Journal of Conflict Resolution
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*Journal of Conflict Resolution* 2009; 53; 161 originally published online Jan 30, 2009;

DOI: 10.1177/0022002708330287

The online version of this article can be found at:
http://jcr.sagepub.com/cgi/content/abstract/53/2/161

Published by:
SAGE
http://www.sagepublications.com

On behalf of:
Peace Science Society (International)

**Journal of Conflict Resolution**
Volume 53 Number 2
April 2009 161-180

10.1177/0022002708330287
http://jcr.sagepub.com
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http://online.sagepub.com

# Importing the Bomb

## Sensitive Nuclear Assistance and Nuclear Proliferation

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Why do nuclear weapons spread? Using new data on sensitive nuclear transfers, this article analyzes the determinants of nuclear proliferation. The author first describes a simple logic of the technical and strategic advantages that potential nuclear proliferators can gain by importing nuclear materials and technology from more advanced nuclear states. The author then shows that sensitive nuclear transfers are an important determinant of nuclear proliferation. In broader terms, the author find strong support for a supply-side approach to nuclear proliferation. States that are better able to produce nuclear weapons, due to either international assistance or domestic capacity, are more likely to do so.

***Keywords:*** *nuclear proliferation; nuclear weapons; sensitive nuclear assistance; supply side; nuclear energy*

Why do nuclear weapons spread? Politicians, policy makers, and pundits often worry that nuclear-capable states will provide sensitive nuclear assistance to other states or terrorist networks, contributing to the international spread of nuclear weapons.[1] The idea that states that get help with their nuclear programs will be more likely to acquire nuclear weapons has intuitive appeal, but international nuclear transfers may have no meaningful effect on nuclear proliferation. Indeed, existing scholarly approaches to nuclear proliferation have examined why states want nuclear weapons (e.g., Sagan 1996/1997) and the relationship between domestic capacity and nuclear acquisition (e.g., Singh and Way 2004; Jo and Gartzke 2007) but have not examined the relationship between international nuclear transfers and the spread of nuclear weapons. This raises an interesting question about the sources of nuclear proliferation: does international nuclear assistance contribute to the spread of nuclear weapons?

**Author's Note:** I would also like to thank the University of California's Institute on Global Conflict and Cooperation, the Center for International Security and Cooperation at Stanford University, and the Project on Managing the Atom and the International Security Program at the Belfer Center for Science and International Affairs at Harvard University for their support. Replication data are available online at http://jcr.sagepub.com/supplemental.

To answer this question, I begin with a simple logic of the technical and strategic advantages that potential nuclear proliferators can gain by importing sensitive nuclear materials and technologies from more advanced nuclear states. I argue that states that receive sensitive nuclear assistance can better overcome the common obstacles that states encounter as they attempt to develop a nuclear-weapons arsenal. They can leapfrog technical design stages, acquire tacit knowledge from more advanced scientific communities, economize on the costs of nuclear development, and avoid international pressure to abandon a nuclear program.

Drawing on a new data set on the international transfer of sensitive nuclear materials and technology, this article demonstrates that sensitive nuclear assistance is an important determinant of nuclear proliferation. States that receive sensitive nuclear assistance from abroad are more likely to acquire nuclear weapons. I also find that states above a certain level of industrial development are more likely to acquire nuclear weapons. Taken together, these findings provide strong support for the supply-side approach to understanding the causes of nuclear proliferation advocated in this journal issue (Gartzke and Kroenig 2009, this issue). States that are better able to produce nuclear weapons, due to either international assistance or domestic capacity, are more likely to do so. Cross-national variation in nuclear proliferation outcomes is best explained not by analyzing which states want nuclear weapons, but by understanding which states are able to get them.

## Explaining Nuclear Proliferation

There is a vast scholarly literature on the causes of nuclear proliferation. Dong-Joon Jo and Erik Gartzke (2007) have recently categorized this research into two camps: arguments that focus on a state's *willingness* to acquire nuclear weapons (demand-side approaches) and those that privilege a state's *opportunity* to acquire nuclear weapons (supply-side approaches). The bulk of scholarly research on nuclear proliferation has focused on demand. This school has sought to identify the factors that drive states to pursue and abandon nuclear-weapons programs. Scott Sagan (1996/1997) argues that there are three primary reasons why states seek nuclear weapons. Sagan maintains that states in competitive security environments desire nuclear weapons as a means to deter external aggression, that domestic political lobbies (primarily the domestic nuclear complex) can encourage states to pursue a national nuclear-weapons program for parochial reasons, and that international norms of prestige or opprobrium associated with nuclear weapons can influence states' nuclear decisions. Sagan concludes that none of these causes is dominant but that they are each in operation to varying degrees in different cases.

