MATTHEW FUHRMANN'S "SPREADING TEMPTATION: PROLIFERATION AND PEACEFUL NUCLEAR COOPERATION AGREEMENTS"

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Introduction

- Peaceful nuclear cooperation
  - *Transfer of nuclear technology, materials, or knowledge from one state to another for peaceful purposes*
  - *December 1953: President Eisenhower's "atoms for peace" speech before the UN General Assembly*
    - Encourages nuclear suppliers to promote international peace & prosperity by sharing their technology & know-how
    - Since then, more than 2,000 bilateral civilian nuclear cooperation agreements (NCAs) have been signed
- NCAs being signed at an increasingly rapid rate
- Article examines the relationship between peaceful nuclear cooperation & nuclear weapons proliferation

Research Question

- Are countries receiving civilian nuclear aid over time more likely to initiate weapons programs and build the bomb?

Conventional Wisdom

- Civilian nuclear cooperation does not lead to proliferation.
- Most scholars argue that nuclear weapons spread when states have a demand for the bomb and not when they have the technical capacity to proliferate.
- Others who see importance of supply side of proliferation argue that “certain types of nuclear assistance enable countries to build nuclear weapons but that others are innocuous or even positive from a nonproliferation standpoint” (8).

Previous Scholarship

Demand-Side

- Most has focused on demand-side
  - *States pursue nuclear weapons when they have a demand for them, not just when they have the technological capacity to built the bomb.*
  - *Treat technological considerations as secondary concerns*
- Often dismissive of supply-side approaches
  - *Several countries (i.e., Germany & Japan) have the technical capacity to build nuclear weapons but have decided not to*

Supply-Side

- Does not sufficiently address the links between civilian nuclear cooperation & weapons proliferation
- Fails to adequately test the argument that diffusion of knowledge & technology makes proliferation more likely
- Does not explore how peaceful aid can encourage countries to pursue nuclear weapons
- Does not examine how strategic factors such as militarized interstate disputes (MIDs) could interact with nuclear assistance.

Author's Theory

- Conventional wisdom is not only wrong, but dangerous.
- All types of civilian nuclear assistance increase the risks of proliferation.
- Peaceful nuclear cooperation and proliferation are causally connected because of the dual-use nature of nuclear technology and know-how.
  - *Civilian cooperation provides technology and materials necessary for a nuclear weapons program & helps to establish expertise in matters relevant to building the bomb.*

Peaceful Nuclear Cooperation & Nuclear Weapons

- Related in two key respects:
  - *Weapons program & civilian programs require similar processes, technology, & materials*
    - Uranium enrichment & plutonium reprocessing facilities
  - *Civilians gain necessary knowledge and experience that can then be applied to weapons-related efforts*
    - Handling of radioactive materials, processes of fuel fabrication & materials having chemical or nuclear properties, operation and function of reactors & electronic controls systems
  - *Linkages suggest peaceful nuclear assistance lowers the expected costs of a weapons program*
    - Increases likelihood that a decision to begin a program will be made
  - *Members of atomic energy commissions often lobby the government when they think there is a good chance of rapid development and reduced costs*
    - Persuades leaders because they know the quicker the bomb can be developed, the less likely it is other national priorities will suffer.

- Peaceful nuclear assistance typically conditions the effect that a security environment has on a state's political decisions to begin a weapons programs
  - *Countries that receive considerable assistance are especially likely to begin weapons programs when threats arise because they have a greater demand for the strategic advantages that nuclear weapons offer*
  - *A State that suffers a defeat in war or feels threatened is unlikely to begin a program if it lacks a developed civilian nuclear program*
    - Saudi Arabia
  - *Countries that do not face a security threat, even if they have gotten significant amounts of assistance, are unlikely to nuclearize*
  - *Initiation of a weapons program in states that are in dangerous security environments & possess peaceful nuclear facilities & a staff of trained scientists & technicians is more likely*

Hypotheses

- H1: Countries receiving peaceful nuclear assistance are more likely to begin nuclear weapons programs.
- H2: Countries receiving peaceful nuclear assistance are more likely to begin nuclear weapons programs when a security threat arises.
- H3: Countries receiving peaceful nuclear assistance are more likely to acquire weapons.
- H4: Countries facing security threats and receiving peaceful nuclear assistance are more likely to acquire weapons.

Testing the Hypotheses

- Produced a data set on civilian nuclear assistance based on the coding of all NCAs signed from 1945 to 2000.
- Combination of qualitative & quantitative analysis
  - *Multimethod assessment inspires greater confidence in findings*
  - *Case study analysis "provides rich description of [Fuhrmann's] argument & illustrates that the causal processes operate as expected in actual instances of proliferation" (23)*
  - *Statistical analysis minimizes the risks of selection bias & allows for the determination of the average effect of independent variables on proliferation aims & outcomes*
    - Control for confounding variables & show that peaceful nuclear cooperation– and not some other factor– explains nuclear proliferation

Qualitative Analysis: Case Studies

- **South Africa**
  - *U.S. began to assist South Africa's peaceful nuclear program in July 1957*
    - Construction of a nuclear research reactor, supply of highly enriched uranium, training of nuclear scientists
    - President of the Atomic Energy Commission pressured Prime Minister to develop nuclear bombs on grounds that it was technologically feasible – PM decided to do so because he recognized that the civil nuclear infrastructure would allow for the quick and successful development of the bomb.
    - Additional security motivations (need for a deterrent against a Soviet-supported attack from Angola or Mozambique) shown to have had little role in decision to initiate weapons program.
- **Israel**
  - *French reprocessing aid between 1958 & 1965*
  - *Heavy water supplied by Norway, the UK, & the U.S.*
- **North Korea**
  - *Soviet Union trained NK nuclear scientists beginning in the late 1950s & completed construction of a research reactor in 1965*

Case Study: India

- Used British-supplied designs to build first research reactor in 1955
  - *Became operational in 1956 using enriched uranium supplied by the UK*
  - *April 1956: Canada agrees to supply India with a 40-megawatt research reactor known as the Canada-India-United States research reactor (CIRUS)*
  - *US provides heavy water to moderate CIRUS*
  - *US and Canadian assistance continued in the 1960s*
  - *1964: Canada agrees to help India develop its first power reactor and supply one-half of the initial uranium fuel charge*
  - *December 1966: Canada agreed to offer assistance in the design & construction of a second nuclear power reactor & US agreed to supply plutonium for research purposes*
  - *November 27, 1964: Prime Minister Bahadur Shastri officially endorsed a nuclear weapons program*
    - Was continuously lobbied by Homi Bhabha, chairman of the Indian Atomic Energy Commission
  - *Rivalry with China provided strategic incentives to build the bomb*

