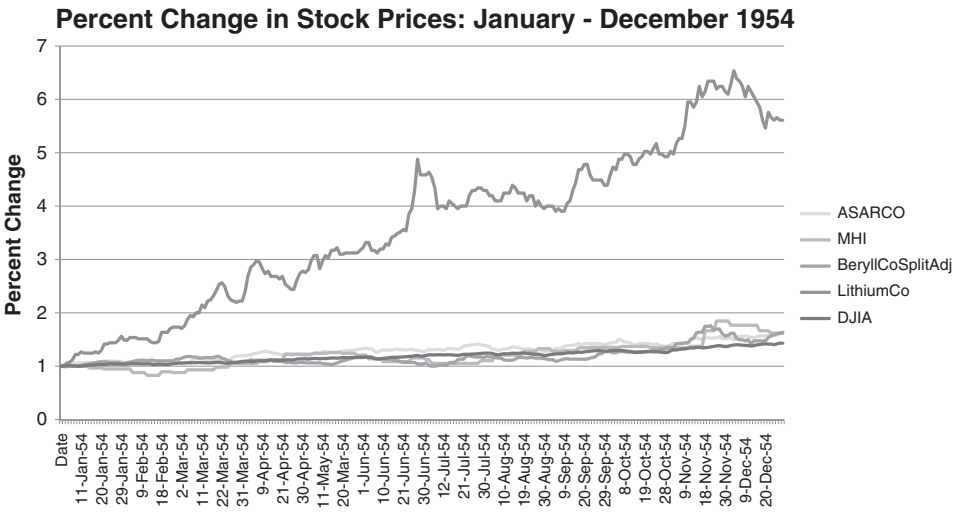

Chart 7. Percent change in stock prices, January–December 1954.

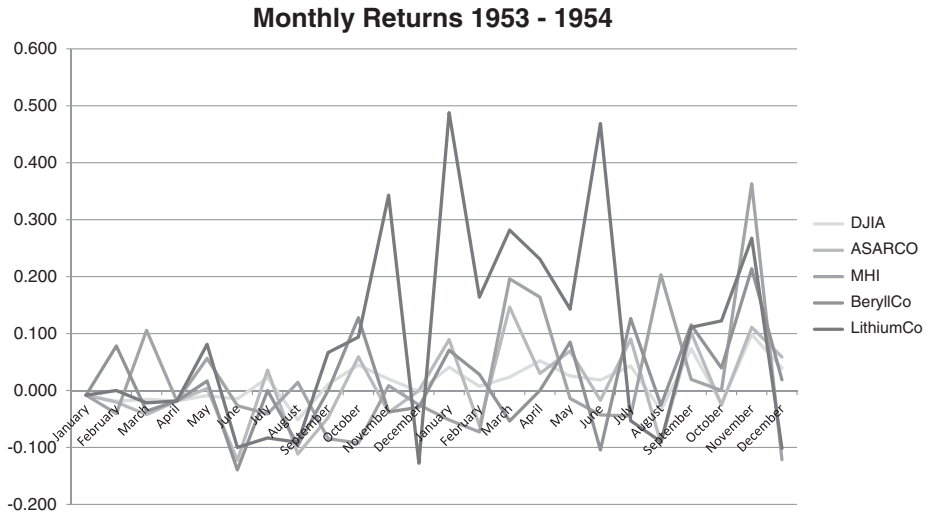

Chart 8. Monthly stock returns 1953–1954.

of lithium in 1953 were West Germany, United Kingdom, France, Netherlands and Australia (Arundale and Marks, 1958 pg. 735). Table 5 lists world production figures for lithium and price per metric ton. While "no official consumption figures were available," the Minerals Yearbook for 1954 states that two thirds of lithium that year was used for greases and ceramics, with a lesser amount input into "air conditioning, refrigeration, aluminum brazing, metallurgy, organic synthesis, batteries, and other applications" (Arundale and Marks, 1958 pg. 730). However, according to Moody's Industrial Manual 1961, over 50% of lithium production was going to the Atomic Energy Commission only seven years later. Also in 1954, the Department of Defense requested a report "on the availability of lithium, past and present, with particular emphasis on the advantages that might come to the national defense" through use of lithium, a report that had not been completed by year's end (Arundale and Marks, 1958 pg. 731). As Table 6 reveals, Lithium Corp. was a major player in the sudden rise in demand for lithium, doubling its net sales from 1954 to 1955, and then doubling again from 1955 to 1956.