Other scholars have suggested additional factors that may influence a state's demand for nuclear weapons. Etel Solingen (1994, 1998, 2007) maintains that domestic political coalitions and their associated economic development strategies determine a state's demand for nuclear weapons. "Liberalizing coalitions" are internationalist, pursue export-oriented industrialization strategies, and will be reluctant to jeopardize international trade and investment on controversial foreign policies such as the pursuit of nuclear weapons. On the other hand, states controlled by "inward looking, nationalist, and radical-confessional coalitions" oppose liberalization, choose an autarchic path to economic development, and are more likely to pursue nuclear weapons because they face fewer international economic costs to doing so and because they are more beholden to nationalist appeals.

Individual psychological drivers have also been invoked to explain a state's willingness to acquire nuclear weapons. Jacques Hymans (2006) argues that leaders' conceptions of their countries' national identities is the key to explaining state demand for nuclear weapons. Other research has drawn on these and other factors to explain why states pursue and abandon nuclear-weapons programs (e.g., Quester 1973; Paul 2000).

In contrast, the supply-side approach to nuclear proliferation recognizes that an analysis of a state's demand for nuclear weapons can only provide a partial explanation for nuclear proliferation (Singh and Way 2004; Jo and Gartzke 2007; Meyer 1984; Lavoy 1993, 1995). Whether or not a state wants nuclear weapons is irrelevant if it is unable to acquire them. States may badly desire nuclear weapons but lack the technology, resources, and expertise required to build them. Moreover, opportunity can shape willingness. States that could conceivably produce a nuclear-weapons arsenal will face a great temptation to go nuclear. According to this view, "once a country acquires the latent capacity to develop nuclear weapons, it is only a matter of time until it is expected to do so" (Singh and Way 2004, 862). The supply-side approach to proliferation claims that states with an advanced industrial capacity can more easily create and maintain a nuclear-weapons program and are thus more likely to acquire nuclear weapons than are less-developed states. This line of argumentation has roots in earlier scholarship (Meyer 1984; Lavoy 1993, 1995) and has been revived by recent quantitative analyses of nuclear proliferation (Singh and Way 2004; Jo and Gartzke 2007). The quantitative studies have found that measures of economic development and industrial capacity are associated with a greater risk of becoming a nuclear power. These authors do not consider, however, how the supply of international nuclear assistance may advance a country's ability to produce nuclear weapons, nor do they explicitly examine the relationship between international nuclear assistance and nuclear proliferation.

The literature on "proliferation rings" has argued that nuclear capabilities in "second-tier" supplier states such as Pakistan, Iran, and North Korea could increase the availability of nuclear materials and technology on the international marketplace, which threatens the nuclear nonproliferation regime (Braun and Chyba 2004; Chestnut 2007). Alex Montgomery (2005) has countered that without the tacit knowledge that comes from deep experience with a nuclear-weapons production program, states that receive nuclear assistance will still struggle to acquire nuclear weapons. Yet, these scholars do not examine systematically the effect of nuclear assistance on the spread of nuclear weapons.

Scholars have also examined the causes of international nuclear assistance. Drawing on the nuclear deterrence literature, Matthew Kroenig (2009) has argued that the spread of nuclear weapons is more threatening to relatively powerful states than it is to relatively weak states. Applying this insight to the problem of sensitive nuclear transfers, he finds that states are more likely to provide sensitive nuclear assistance under three strategic conditions. First, the more powerful a state is relative to a potential nuclear recipient, the less likely it is to provide sensitive nuclear assistance. Second, states are more likely to provide sensitive nuclear assistance to states with which they share a common enemy. Third, states that are less vulnerable to superpower pressure are more likely to provide sensitive nuclear assistance. Matthew Fuhrmann has examined why states trade in dual-use weapons of mass destruction (WMD) technologies (2008) and why states sign civilian nuclear cooperation agreements (2009, this issue). Fuhrmann also finds that strategic and not economic or normative concerns drive states to export civilian nuclear technologies. Unlike this analysis, however, these studies explore the causes but not the consequences of international nuclear assistance.