Case Study: **Pakistan**

- U.S. & Pakistan sign a nuclear cooperation agreement in August 1955
  - *Research reactor & highly enriched uranium*
- 1960s: Canada & Pakistan signed a nuclear cooperation agreement that allowed Canada to build the Karachi Nuclear Power Plant, supplied heavy water & uranium to fuel the reactor, & helped them develop a fuel fabrication facility in the late 1970s.
- UK provided hot cells
- Belgium & France assisted in developing the “New Laboratories” at PINSTECH to reprocess spent nuclear fuel
- Brussels provided Islamabad with a heavy water production facility
  - *Came online in 1980*
- 1976: Paris agreed to supply a large-scale reprocessing center but suspended deal in 1978
- US trained young scientists from Pakistan between 1955 & 1961
  - *UK, Belgium, & other western European countries provided similar training*
- Weapons program started in 1971 in response to humiliating loss in the Indo-Pakistani War
  - *Redoubled efforts after India tested a nuclear weapon in 1974*
- 1975: A.Q. Khan stole sensitive information dealing with centrifuge technology that could be used to enrich uranium & a list of 100 companies that supplied enrichment technology from a subcontractor of the European enrichment consortium URENCO in the Netherlands

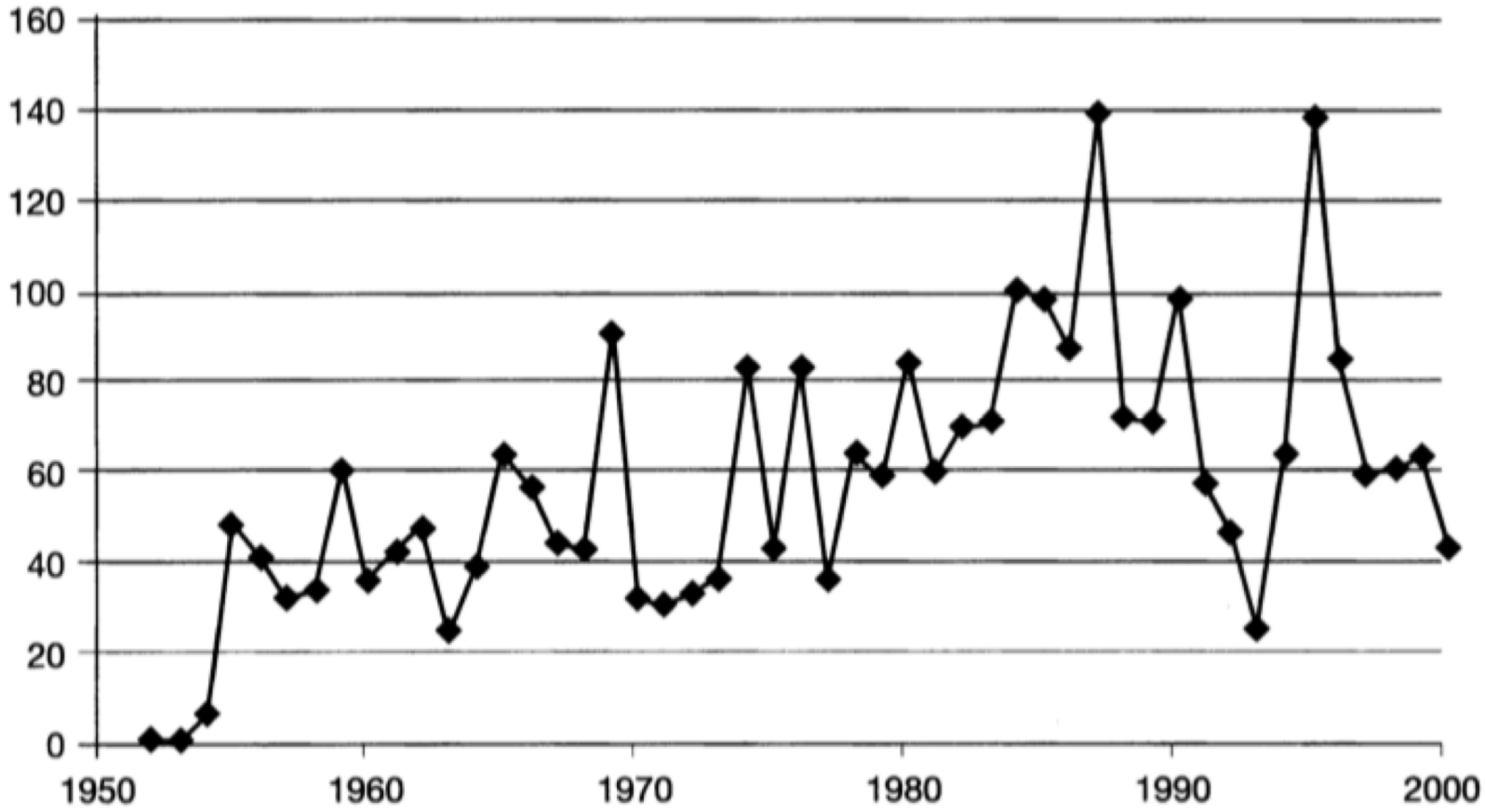
Empirical Set-Up

- Use data set complied by Singh and Way to identify determinants of nuclear proliferation
- Adopts a standard time-series cross-sectional data structure for the period 1945 to 2000
- Unit of analysis is the country (monad) year
- For analysis of nuclear weapons program onset, a country exits the data set once it initiates a weapons acquisition campaign.
- For analysis of nuclear weapons acquisition, a country exits the data set once it obtains at least one nuclear bomb.
- Dependent Variables (DV)
  - *Codes two variables, both dichotomous*
  - *First is coded as 1 if the country **initiated** a nuclear weapons program in year t and 0 otherwise.*
  - *Second is coded 1 if the country **acquired** nuclear weapons in year t and 0 otherwise.*
  - *Created variables by consulting list of nuclear proliferation dates compiled by Singh & Way*