4. Generalizations

Market efficiency "gauges the extent to which stock prices quickly and accurately respond to new information" (Maloney and Mulherin, 2003). How secret was Operation Castle in its timing and the nature of the tests, including its role in developing the MK21 and MK17 weapons, and how quickly and by what means was this private information disseminated to the public? The

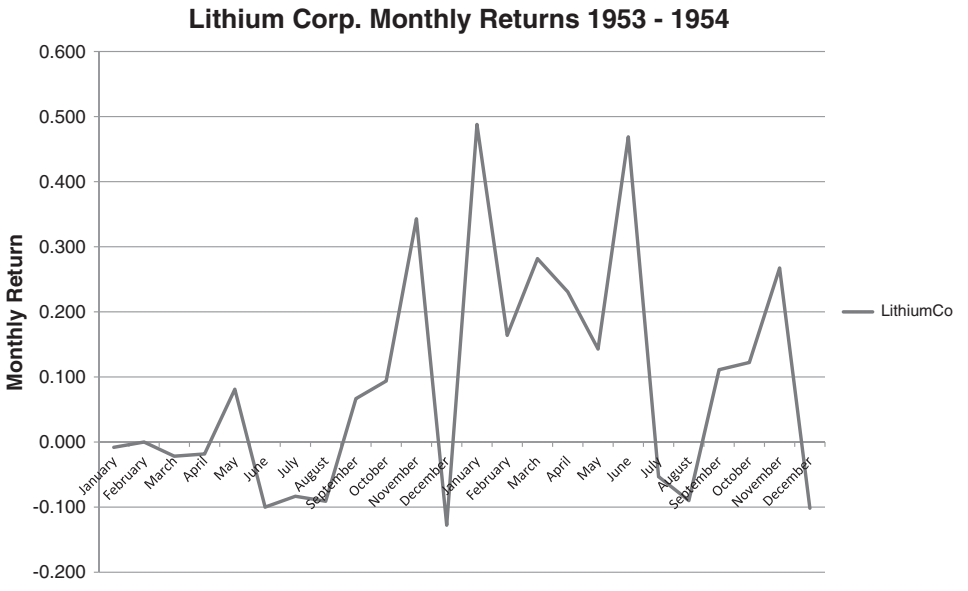

Chart 9. Monthly stock returns 1953–1954, Lithium Corp. only.

large, sudden increase in price and volatility seen in Lithium Corp. stock beginning in January 1954 indicates new, positive information being absorbed into the price discovery process that singled out Lithium Corp. among metal producers as suddenly warranting a higher valuation. The continued rise in the price of Lithium Corp. through 1954 demonstrates market efficiency given the ongoing uncertainty surrounding lithium fuel and the slow release of private information into the market.

The government statements concerning the tests that occurred as part of Operation Castle were vague, neither revealing the exact dates nor the nature of the tests. The first reports following the test stated that it was not clear whether the tests were atomic or hydrogen bombs. Even to those who understood the importance of lithium in new hydrogen bombs, the success of Castle Bravo could not be interpreted positively for the lithium market without first ascertaining if the test was of an atomic or hydrogen bomb. Indeed the price of Lithium Corp. remained flat for several days after the test. To the extent that subsequent price movements were in response to Castle Bravo, this slow reaction reveals a gradual spread of information regarding its implications for profitability of lithium producers. The lead-up to the test also shows significant gains in Lithium Corp., consistent with the possible dispersion of insider information. Since Castle Bravo also represented a test of what was to become the MK21 bomb which was built and deployed thereafter, this knowledge would have made investments in lithium producers seem highly lucrative following the successful test.