## Importing the Bomb

A state's ability to produce nuclear weapons often hinges on the availability of external assistance from a more advanced nuclear state. There are a number of common hurdles that states face as they attempt to develop a nuclear-weapons program, but sensitive nuclear assistance from a more advanced nuclear state can help a state to overcome these technical and strategic challenges.[2]

First, the designs for many sensitive nuclear technologies, such as uranium-enrichment plants and implosion-type nuclear weapons, are not available in the public realm. States pursuing these technologies, without external assistance, must fashion designs for these complicated and advanced technologies indigenously. Second, the construction and successful operation of nuclear facilities requires much trial and error. Previous scholarship has emphasized the importance of tacit knowledge in successful nuclear-weapons programs (MacKenzie and Spinardi 1995; Montgomery 2005). For example, the operation of a gaseous-centrifuge uranium-enrichment plant requires the spinning of large metal cylinders at a rate of 300 meters per second, roughly the speed of sound. Inexperienced engineers often struggle to prevent the cylinders from spinning out of control and crashing on the ground. The kind of trial and error required for the indigenous development of advanced nuclear technology often ends in failure. For example, from 1981 to 1991, Iraq tried and failed in multiple attempts to produce highly enriched uranium using several different methods, including gaseous centrifuge, chemical enrichment, ion exchange, and laser isotope separation, before finally settling on electromagnetic isotope separation.[3] Third, the development of a nuclear-weapons infrastructure from scratch is an expensive enterprise.

A state must, at a minimum, procure the relevant raw materials and technologies at home or on the open market; develop an advanced industrial and nuclear infrastructure; train and provide for a specialized cadre of physicists, mathematicians, engineers, and metallurgists; and provide adequate finances to continue to develop and support the program throughout its lifetime. For example, it is estimated that Iraq spent many billions of dollars in its unsuccessful bid to develop nuclear weapons.[4] Fourth, states striving for a nuclear-weapons capability must overcome these significant technical challenges under intense international pressure. Other states, international organizations, and nongovernmental organizations opposed to nuclear proliferation apply a variety of economic, diplomatic, and military pressures to dissuade states from fulfilling their nuclear ambitions. In 1981, for example, Iraq's nuclear reactor at Osiraq, then the centerpiece of Iraq's nuclear program, was destroyed by Israel in a preventive military strike.

International nuclear assistance can ease each of the challenges faced by potential nuclear-weapon states. First, nuclear suppliers can provide the aspiring nuclear-weapon state with proven designs for nuclear technology. With a guaranteed design in hand, scientists and technicians can leapfrog technical design stages and focus their effort on replicating a model that has proven effective elsewhere. For example, without access to Chinese nuclear bomb designs, it is believed that Pakistan would have had great difficulty developing a design for the implosion-type nuclear weapon that now constitutes its nuclear arsenal (Corera 2006, 46). Second, nuclear assistance can reduce the amount of trial and error needed to successfully operate nuclear facilities. States supplying nuclear assistance can construct and even operate nuclear facilities for the recipient state. For example, when China provided Pakistan with uranium-enrichment technology in the early 1980s, Chinese technicians remained in Pakistan until the uranium-enrichment facility was fully operational (Jones et al. 1998, 50n57). In this way, the nuclear recipient benefits from the tacit knowledge acquired by the scientific community in the more advanced nuclear state. Third, importing sensitive nuclear technology can help states to economize on the costs of nuclear development. Procuring sensitive nuclear assistance from abroad can be less expensive than the indigenous development of a complete nuclear infrastructure. In fact, previous research has demonstrated that states have often received substantial amounts of sensitive nuclear materials and technology at little or no cost because nuclear suppliers had a strategic interest in helping them to acquire sensitive nuclear technology (Kroenig 2007). For example, from 1958 to 1960, the Soviet Union "loaned" China the key component parts for the Lanzhou uranium-enrichment facility and the Jiuquan plutonium-reprocessing plants, partly because Moscow feared a U.S. attack on the Chinese mainland following the Second Taiwan Straits Crisis and wanted to enhance China's defensive and deterrent capabilities (Goncharenko 1998; Lewis and Xue 1988). Fourth, and finally, sensitive nuclear assistance can help a state to avoid international scrutiny. The receipt of sensitive nuclear materials and technology from abroad can quickly remake a state without a nuclear-weapons program into a state with a latent nuclear-weapons capability, presenting the international community with a fait accompli and preempting international efforts at dissuasion. For example, France provided Israel with sensitive nuclear assistance from 1959 to 1965, transforming Israel from a state with a rudimentary, civilian nuclear research program into a nuclear-weapon state in less than a decade. The United States was strictly opposed to nuclear proliferation in Israel, but by the time U.S. intelligence agencies recognized the extent of Israel's nuclear program, the United States had few remaining policy options to dissuade Israel from its nuclear course (Richelson 2006; Cohen 1998).