Explanatory Variables: Operationalizing Variables

- Civilian nuclear assistance
  - *Collected & coded new data on NCAs signed from 1945 to 2000 to operationalize civilian nuclear assistance*
    - Produced data from list compiled by James Keeley of more than 2,000 NCAs
  - *Independent variable that measures aggregate number of NCAs that a state signed in a given year entitling it to nuclear technology, materials, or knowledge from another country*
    - If a state signed an NCA but only supplied- and did not receive- nuclear assistance as part of the terms of the deal, then this would not be captured by the NCAs variable
- Security threats
  - *Creates a variable measuring the 5-year moving average of the number of militarized interstate disputes (MIDs) per year in which a country was involved.*
    - Based on version 3.0 of the Correlates of War's MID data set
- Codes a third variable that interacts these two measures to test for conditional effect of nuclear cooperation on proliferation

Figure 1. Total Number of Nuclear Cooperation Agreements Signed, 1950–2000



SOURCES: Matthew Fuhrmann, "Taking a Walk on the Supply Side: The Determinants of Civilian Nuclear Cooperation," *Journal of Conflict Resolution,* Vol. 53, No. 2 (April 2009), pp. 181–208; and James F. Keeley, "A List of Bilateral Civilian Nuclear Cooperation Agreements," University of Calgary, 2003.

Table 1. Top Recipients of Nuclear Cooperation Agreements, 1945–2000

Country	Total Number of Agreements
United States	396
France	221
Germany	171
Russia	136
United Kingdom	133
Japan	122
Italy	112
Belgium	93
Argentina	92
Netherlands	80
Canada	77
Brazil	70
Spain	70
Switzerland	68
Luxembourg	63
Sweden	56
Denmark	55
China	53
South Korea	49
India	39
Ireland	36
Romania	35
Portugal	33
Czechoslovakia (1945–91)	30
Greece	30
Egypt	29
Finland	29
Poland	28
Australia	25
Indonesia	22

NOTE: summary statistics: $N = 186$; mean = 15.34; minimum = 0; maximum = 396

Control Variables

- Technological Capacity
- State's Industrial Capacity
- Enduring Rivalry
- Defense-Pact with One of the Nuclear-Capable Great Powers
- "Internal Determinants"
  - *Two variables related to democracy*
  - *State's Exposure to the Global Economy*
- For robustness
  - *Variable Singh & Way excluded from their model*
    - Dichotomous variable coded 1 if state signed the NPT in year t and 0 otherwise
      - *NPT membership could be important in explaining decisions to proliferate because, when states sign this treaty, they make legal oaths not to pursue nuclear weapons*

Methods of Analysis

- To estimate the effect of independent variables on nuclear weapons program onset & bomb acquisition, Fuhrmann used
  - *Probit regression analysis*
  - *Rare events logit*
- Used clustering over states to control for heteroskedastic error variance
- Included a variable to count number of years that passed without a country pursuing nuclear weapons or acquiring the bomb to control for possible temporal dependence in the data
- Lagged all independent variables one year behind the dependent variable to control for possible simultaneity bias

RESULTS OF STATISTICAL TESTS

Table 2. Nuclear Cooperation, Militarized Disputes, and Nuclear Weapons Program Onset, 1945–2000

		Civilian Nuclear Cooperation			Civilian Nuclear Cooperation and Militarized Disputes		
		No	Yes	Total	No	Yes	Total
Nuclear weapons program onset	No	4,066 (99.93%)	2,865 (99.58%)	6,931 (99.78%)	5,080 (99.92%)	1,851 (99.41%)	6,931 (99.78%)
	Yes	3 (0.07%)	12 (0.42%)	15 (0.22%)	4 (0.08%)	11 (0.59%)	15 (0.22%)
	Total	4,069 (100%)	2,877 (100%)	6,946 (100%)	5,084 (100%)	1,862 (100%)	6,946 (100%)
		Pearson Chi2(1) = 9.22, Pr = 0.002			Pearson Chi2(1) = 16.59, Pr < 0.0001		

Table 3. Nuclear Cooperation, Militarized Disputes, and Nuclear Weapons Acquisition, 1945–2000

		Civilian Nuclear Cooperation			Civilian Nuclear Cooperation and Militarized Disputes		
		No	Yes	Total	No	Yes	Total
Nuclear weapons program onset	No	4,077 (99.95%)	3,050 (99.77%)	7,127 (99.87%)	5,099 (99.96%)	2,028 (99.66%)	7,127 (99.78%)
	Yes	2 (0.05%)	7 (0.23%)	9 (0.13%)	2 (0.04%)	7 (0.34%)	9 (0.13%)
	Total	4,079 (100%)	3,057 (100%)	7,136 (100%)	5,101 (100%)	2,035 (100%)	7,136 (100%)
		Pearson Chi2(1) = 4.49, Pr = 0.034			Pearson Chi2(1) = 10.73, Pr = 0.0001		