For the public, how well-understood was the importance of lithium in the development of hydrogen bombs? The bidding up of the price of Lithium Corp. in response to the Castle Bravo test relies on bidders not only being aware that the test was of a hydrogen rather than an atomic bomb, but also that lithium deuteride was being used in the hydrogen bombs to increase their destructive power. Three stories appearing in the Wall Street Journal in 1953 to 1954 mention lithium with regard to atomic weapons. On January 28, 1954, the story “Firms Flock to Adapt Bomb-Making Research to Scores of Civil Uses” noted that lithium is used in newly-developed hydrogen bombs. The March 9, 1954 story “Abreast of the Market” notes that lithium is used in atomic weapons. The December 30, 1954 story “A Special Background Report on Trends in Industry and Finance” also notes that hydrogen bombs use lithium. However, the fuel used in atomic weapons, including hydrogen bombs, differed from test to test. Even Alchian who worked at RAND didn't know which fuel was used in Castle Bravo, and the engineers refused to tell him. This suggests that nobody outside of a small circle of scientists knew that Castle Bravo was the first test of a hydrogen bomb using dry fuel in the form of lithium deuteride, and in any case its effects were only speculative before the test. Up to that point, lithium had been used only as a booster in a couple of tests following Ivy Mike. It was in these tests that the importance of lithium in the construction of hydrogen bombs was discovered as it increased the destructive power of the bombs. Yet as late as Castle Romeo, there were doubts as to how useful lithium would be in hydrogen bomb construction. Even if the information surrounding the tests was fully public, this uncertainty would have resulted in greater volatility and price discovery being drawn out over time.

The tests were announced by the military beforehand and reported on by major newspapers afterwards, but the exact dates were not known by the public ahead of time, nor did they know the internal bomb components, nor what was specifically being tested by the military, whether energy output, effects of radioactive fallout, nuclear war-fighting strategy, posturing to the Soviets, or some combination of intentions. Nor could they have known that Castle Bravo was in fact a test of the MK21 bomb prototype that was to be mass produced and deployed within the next 18 months as the US military's first deliverable hydrogen weapon pending the successful test. As news stories following the test reveal, information surrounding Castle Bravo was disseminated slowly, and some remained classified throughout the Cold War.

This seems to be a case where private information held by a few was slowly dispersed among market participants until this knowledge was reflected in stock prices allowing for the efficient allocation of lithium, consistent with Hayek's (1945) analysis of the price mechanism as a means of communicating information. While Romer (1993) notes that “outside observers very often cannot identify any news that could plausibly have been the source of observed changes in stock prices,” this is expected in a market involving secret military weapon testing. Together, Romer and Hayek can explain the volatility seen in Lithium Corp. stock surrounding the Castle tests as new information was dispersed and market actors made judgments about the uncertain but promising future for lithium. Under secret information and uncertain benefits of lithium, a slower price reaction and greater volatility is perfectly consistent with well-functioning efficient markets. Dow and Gorton (1993) argue that price responses to information may not be quick, with a resulting pattern of price discovery that is not obviously related to any specific news. To the extent that the stock price of Lithium Corp. was responding to Operation Castle, some of the price movement must have emanated from what was once private information including the use of lithium fuel, the yield boost it generated, and the consequent mass production and deployment of lithium fuel hydrogen bombs, but such price responses need not have occurred on any specific day

Table 5
Spot price of lithium 1950–1955.

Year	US production	World production	Value ($/t)
1950	347	18,000	NA
1951	444	25,200	NA
1952	505	25,500	2380
1953	821	57,800	1870
1954	1140	93,200	2200
1955	1250	86,000	2130

Source: Lithium Statistics, U.S. Geological Survey, http://minerals.usgs.gov/ds/2005/140/ds140-lithi.pdf. Production is in metric tons.

Table 6
Lithium Corp. annual accounting.