The above discussion suggests that the receipt of sensitive nuclear assistance increases the probability of nuclear proliferation. This logic leads us to the central hypothesis of this article:

*Hypothesis 1:* States that receive sensitive nuclear assistance will be more likely to acquire nuclear weapons.

There are clearly other, alternative explanations for why states acquire nuclear weapons. I therefore control for a wide set of opportunity and willingness determinants of nuclear proliferation. I discuss these variables in the below sections in which I describe the data and examine the evidence for the above hypotheses.

## Empirical Analysis

To examine the relationship between sensitive nuclear assistance and nuclear proliferation, I use qualitative and quantitative research methods. Nuclear proliferation and sensitive nuclear assistance are both rare events. From 1945 to 2000, the time period under investigation, nine countries acquired nuclear weapons and, of these, three (Israel, China, and Pakistan) received sensitive nuclear assistance.[5] The relatively small number of positive cases allows me to examine the role of sensitive nuclear assistance in the positive cases and to compare these countries to other similar countries that did not receive sensitive nuclear assistance. The qualitative analysis is only the first step, however. To analyze the relationship between sensitive nuclear assistance and nuclear proliferation in the entire universe of cases and to control for potentially confounding factors, a large-*N* statistical analysis forms the core of the empirical investigation.

### Case Studies

A brief review of important cases of nuclear proliferation demonstrates that assistance from abroad can be an important factor in determining whether a state eventually acquires nuclear weapons. For example, in 1958, Israel's nuclear program consisted of nothing more than a national atomic-energy commission and a small research reactor at Nahal Soreq. From 1958 to 1965, however, France provided sensitive nuclear assistance to Israel, which greatly enhanced Israel's ability to produce nuclear weapons. France constructed a large, plutonium-producing nuclear reactor and a plutonium-reprocessing facility at Dimona, transferred a nuclear-weapon design, trained Israeli scientists at nuclear facilities in France, and allowed Israeli observers at French nuclear-weapon tests (Cohen 1998). By 1967, after seven full years of sustained French assistance, Israel was able to assemble its first nuclear weapon.

Other states with nuclear arsenals received substantial assistance from abroad. In fact, much of the history of nuclear proliferation can be read as a history of a chain of cases of nuclear assistance. From 1958 to 1960, the Soviet Union provided China with key component parts for uranium-enrichment and plutonium-reprocessing plants and trained Chinese technicians, contributing to China's ability to conduct its first nuclear-weapon test in 1964 (Lewis and Xue 1988). Thereafter, China itself became a nuclear supplier. From 1981 to 1986, China transferred significant quantities of highly enriched uranium, uranium-enrichment technologies, and a nuclear-weapon design to Pakistan (Corera 2006). While Pakistan refrained from testing a nuclear device until 1998, it is believed that with China's assistance, Pakistan assembled its first nuclear weapon in 1990 (Jones et al. 1998, 132, 140n). More recently, from 1987 to 2002, Pakistan, with the help of Pakistani nuclear scientist A. Q. Khan, distributed sensitive nuclear technology and materials to Iran, Libya, and North Korea.[6] Since the end of cooperation in 2002, Libya has agreed to give up its nuclear program, but North Korea tested its first nuclear device in 2006, and Iran is making steady progress on developing its nuclear capability. In fact, according to a 2007 U.S. National Intelligence Estimate, Iran may be able to produce nuclear weapons as early as 2009, thanks in large part to uranium-enrichment assistance from Pakistan.[7]

On the other hand, states with a persistent demand for nuclear weapons but that were unable to acquire substantial international assistance failed to sustain national nuclear-weapons programs. Egypt, during the course of many decades, has been rebuffed in numerous attempts to secure an international nuclear supplier and to this day lacks a nuclear-weapons arsenal. Beginning in the 1960s, Egypt sought sensitive nuclear assistance, first from the Soviet Union and then from China, but was denied by both states.[8] There is also evidence to suggest that Egyptian officials may have met with representatives from the A. Q. Khan network, but Egypt never received sensitive nuclear assistance from Pakistan.[9] Unlike Israel and other current nuclear-weapon states that received substantial imports of sensitive nuclear materials and technology, Egypt presently maintains a rudimentary civilian nuclear program. Other states that have shown a historical interest in nuclear weapons but that have not yet acquired the bomb include states that have received little sensitive nuclear assistance from abroad, including Iraq and Taiwan, and states that have received no sensitive nuclear assistance whatsoever, such as Argentina, Saudi Arabia, Syria, and South Korea.[10]