Table 4. Determinants of Nuclear Weapons Proliferation, 1945–2000

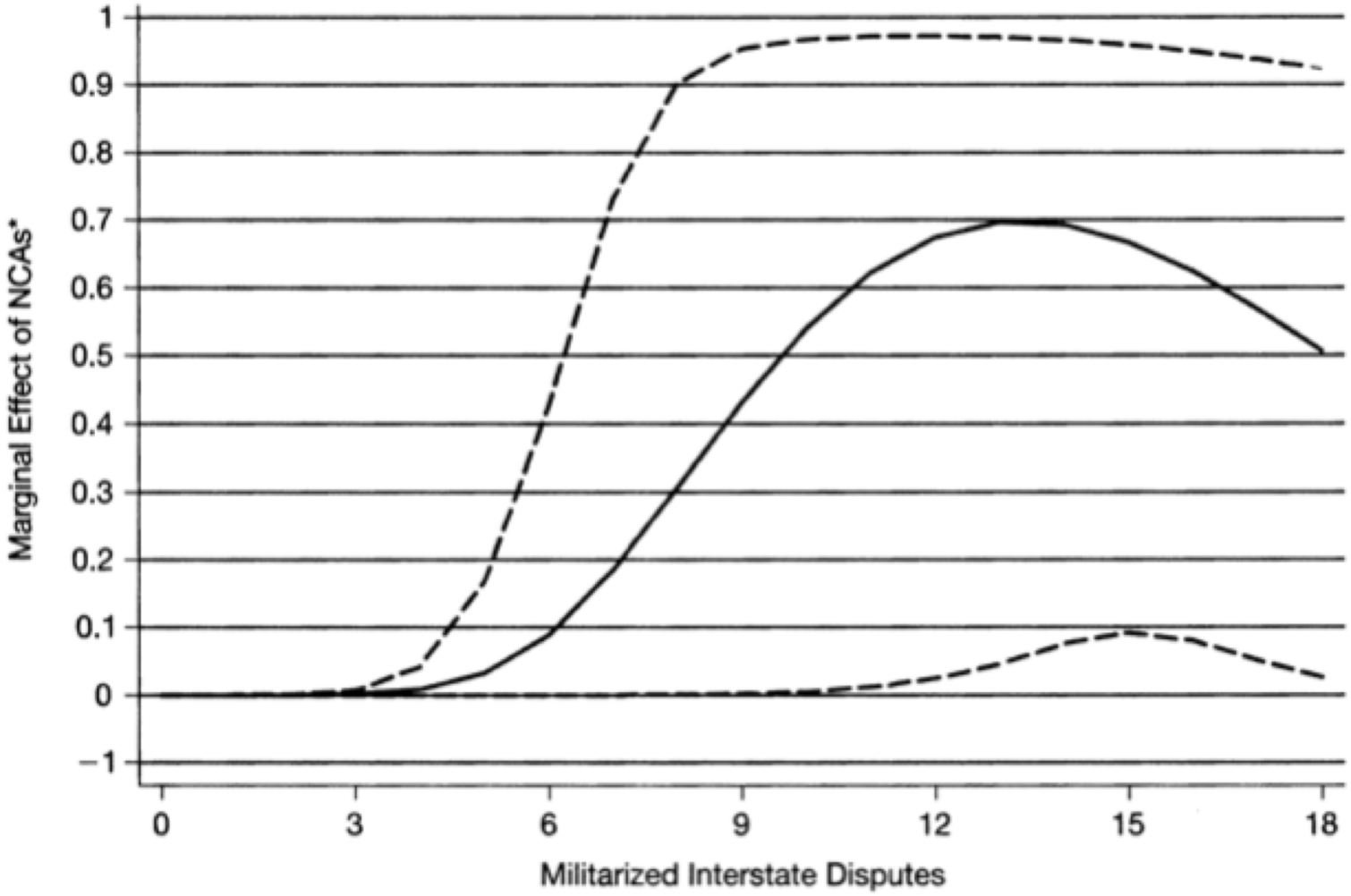
Atomic Assistance	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Peaceful nuclear cooperation	0.023***	0.062***	0.016**	0.049***	0.019***	0.055***	0.004	0.014
	(0.009)	(0.023)	(0.007)	(0.018)	(0.006)	(0.020)	(0.011)	(0.033)
Militarized disputes	0.152***	0.286***	0.132***	0.265***	0.107**	0.206	0.069*	0.155
	(0.040)	(0.095)	(0.030)	(0.066)	(0.047)	(0.126)	(0.041)	(0.121)
Peaceful nuclear cooperation × militarized disputes			0.025**	0.057***			0.013**	0.024**
			(0.010)	(0.022)			(0.006)	(0.011)
Control Variables								
Nuclear protection	0.085	0.105	0.043	0.005	−0.297	−0.544	−0.340	−0.693
	(0.264)	(0.742)	(0.274)	(0.775)	(0.348)	(1.042)	(0.360)	(1.121)
Nuclear Nonproliferation Treaty	−1.040**	−2.375*	−1.168**	−2.642*				
	(0.463)	(1.286)	(0.536)	(1.435)				
Democracy	−0.000	0.007	−0.006	−0.008	0.016	0.025	0.010	0.011
	(0.016)	(0.045)	(0.016)	(0.042)	(0.016)	(0.053)	(0.017)	(0.055)
Democratization	−0.014	−0.034	−0.015	−0.036	−0.036	−0.079	−0.036	−0.099
	(0.022)	(0.065)	(0.024)	(0.075)	(0.035)	(0.103)	(0.040)	(0.127)
Economic openness	0.002	0.008	0.001	0.008	0.003	0.014	0.003	0.015
	(0.005)	(0.013)	(0.005)	(0.015)	(0.003)	(0.012)	(0.003)	(0.009)
Liberalization	−0.001	−0.004	0.003	0.019	0.005	0.040***	0.005	0.036***
	(0.006)	(0.017)	(0.006)	(0.017)	(0.004)	(0.012)	(0.003)	(0.011)
GDP per capita	0.000*	0.000	0.000**	0.001	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP per capita squared	−0.000***	−0.000*	−0.000***	−0.000**	−0.000***	−0.000	−0.000**	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Industrial capacity threshold	0.874***	2.150**	0.878***	2.219***	1.259***	2.666**	1.268***	2.867***
	(0.334)	(0.875)	(0.340)	(0.861)	(0.233)	(1.056)	(0.248)	(1.099)
Rivalry	0.909***	2.385**	0.758***	1.863**	0.884**	1.977	0.769*	1.688
	(0.317)	(0.975)	(0.286)	(0.816)	(0.394)	(1.286)	(0.404)	(1.323)
No proliferation years	0.012	0.031	0.007	0.015	−0.017**	−0.038	−0.021**	−0.049*
	(0.009)	(0.026)	(0.009)	(0.026)	(0.008)	(0.024)	(0.009)	(0.026)
Constant	−4.510***	−9.280***	−4.417***	−9.097***	−4.431***	−8.787***	−4.232***	−8.155***
	(0.459)	(1.195)	(0.430)	(1.067)	(0.481)	(1.433)	(0.461)	(1.264)
Observations	5,511	5,511	5,511	5,511	5,702	5,702	5,702	5,702

NOTE: Robust standard errors in parentheses; *significant at 0.10; **significant at 0.05; ***significant at 0.01. GDP = gross domestic product.