Year	Dividend	Net sales	Net income	No. sales
1953		$2,296,619	$197,807	547,750
1954		$3,178,287	$298,362	737,500
1955	.05	$6,381,876	$172,622	763,622
1956	.06	$12,151,856	$365,620	812,885
1957	.03	$12,209,874	$485,674	837,303
1958	.04	$11,186,616	$763,368	877,556
1959		$10,841,382	$593,357	930,698

Data on Lithium Corp. revenue Moody's Industrial Manual 1961.

since the dissemination of this private information is expected to be gradual given its classified nature. Castle Bravo occurred 12 years before the case SEC v. Texas Gulf Sulphur Co. (1966) where federal circuit court ruled that those who possess insider information cannot trade on it. Major legislation restricting insider trading did not come about until the 1980s.

In addition to hydrogen bomb manufacturing, lithium was used in a variety of products including ceramics, greases, glass, and batteries, and it is expected that the price of Lithium Corp. would respond to information regarding these products as well. Many of the news stories cover the expansion of lithium interests by major lithium producers. Of the 22 Wall Street Journal articles found that mention lithium between 1953 and 1954, 11 are primarily on the expansion of lithium mines, the upfront costs these investments entail and thus the declines in earnings, even though they are expected to increase future profits as demand for lithium continues to increase. On April 23, 1954, Foote Mineral Co. announces that a large portion of first quarter sales were of lithium and that the company is well-positioned to supply lithium to the US government if it demanded it. On June 10, 1954, it is reported that a Senate committee votes to increase the depletion rate of lithium mines for tax purposes. On August 31, 1954, the Wall Street Journal reported earnings for Lithium Corp. of America for the 6 month period ending June 30. A net income (after federal taxes) of $152,287 for 1954 was reported versus a 1953 net income of $77,980, an increase of 95%. It was clear in the press at the time that the market for lithium was doing well and that it was expected to continue growing due to both commercial and military uses of lithium.

Given the large returns seen by Lithium Corp. in 1954, perhaps the market also foresaw the massive magnitude of the arms race that followed. If lithium was considered to be the likely source of the much greater destructiveness of new hydrogen bombs, and if this destructiveness suggested to investors that the arms race would only accelerate, then an expectation of massively increased demand for lithium by the government could justify the returns seen by Lithium Corp. This would suggest that the market predicted that increasingly powerful weapons would, perhaps counter-intuitively, result in the stockpiling of even more nuclear weapons than otherwise would have been built. Indeed, the US achieved its all-time high of 31,255 nuclear warheads in 1967, up from 1436 in 1953, an increase of 2000% in 14 years. Ex post, the returns seen by Lithium Corp. following Castle Bravo seem quite reasonable.

Even with insider trading still legal, the slow speed of adjustment in Lithium Corp. prices could be explained in part by the high cost of information over large distances in 1954 given that the proving grounds were thousands of miles away from the mainland US. With the cost of information higher over greater physical differences, such a rate of price adjustment is not unexpected. Indeed, Peterson and Rajan (2002) find that “advances in computing and communications have increased the availability and timeliness of hard information” since the 1970s, allowing for more distant and impersonalized bank lending, so it is reasonable that investors of the past were biased toward investments that were close to home in the age preceding artificial satellites and subsequent advances in telecommunications, and that information from Castle Bravo and lithium production trickled in over the course of days or weeks.

5. Conclusion

This event study confirms Armen A. Alchian's report of the event study he conducted at RAND, revealing that he successfully determined the fuel that started being used in hydrogen bombs at that time, contributing to his reputation among the scientists and engineers who developed them. He accomplished this 15 years before what Fama referred to as the original event study, conducted by Fama, Fisher, Jensen, and Roll in 1969 in a study that analyzed stock splits, a development that Fama himself attributed to mere “serendipity” as a means to justify continued monetary support for CRSP data (Fama, 1991 pg. 1599). The price responses of mineral producers seen before and after Operation Castle provide evidence in support of market efficiency through the dissemination of formerly private information into the public sphere. Whereas previous research by Maloney and Mitchell (1989) and Maloney and Mulherin (2003) demonstrates the ability of the stock market to place blame, Alchian's event study shows that it incorporates positive news just as well, including secret or unknown information. Following the Operation Castle series of nuclear tests, it would have been apparent to insiders that the use of lithium fuel in hydrogen bombs was a tremendous innovation that boosted the energy output of smaller weapons, and that whoever manufactured the components of what was to become the MK21 bomb stood to profit from the test's success. There is some evidence that the Lithium Corp. stock price reflected this positive implication for the lithium market due to the Castle Bravo test, information that was not immediately known to the

public. Lithium Corp. stock increased greatly in the two months preceding the test and then exploded for the remainder of 1954 with a return of 461% for the year.