## Nuclear Proliferation Data

To test the effect of sensitive nuclear assistance on the spread of nuclear weapons, I construct an original sensitive-nuclear-assistance data set. The data set contains yearly information for all states in the international system from 1945 to 2000. The unit of analysis is the country-year. I also draw on data from Singh and Way (2004) and Jo and Gartzke (2007) to construct other nuclear proliferation variables.

### *Dependent Variable*

The dichotomous dependent variable is *nuclear proliferation.* This variable measures whether a state acquires nuclear weapons in a given year.[11] To construct this variable, I draw on the nuclear proliferation dates from Gartzke and Kroenig (2009, this issue). A state is coded as acquiring nuclear weapons when it first explodes a nuclear device, or if it does not immediately conduct a nuclear test, when it first assembles a deliverable nuclear weapon.

### *Independent Variable*

I construct independent variables to test the hypotheses about the effects of nuclear assistance explicated above. *Sensitive nuclear assistance* is a dichotomous variable measuring whether a state has ever received the key materials and technologies necessary for the construction of a nuclear-weapons arsenal from a capable nuclear-supplier state.[12] Sensitive nuclear assistance takes three forms. States receive sensitive nuclear assistance when they receive assistance in the design and construction of nuclear weapons, receive significant quantities of weapons-grade fissile material, or receive assistance in the construction of uranium-enrichment or plutonium-reprocessing facilities that could be used to produce weapons-grade fissile material.[13]

Sensitive nuclear assistance excludes other types of nuclear cooperation less relevant to the development of a nuclear-weapons program. I exclude the receipt of the platforms that could potentially be used to deliver nuclear weapons, such as bombers and ballistic missiles. The receipt of nonsensitive nuclear assistance, such as scientific exchanges, assistance in the surveying and mining of natural uranium, fuel-cycle services, and the construction of research and power reactors, does not qualify as sensitive nuclear assistance.

To code the sensitive-nuclear-assistance variable, I began with an online nuclear-weapons database maintained by the Nuclear Threat Initiative. I also drew on prominent reviews on the proliferation of nuclear weapons and on historical studies of countries' nuclear-weapons programs. To be included in the data set, a case of sensitive nuclear transfer had to be verified by at least two sources.[14] A list of the cases of sensitive nuclear assistance can be found in Table 1.[15]

**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*

I also include a number of variables to control for other factors thought to influence the likelihood of nuclear proliferation. All control variables are drawn from Singh and Way (2004), unless otherwise specified.[16] To assess a country's domestic capacity to produce nuclear weapons, I include a measure of economic development. *GDP* is measured as a country's GDP per capita in constant 1996 dollars. To test for a nonmonotonic relationship between level of economic development and nuclear acquisition, I include a squared term, *GDP squared*.[17] *Industrial capacity* is a dichotomous variable that measures whether a country produces steel domestically and has an electricity-generating capacity greater than 5,000 MW. States above a certain threshold of industrial development may be better able to support a nuclear-weapons program.

Scholars (e.g., Sagan 1996/1997) have argued that states may pursue nuclear weapons to improve their security. If this is the case, we may expect that states in threatening security environments may be more likely to acquire nuclear weapons. To test the effect of a state's security environment on its risk of acquiring nuclear weapons, I include a *rivalry* variable that measures whether a state is involved in at least one enduring rivalry (Diehl 1998; Bennett 1998). *Alliance* is a dichotomous variable that assesses whether a state is in a defense pact with a nuclear-armed state. States under an ally's nuclear umbrella may have fewer incentives to develop nuclear weapons.

A number of variables gauge the institutional and economic determinants of nuclear acquisition. Scholars have argued that democratic states, because of their position in the "core" of the international system, may feel more secure and may be less likely to pursue nuclear weapons (e.g., Chafetz 1993). On the other hand, democratic states may be more beholden to nationalist appeals and to domestic political lobbies that favor nuclear proliferation (Sagan 1996/1997). I include *regime type*, which measures a country's domestic political regime type, drawing on data from the Polity IV index (Jaggers and Gurr 1995). Scholars have also argued that states that are open to the international economy or that are pursuing a strategy of economic liberalization are less likely to seek nuclear weapons, because they are reluctant to risk international trade and investment on controversial foreign policies (Solingen 1994, 1998, 2007; Paul 2000). *Openness* assesses a state's openness to the international economy and is calculated as a country's trade ratio (exports plus imports, divided by GDP). *Liberalization* measures changes in a country's trade ratio over spans of three, five, and ten years.