Table 4

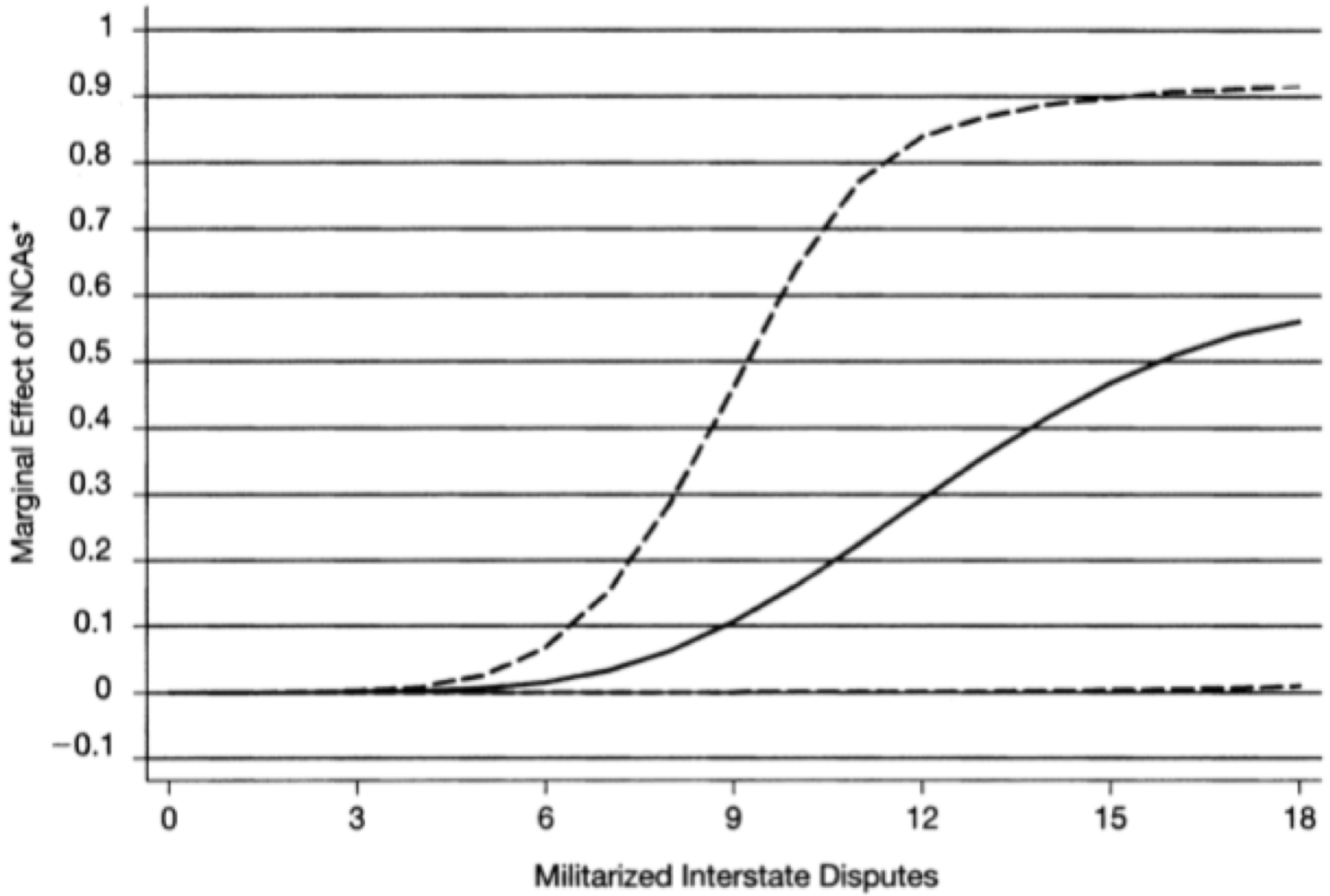
- Presents initial results from multivariate statistical analysis
- Odd-numbered models = estimated using probit
- Even-numbered models = estimated using rare events logit
- In models 1-4, the DV is weapons program onset
  - *Models 1 & 2 exclude interaction term*
    - Allow evaluation of whether peaceful nuclear assistance affects decisions to begin nuclear weapons programs independent of security environment
  - *Models 3 & 4 include interaction term*
    - Allow for evaluation of the conditional effect of atomic assistance on beginnings of nuclear weapons campaigns
- In models 5-8, the DV is acquisition
  - *Models 5-6 exclude interaction term*
    - Allow evaluation of unconditional effect of nuclear aid on bomb development
  - *Models 7 & 8 include interaction term*
    - Allow assessment of conditional effect of atomic assistance on a country successfully building nuclear weapons
- Results show peaceful nuclear assistance continues to contribute to both nuclear weapons program onset & bomb acquisition, even when accounting for confounding variables

Figure 2. Marginal Effect of Nuclear Assistance on Weapons Program Onset as Number of Disputes Increases



*NCAs = nuclear cooperation agreements

Figure 3. Marginal Effect of Nuclear Assistance on Weapons Acquisition as Number of Disputes Increases



*NCAs = nuclear cooperation agreements

Further Robustness Checks

- Conducts a sensitivity analysis
  - *Used new estimator to account for possible endogeneity & an alternate coding for the dependent variable*
  - *Excluded "sensitive" NCAs from the coding of key independent variables*
- Results
  - *Endogeneity*
    - Nuclear cooperation may be endogenous to nuclear weapons pursuit because it is possible that states seek nuclear assistance when the are pursuing nuclear weapons
    - Standard approach to address endogeneity – lag independent variables 1 year behind dependent variable
    - Additional way to address endogeneity – estimated 2 endogenous equations simultaneously
      - *1st equation represents total # of NCAs a state has made in a particular year*
      - *2nd equation estimates the likelihood that it is pursuing nuclear weapons*
      - *To estimate equations simultaneously, uses method where one of the endogenous variables is continuous & the other dichotomous*
        - 2-stage estimation technique- generates instruments for each endogenous variable & then substitutes them in respective structural equations
        - 1st equation estimated using ordinary least squares, & 2nd using probit

- Results of 2-stage probit least squares model that addresses the simultaneity issue = generally consistent with previous findings.
  - *Nuclear cooperation has a positive & statistically significant effect on nuclear weapons pursuit*
  - *Result robust to alternate model specifications*
- Dependent Variable Coding
  - *Used an alternate set of proliferators & dates compiled by Jo & Gartzke to explore whether results are sensitive to proliferation codings*
  - *Estimating earlier models with the alternate proliferation dates does not effect results relating to argument*
- Removal of Sensitive Agreements
  - *Recent research finds countries receiving particular "sensitive" nuclear assistance are more likely to obtain nuclear weapons*
  - *Testing whether results may be driven by a few sensitive details by excluding them from coding of the independent variable*
  - *Type of sensitive agreements is extremely rare → change resulted in removal of a small # of agreements*
  - *Finding relevant to argument are "generally unaltered" (39) when sensitive agreements are excluded from codings of atomic assistance*