Alchian's event study also implies that through capital markets, inferences can be made about military secrets in countries that outsource military technology research and development to the private sector, and outsiders may be able to make such inferences about US military technology as well. Much as prediction markets can help predict political events (Wolfers and Zitzewitz, 2004), careful analysis of foreign stock exchanges may reveal secret government activities that affect the profitability of publicly traded firms.

Acknowledgments

Thanks to Harold Mulherin, William R. Dougan, Robert D. Tollison, Mike Maloney, and the participants of the public economics workshop at Clemson University and the finance department seminar at University of Georgia for helpful comments, and to Daniel K. Benjamin for introducing me to the work of Alchian.

Appendix A. Timeline of public and private events regarding lithium

Date	Private information	Public information
Late 1948	Soviets theorize that lithium deuteride fuel could replace deuterium and tritium in nuclear weapons	
June 1951	Edward Teller writes a memo on the possible advantages of lithium deuteride fuel	
June 17, 1951	AEC agrees to begin producing lithium for possible use in the hydrogen bomb	
August 1952		*Popular Science* speculates that lithium may be used in the hydrogen bomb due to its use in producing tritium
November 1, 1952	Ivy Mike, world's first hydrogen bomb, using liquid deuterium fuel is a success.	
March 9, 1953		Foote Mineral Co. earnings down for 1952 due to in part to heavy non-capital expenditures in its lithium expansion program.—WSJ
March 18, 1953		"Much about the new development is secret. But what is known is this: the new device uses only three-quarters as much f issionable material as the bombs that destroyed the Japanese cities"
July 13, 1953		Foote Mineral Co. is completing new plants in NC and VA to produce various ores and lithium chemicals, which are expected to increase assets, sales, and profits.—WSJ
August 1953	Los Alamos is preparing a lithium fuel hydrogen bomb test for 1954	
August 1953	Soviets test their first lithium deuteride bomb	
August 7, 1953		Foote Mineral Co. sees a decline in earnings due in part to investments in new plants. A decline in sales was the result of its "temporary inability to fully supply the expanding market for lithium chemicals and ores," but is increasing production. "Current market estimates indicate continued high demand for lithium ores and chemicals and Foote is intensifying its search for lithium-bearing deposits and other chemicals."—WSJ
November 19, 1953		American Potash and Chemical Corp. is adding lithium ores from a new source in Africa. It will "handle lepidolite and petalite ore mined from a large deposit of high-grade lithium-bearing minerals near Fort Victoria, Southern Rhodesia." "Lepidolite and petalite are used primarily by manufacturers of specialty glass and ceramics. Demand for all lithium products has been steadily increasing, and they have long been in short supply."—WSJ
November 30, 1953		Lithium Corp. of America reports quarterly earnings ending Sep. 30 with a net income of $53,448 or 10 cents per share, no indication of net income for same quarter in previous year. Its 9 month earnings ending Sep. 30 are reported to be $113,071 for 1953 vs. $16,446, in 1952, an increase in earnings per share from 3 cents to 26 cents.—WSJ
January 15, 1954		Foote Mineral Co. reports a record month in earnings for December due to its new lithium-producing plants. "In addition to lithium, which is finding expanding uses in lubricants, industrial coatings and other chemical applications, Foote produces a variety of other rare metallic articles used in electronics and atomic power fields."—WSJ

(*continued on next page*)

Appendix A. (*continued*)