Conclusion

- Analysis supports arguments that civilian assistance & weapons proliferation are linked
- Peaceful nuclear cooperation is one of the more salient variables in explaining nuclear proliferation
- Students of proliferation should think more carefully about civilian nuclear assistance
- No such thing as “proliferation-proof” atomic assistance
- “atoms for peace” policies have, on average, facilitated-–not constrained– nuclear proliferation
  - *Atoms for peace become atoms for war*
- Proliferation will occur as the nuclear renaissance unfolds
- Combination of atomic assistance & security threats is a recipe for the spread of nuclear weapons

Criticisms

- Does not explain how South Africa's security concerns had little role in decision to start nuclear weapons program
- Does not elaborate on what findings were altered when sensitive agreements were excluded from the coding of atomic assistance
  - *"generally unaltered" (39)*

MATTHEW KROENIG'S "IMPORTING THE BOMB: SENSITIVE NUCLEAR ASSISTANCE & NUCLEAR PROLIFERATION"

Research Question

- Does international nuclear assistance contribute to the spread of nuclear weapons?

Argument

- States that receive sensitive nuclear assistance can better overcome the common obstacles that states encounter as they attempt to develop a nuclear weapons arsenal
- Can skip technical design stages, acquire implicit knowledge from more advanced scientific communities, economize on costs of nuclear development, & avoid international pressure to abandon a nuclear program.
- Sensitive nuclear assistance is an important determinant of nuclear proliferation

Approaches to Explaining Nuclear Proliferation: Demand-Side

- Arguments focusing on a state's *willingness* to acquire nuclear weapons
- Bulk of scholarly research on nuclear proliferation has focused on demand
- Identify factors that drive states to pursue & abandon weapons programs
- Sagan (1996/97): 3 primary reasons why states seek nuclear weapons
  - *Competitive security environment – want bomb as a means to deter external aggression*
  - *Domestic political lobbies encourage states to pursue a national nuclear weapons program for parochial reasons*
  - *International norms of prestige or disgrace associated with nuclear weapons*
  - *Concludes none of these causes is dominant but that they are each in operation to varying degrees in different cases*
- Etel Solingen (1994, 1998, 2007): domestic political coalitions & economic development strategies determine state's demand for nuclear weapons
- Jacques Hymans (2006): leaders' conceptions of their countries' national identities is the key to explaining state demand for nuclear weapons

Approaches to Explaining Nuclear Proliferation: Supply-Side

- Arguments focusing on a state's *opportunity* to acquire nuclear weapons
- Recognizes that an analysis of a state's demand for nuclear weapons can only provide a partial explanation for nuclear proliferation.
- Whether or not a state wants nuclear weapons is irrelevant if it is unable to acquire them.
- Opportunity can shape willingness
- Singh & Way (2004): it is only a matter of time before a country develops nuclear weapons once it has latent capacity to develop nuclear weapons
- Claims that states with an advanced industrial capacity can more easily create & maintain a nuclear weapons program & are therefore more likely to acquire nuclear weapons than less developed states are

Challenges States Face & How International Nuclear Assistance Can Ease Them

- Designs for many sensitive nuclear technologies are not available in the public realm
  - *Nuclear suppliers can provide established designs for nuclear technology*
  - *With proven designs, scientists & technicians can skip the technical design stage & focus on replicating a model already shown to be effective*
- Construction & successful operation of nuclear facilities requires much trial & error
  - *States supplying assistance can construct & even operate nuclear facilities for recipient state*
- Development of a nuclear weapons infrastructure from scratch is an expensive enterprise
  - *Importing sensitive nuclear technology from can help states economize on costs of nuclear development*
    - Getting sensitive nuclear assistance from abroad can be less expensive than domestic development of an entire nuclear framework
- States striving for a nuclear weapons capability must overcome these considerable technical challenges under extreme international pressure
  - *Sensitive nuclear assistance can help a state evade international scrutiny*

Hypothesis

- H1: States that receive sensitive nuclear assistance will be more likely to acquire nuclear weapons.

Empirical Analysis

- Uses both qualitative & quantitative research methods
- Period under investigation: 1945 to 2000
  - *9 countries acquired nuclear weapons during this period and, of these only 3 (Israel, China, & Pakistan) received sensitive nuclear assistance*
- Large-*N* statistical analysis forms core of empirical investigation
  - *Analyze relationship between sensitive nuclear assistance & nuclear proliferation in entire universe of cases & control for potentially confounding factors*

Qualitative Analysis: Case Studies

- **Israel**
  - *1958-1965: France provided sensitive nuclear assistance that greatly enhanced Israel's ability to produce nuclear weapons*
  - *France built large, plutonium-producing nuclear reactor & plutonium-reprocessing facility at Dimona, transferred nuclear weapons design, trained Israeli scientists, & allowed Israeli observers at French nuclear weapons tests*
  - *By 1967, Israel was able to build first nuclear weapon*
- **China**
  - *1958-1960: Soviet Union gave China key components for uranium-enrichment & plutonium–reprocessing plants & trained Chinese technicians*
    - Contributed to China's ability to conduct first nuclear weapons test in 1964
      - *Afterwards, China became a nuclear supplier*
- **Pakistan**
  - *China transferred substantial quantities of highly enriched uranium, uranium-enrichment technologies, & nuclear weapons design*
  - *1987-2002: Pakistan distributed sensitive nuclear technology & materials to Iran, Libya, & North Korea*

- States that had an enduring demand for nuclear weapons but were unable to acquire significant international assistance failed to maintain national nuclear weapons programs
  - *Egypt*
    - Continuously opposed in attempts to get an international nuclear supplier
    - To this day, lacks a nuclear weapons arsenal
    - Beginning in the 1960s, sought sensitive nuclear assistance from the Soviet Union, then from China (& may be from Pakistan).
  - *Other states that have shown interest in nuclear weapons but have not yet acquired them*
    - States that have received little sensitive nuclear assistance from abroad
      - *Iraq & Taiwan*
    - States that have received no assistance whatsoever
      - *Argentina, Saudi Arabia, Syria, & South Korea*

Nuclear Proliferation Data

- Original sensitive-nuclear-assistance data set
  - *Contains yearly information for all states in the international system from 1945 to 2000*
  - *Unit of analysis = country-year*
- Also draws data from Singh & Way (2004) and Jo & Gartzke (2007) to construct other nuclear proliferation variables
- Dependent Variable
  - *Nuclear proliferation*
    - Measures whether state acquires nuclear weapons in a given year
- Independent Variable
  - *Sensitive nuclear assistance*
    - Takes 3 forms
      - *When states receive assistance in design & construction of nuclear weapons, receive significant quantities of weapons-grade fissile material, or receive assistance in construction of uranium-enrichment or plutonium-reprocessing facilities that could be used to produce weapons-grade fissile material*
    - Excludes other types of nuclear cooperation less relevant to development of a nuclear weapons program
    - Coded using online nuclear weapons database maintained by the National Threat Initiative and drawing on prominent reviews on proliferation of nuclear weapons & on historical studies of countries' weapons programs.
      - *At least two sources had to verify a case of sensitive nuclear assistance transfer for it to be included in the data set*

Table 1
Cases of Sensitive Nuclear Assistance

Recipient	Year of First Assistance	Supplier(s)	Type of Assistance
China	1958	Soviet Union	Plutonium reprocessing, uranium enrichment
Israel	1959	France	Plutonium reprocessing, nuclear-weapon design
Japan	1971	France	Plutonium reprocessing
Pakistan	1974	France, China	Plutonium reprocessing, uranium enrichment, nuclear-weapon design
Taiwan	1975	France	Plutonium reprocessing
Iraq	1976	Italy	Plutonium reprocessing
Brazil	1979	Germany	Plutonium reprocessing, uranium enrichment
Egypt	1980	France	Plutonium reprocessing
Iran	1984–1995	China, Pakistan	Plutonium reprocessing, uranium enrichment[a]
Algeria	1986	China	Plutonium reprocessing
Libya	1997	Pakistan	Plutonium reprocessing, uranium enrichment, nuclear-weapon design
North Korea	1997	Pakistan	Plutonium reprocessing, uranium enrichment[a]

a. It is widely suspected that Pakistan provided a nuclear-weapon design to Iran and North Korea, although, as of yet, there is no firm evidence to prove it.

Control Variables

- All drawn from Singh & Way (2004) unless otherwise specified
- Other variable thought to influence likelihood of nuclear proliferation
  - *GDP per capita in constant 1996 dollars – evaluate country's domestic capacity to produce nuclear weapons*
  - *GDP squared – test for nonmonotonic relationship between level of economic development & nuclear acquisition*
  - *Industrial capacity – dichotomous variable – whether a country can produce steel domestically & has an electricity-generating capacity greater than 5,000 MW*
  - *Rivalry – states in threatening security environments may be more likely to pursue nuclear weapons to improve security – whether a state is involved in at least one enduring rivalry*
  - *Alliance – dichotomous variable – whether state is in a defense pact with a nuclear-armed state*
  - *Regime type – measures country's domestic political regime type – drawing on data from the Polity IV index*
  - *Openness – state's openness to international economy – calculated as country's trade ratio (exports plus imports, divided by GDP)*
  - *Liberalization – changes in country's trade ratio over spans of 3, 5, & 10 years*

Data Analysis

- Uses Cox proportional-hazard models to test claims about the correlates of nuclear acquisition
  - *Robust standard errors are adjusted for clustering by country*
- Examine simple bivariate relationship between sensitive nuclear assistance & nuclear proliferation (Table 2, model 1)
  - *TO control for potentially confounding factors, then evaluate effect of sensitive nuclear assistance after including control variables (Table 2, model 2)*
  - *Estimate trimmed model that includes only variables that were statistically significant in previous model (Table 2, model 3).*
  - *Uses censored hazard model of the risk of nuclear acquisition contingent on state's possessing a nuclear weapons production program to assess relationship between sensitive nuclear assistance & nuclear proliferation among states that actively pursued nuclear weapons (Table 2, model 4).*

Table 2
Hazard Models of Nuclear Proliferation

	Model			
Independent Variable	1	2	3	4
Sensitive nuclear assistance	3.323**** (0.951)	2.093**** (0.641)	2.024*** (0.786)	1.478** (0.694)
GDP		0.649*** (0.240)	0.625*** (0.227)	0.609 (0.378)
GDP squared		–5.13e–5**** (1.54e–5)	–5.69e–5*** (2.03e–5)	–4.60e–5 (3.02e–5)
Industrial capacity		3.430**** (0.387)	3.606**** (0.497)	3.276**** (0.756)
Rivalry		2.382* (1.367)	2.371* (1.252)	1.517 (1.651)
Alliance		–1.800* (1.061)	–1.705* (0.945)	–.8253 (0.835)
Regime type		0.114** (0.050)	0.112** (0.055)	0.112** (0.050)
Openness		–0.022 (0.018)		–0.027 (0.026)
Liberalization		0.028 (0.026)		0.059** (0.028)
Log likelihood	–32.669	–18.784	–19.260	–15.413
Number of countries	156	156	156	18
Total observations	5,901	5,901	5,901	398

Note: Statistically significant parameter estimators are denoted by *($p = .10$); **($p = .05$); ***($p = .01$); ****($p = .001$). Coefficients are estimates for Cox proportional hazard models; robust standard errors, adjusted for clustering by country, are in parentheses. GDP = gross domestic product.

Findings

- Supporting Supply-Side Approach
  - *Relationship between sensitive nuclear assistance & nuclear proliferation is positive & statistically significant (SS) in each & every model*
  - *Strong empirical support for causal significance of sensitive nuclear assistance for understanding nuclear proliferation*
  - *GDP and GDP squared are SS & have positive signs in 2 of 3 models in which they are included*
    - Provides some support for existence of a monotonic relationship between economic development & nuclear proliferation
  - *Industrial capacity is positive & SS in every model*
    - Shows that states above a certain level of industrial development are more likely to acquire nuclear weapons

- Supporting Demand-Side Approach
  - *Rivalry is positive & SS in 2 of 3 models in which its included*
    - States on a threatening security environment are more likely to acquire nuclear weapons
  - *Alliance is negative & SS in 2 of 3 models in which its included*
    - States in defense pact with a nuclear-armed state are less likely to acquire nuclear weapons
  - *Regime Type is positive and SS in every model*
    - Supports idea that democratic states may be more inclined to nuclear proliferation because they may be subject to pressure from domestic constituencies that favor nuclear development
  - *Openness is not SS in any of the models its included in*
    - No discernable relationship between economic openness & nuclear proliferation
    - States open to international economy are neither more or less likely to obtain nuclear weapons
  - *Liberalization is SS in model 4 only – sign on coefficient is positive*
    - No support for idea that liberalizing states will look to stay away from controversial foreign policies like nuclear proliferation
    - Contrary to theoretical expectation, this suggests that liberalizing states may be more, not less, likely to obtain nuclear weapons
  - *Finds limited support for demand-side approaches*
  - *Security environment & domestic politics appear to play some role, but relationship of a state to international economy does not*

Table 3
Substantive Effects of the Explanatory Variables on the Likelihood of Nuclear Proliferation

	Percentage Change in the Hazard Ratios	
Variable	Uncensored	
Censored		
Sensitive nuclear assistance	+711	+338
Industrial capacity	+2,986	+2,546
Regime type	+12	+12

Note: Hazard ratios on whether a state acquires a nuclear weapon are based on the hazard models reported in Table 2, models 2 and 4.