Date	Private information	Public information
January 28, 1954		"Lithium is one of several other scarce metals not previously refined I commercial quantities but now easier to extract as a result of research spurred by the A.E.C.'s need for this light metal. It is the key in making a new top-secret hydrogen bomb that's simpler, cheaper, and easier to transport than earlier models. The increased knowledge and availability of this metal has now led its producers – Foote mineral Co., American Potash & Chemical Corp., and Lithium Corp. of America – to embark on experiments aimed at developing commercial uses for it, too."—WSJ
March 1, 1954	Castle Bravo, the first US test of a lithium fuel hydrogen bomb exceeds expected yield. Navy and Japanese fishing ships are dusted with radioactive fallout.	
March 2, 1954		"'Joint Task Force Seven has detonated an atomic device at the A.E.C.'s Pacific proving ground in the Marshall Islands. This detonation was the first in a series of tests.' The statement did not make clear whether the 'atomic device' was of the fission or thermonuclear (hydrogen) type."—NYT
March 4, 1954		Foote Mineral Co. directors approve expansion of production facilities for lithium ores and chemicals.—WSJ
March 7, 1954		"The United States detonated last week its forty-sixth nuclear device and prepared to test in the next couple of weeks its first operating model of a hydrogen bomb."—NYT
March 9, 1954		"Markets for lithium products have developed even more rapidly than anticipated," with Foote Mineral Co. planning to increase output. "Lithium compounds are used in wide temperature range lubricating greases, ceramics, welding rod coatings, alkaline type electric storage batteries, air conditioning materials and atomic energy development." —WSJ
March 10, 1954		"An expansion since 1946 of approximately 1000% in the consumption of lithium in the ceramic, grease, air conditioning, metallurgical and organic chemical fields, according to K. M. Leute, president of Lithium Corp. of America, Inc., is behind that firm's $7 million expansion program at Bessemer City, NC adjacent to deposits of lithium ore acquired by the company in the past 8 years and said to be the largest single reserve of lithium ore in the world."—WSJ
March 11, 1954		"A hydrogen bomb designed for combat may produce history's greatest man-made blast in the Marshall Islands between March 16 and 28… The first blast in the current series of tests was March 1. The commission announced that an atomic device had been detonated, indicating that the hydrogen bomb was yet to come since hydrogen bombs are usually referred to as thermonuclear."—NYT
March 12, 1954		"Twenty-eight Americans and 236 natives were "unexpectedly exposed to some radiation" during recent atomic tests in the Marshall Islands."—WSJ
March 12, 1954		"The United States is expected to set off the mightiest nuclear explosion in history sometime between March 15 and 28."—NYT
March 14, 1954		"A high government official indicated today that the United States has set off the most powerful hydrogen blast yet achieved… a few days ago."—NYT
March 18, 1954		"Shattering power hundreds of times greater than any previous man-made explosion was unleashed when the US set off its hydrogen explosion No. 2."—NYT
March 18, 1954		"That hydrogen blast two weeks ago jarred a Pacific isle 176 miles distant. It unleashed power hundreds of times greater than any previous weapon."—WSJ
March 19, 1954		"A Japanese fishing boat, 800 miles away from the test site when the US set off a hydrogen bomb March 1 at Bikini Atoll was found to be radioactive."—WSJ
March 19, 1954		"The March 1 explosion had left an area of total destruction about twelve miles in diameter."—NYT
March 20, 1954		"A Congressional investigation of the immense hydrogen explosion in the Pacific March 1 has been started to determine whether adequate security and safety precautions were taken in the area."—NYT
March 22, 1954		"Commentators and some congressmen are busily telling us that the horrors implied by the latest explosion are beyond belief."—WSJ
March 25 1954		"All fish brought into Japanese and West Coast ports are being checked for radioactivity."—WSJ
March 26, 1954		"Atomic Energy Commission reported plans to step up US production of hydrogen and other atomic weapons."—WSJ
March 26, 1954	MK-21 bomb based on Castle Bravo test begins production	
March 27, 1954	Castle Romeo test is successful	
March 28, 1954		"The biggest explosion in the current nuclear tests in the Pacific will be set off next month, probably about April 22."—NYT

Appendix A. (*continued*)

Date	Private information	Public information
March 29, 1954		"The hydrogen bomb test early this month is having some delayed but not necessarily surprising reactions… demanding an outright end to nuclear tests"—WSJ
March 31, 1954		"Churchill rejected Laborite demands to try to persuade the U.S. to halt H-bomb tests."—WSJ
April 1, 1954		American Potash & Chemical Corp.'s new high grade lithium beryllium interests in Southern Rhodesia "have resulted in a 'significant strengthening' of the company's position in [lithium]."—WSJ
April 5, 1954		Foote Mineral Co. "expects 1954 to be the best year in Foote's long history… 'the market is expected to absorb readily both the present and proposed capacity' for lithium and its compounds, which Foote produces and markets." —WSJ
April 7, 1954	Castle Koon test	
April 23, 1954		"A 'large portion' of the first quarter sales were in lithium, L. G. Bliss, sales vice president, stated. He remarked that queries were often made as to what effect developments in nuclear physics may have on Foote's prospects, and added 'If the US government desires lithium for any purpose we believe we are in the best position of any firm in the industry to serve that need. You can draw any conclusion you wish from that'."—WSJ
April 26, 1954	Castle Union test	
May 5, 1954	Castle Yankee test	
May 14, 1954	Castle Nectar test	
June 10, 1954		"The committee voted to give lead, zinc and lithium a 23% depletion rate on domestic mining operations. They now get 15% and would continue to get 15% on any overseas operation."—WSJ
June 16, 1954		"Cash is also being poured into preliminaries for a German leap into the atomic age. Although Allied regulations forbid West German atomic research or production, chemists here are making all the preparations for the day when these rules are scrapped. They already extract atomic energy materials, such as lithium from the giant cinder dumps of the industrial Ruhr. And researchers, financed by industry and the government, are doing extensive 'paper work' in the atomic field."—WSJ
July 30, 1954		"H. C. Meyer, chairman, said record sales and earnings figures could be attributed to increased production from new facilities added in 1953. He said the company's current enlargement of facilities for production of lithium ore concentrates will be substantially completed by the end of this year and further expansion of lithium chemical refining plants should be in operation early in 1955."—WSJ
August 31, 1954		For the 6 month period ending June 30, Lithium Corp. of America reports net income of $152,387 in 1954 vs. $77,980 for 1953—WSJ
September 10, 1954		"Lithium Corp. of America thinks increased operating efficiency will put second half earnings 'substantially in excess' of the $152,387 posted for the first six months of this year, which was up from $77,980 in the 1953 first half, according to Herbert W. Rogers, president."—WSJ
October 20, 1954		American Potash & Chemical Corp. plans to construct a lithium chemical plant in San Antonio, to be owned by the newly-formed American Lithium Chemicals, Inc. of which American Potash owns 50.1%. "Initially, lithium hydroxide will be produced there. Addition of the San Antonio plant is a major step in American Potash & Chemical Corp.'s program of expansion in the lithium chemicals field… 'There is a large unsatisfied demand for lithium products as a result of substantial growth in their use in enamels, ceramics, all-weather greases, air conditioning and other fields'."
October 29, 1954		"Foote Mineral's Quarter Indicated Sales Jumped 85% over a Year Earlier"—WSJ
November 1, 1954		"To get both stability and water resistance, more and more grease makers are turning to thickeners which replace sodium or calcium with lithium or barium, both of which are soft white metals. The new Cities Service, Tide Water and Gulf greases all are lithium based. Lithium or barium increases the water resistance and raises the melting point of greases."—WSJ
December 12, 1954		"Development of the hydrogen bomb and intensive industrial promotion have raised the world's lightest metal, lithium, from obscurity to a stellar role in half a dozen civilian and defense industries in the last five years."—NYT
December 30, 1954		"Next mining boom may be in lithium, lightest of metals. It's greatly needed for the hydrogen bomb. But it also has growing and important uses, in the form of lithium compounds, in all-weather greases for autos, enamels, special kinds of glass, air conditioning and in low temperature batteries."—WSJ

Timeline of major events surrounding Operation Castle, from New York Times and Wall Street Journal articles.

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