Table 3

- Interprets substantive effect of variables that were SS in all of the previous models on nuclear proliferation
- Uses results from uncensored hazard model reported in Table 2, model 2, & censored hazard model reported in Table 2, model 4
- Entries portray percentage change in the baseline hazard ratios of nuclear acquisition for a given change in independent variable
- Findings
  - *Results from uncensored model:*
    - Providing a state with sensitive nuclear assistance increases risk it will obtain nuclear weapons by more than 700%
      - *Sensitive nuclear assistance has a SS & substantively significant effect on nuclear proliferation*
    - Industrial capacity has substantive effect on nuclear proliferation
      - *States above certain threshold are 29 times more likely to proliferate than similar states below threshold*
    - Regime type has smaller substantive effect
      - *Increasing a state's level of democracy by 1 point on 20 point scale increases risk of it acquiring nuclear weapons by only 12%*

Addressing Problems Related to Non-Random Assignment of the Treatment

- Non-Random Assignment of Treatment
  - *Sensitive nuclear assistance is not randomly assigned*
  - *States that receive sensitive nuclear assistance are different from those who do not*
- Addressing the Problem
  - *Use nonparametric, matching techniques as recommended by Ho et al. (2007)*
    - Preprocessing data using matching techniques to match up treated cases with similar untreated cases
    - Observations within the control group (states that did not receive sensitive nuclear assistance) are matched as closely as possible with treatment group (states who did receive assistance)
- Analysis
  - *Identifies confounding factors the control variables GDP, GDP squared, rivalry, alliance, regime type, openness, & liberalization*
  - *One-to-one nearest neighbor matching with replacement used to preprocess the data*
  - *Balance statistics (see Table 4) indicate great balance was achieved*
    - P values on all t-tests are greater than .56, with exception of t-test on alliance (.111)
    - QQ statistics improve in all cases except alliance & regime type

Table 4
Balance Statistics

Std. Variable		Mean Treated	Mean Control	*t*-test *p* value	K-S test *p* value	Var. ratio (Tr/Co)	Mean eQQ Diff.
GDP	Before matching	7,057.700	5,452.500	0.000	0.000	1.077	0.114
	After matching	6,943.900	6,608.600	0.574	0.144	1.063	0.046
GDP squared	Before matching	86,540,299.000	63,991,650.000	0.031	0.000	0.976	0.105
	After matching	84,853,891.000	78,135,099.000	0.625	0.144	1.154	0.045
Industrial capacity	Before matching	0.746	0.229	0.000		1.079	0.259
	After matching	0.751	0.726	0.571		0.940	0.012
Rivalry	Before matching	0.761	0.269	0.000		0.929	0.246
	After matching	0.766	0.741	0.564		0.934	0.012
Alliance	Before matching	0.462	0.466	0.915		1.004	0.002
	After matching	0.453	0.532	0.111		0.995	0.040
Regime type	Before matching	–0.523	–0.274	0.647	0.124	0.968	0.035
	After matching	–0.692	–0.557	0.860	0.114	0.936	0.049
Openness	Before matching	39.030	52.432	0.000	0.000	0.370	0.096
	After matching	38.304	38.621	0.902	0.273	1.239	0.028
Liberalization	Before matching	–0.195	2.587	0.008	0.195	0.697	0.033
	After matching	–0.185	0.044	0.869	0.330	1.037	0.029

Note: GDP = gross domestic product.

Table 5
Hazard Model of Nuclear Proliferation, Postmatching

Matched observations	280
Number of countries	48
Coefficient	2.552
Standard error	1.029
p value	.013

Table 5

- Presents effect of sensitive nuclear assistance on nuclear acquisition as estimated by the Cox regression in the matched sample
- Results of Cox estimation in matched sample present further support Hypothesis 1
- Analysis of matched data suggests sensitive nuclear assistance may have an even greater effect than indicated by analysis of unmatched sample
  - *Unmatched sample: sensitive nuclear acquisition increased risk of nuclear proliferation by more than 700%*
  - *Matched sample: sensitive nuclear assistance increases risk of nuclear proliferation by more than 1,200%*

Robustness Checks

- Examines extent to which results depend on coding of dependent variable, model specification, & nuclear-proliferation behavior of a few key states
- Difficult to define precisely when states acquired nuclear weapons
- Checks using alternate codings of nuclear proliferation revealed that results are not sensitive to different measurements of the dependent variable
- Reran dozens of models, omitting right-hand-side variables one at a time to ensure results were not being driven by inclusion of specific control variables
  - *Core results were not affected*
- Dropped observations containing certain key countries and repeated analysis to gauge whether findings were being driven by proliferation behavior of particular states
  - *Sequentially removing observations containing China, Israel, & Pakistan & reestimating models did not affect findings*

Conclusion

- States that receive sensitive nuclear assistance from more advanced countries are more likely to acquire nuclear weapons than are similar states that do not receive assistance.
- Receiving of sensitive nuclear assistance helps potential nuclear proliferators overcome common obstacles states encounter when trying to build a nuclear arsenal
- Importing the bomb helps states skip technical design stages, benefit from tacit knowledge in more advanced scientific communities, save money on the costs of nuclear weapons development, & sidestep international scrutiny
- Findings provide strong support for the supply-side approach to nuclear proliferation
  - *States that are capable of producing nuclear weapons, either through international assistance or domestic capacity, are much more likely to do so*
- Found only modest support for the demand-side approach
- Scholarly study of nuclear proliferation should place less emphasis on understanding which states want nuclear weapons & focus more analytical attention on examining which states can produce them.

Criticisms

- Could benefit from defining/explaining terms used in empirical analysis