## Data Analysis

My central hypothesis concerns the importance of international nuclear assistance for understanding nuclear proliferation. I use Cox proportional-hazard models to test claims about the correlates of nuclear acquisition (Box-Steffensmeier and Jones 1997). Robust standard errors are adjusted for clustering by country.[18]

Several types of statistical analyses prove useful in exploring the evidence for or against each of the hypotheses described earlier. To begin the investigation, I examine the simple bivariate relationship between *sensitive nuclear assistance* and *nuclear proliferation* (Table 2, model 1). To control for potentially confounding factors, I then evaluate the effect of *sensitive nuclear assistance* after including the control variables (Table 2, model 2).[19] I then estimate a trimmed model that includes only the variables that were statistically significant in the previous model (Table 2, model 3). To assess the relationship between *sensitive nuclear assistance* and *nuclear proliferation* among the states that actively pursued nuclear weapons, I use a censored hazard model of the risk of nuclear acquisition contingent on a state's possessing a nuclear-weapons-production program (Table 2, model 4), as measured by Jo and Gartzke (2007).[20]

I first evaluate the hypothesis that sensitive nuclear assistance is positively related to nuclear acquisition. According to Hypothesis 1, states that receive sensitive nuclear assistance will be more likely to acquire nuclear weapons than are similar states that do not receive sensitive nuclear aid. Turning to the hazard models, we see that the relationship between *sensitive nuclear assistance* and *nuclear proliferation* is positive and statistically significant in each and every model. There is strong empirical support for the causal significance of sensitive nuclear assistance for understanding nuclear proliferation.[21]

**Table 2**
**Hazard Models of Nuclear Proliferation**

| Independent Variable | Model 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.

Next, I examine the control variables to assess the relative support for the supply-side, as opposed to the demand-side, approach to nuclear proliferation. International assistance and domestic capacity are the primary means by which a state acquires the capability to produce nuclear weapons. I have already found a relationship between sensitive nuclear assistance and nuclear proliferation. *GDP* and *GDP squared* are statistically significant and have positive signs on the coefficients in two of the three models in which they are included, which provides some support for the existence of a nonmonotonic relationship between economic development and nuclear proliferation. Furthermore, we see that *industrial capacity* is positive and statistically significant in every model, which demonstrates that states above a certain level of industrial development are more likely to acquire nuclear weapons. Taken together, the results provide strong support for the supply-side approach to understanding nuclear proliferation. States that can more easily produce nuclear weapons, because of international assistance or domestic capacity, are more likely to do so.

Turning to the demand variables, we find that *rivalry* is positive and statistically significant in two of the three models in which it is included. Consistent with security-based approaches to nuclear proliferation and the findings of previous quantitative studies (Singh and Way 2004; Jo and Gartzke 2007), states in a threatening security environment are more likely to acquire nuclear weapons. Next, we find that the protection provided by a nuclear umbrella appears to mitigate a state's demand for nuclear weapons. *Alliance* is negative and statistically significant in two of the three models in which it is included. States that are in a defense pact with a nuclear-armed state are less likely to acquire nuclear weapons. The sign on the coefficient of *regime type* is positive and statistically significant in each model. This finding provides support for the idea that democratic states may be more prone to nuclear proliferation because they may be subject to pressure from domestic constituencies that favor nuclear development. The alternate hypothesis that democratic states will be less likely to acquire nuclear weapons because they form the secure core of the international system does not find support. There is no discernable relationship between economic openness and nuclear proliferation. *Openness* is not statistically significant in any of the models in which it is included. States that are open to the international economy are neither more nor less likely to acquire nuclear weapons. Neither is there support for the idea that liberalizing states will seek to avoid controversial foreign policies such as nuclear-weapons proliferation. *Liberalization* is statistically significant in model 4 only, but the sign on the coefficient is positive. This suggests, contrary to theoretical expectation, that liberalizing states may be more, not less, likely to acquire nuclear weapons. Taken together, I find modest support for demand-side approaches to the study of nuclear proliferation. Security environment and domestic politics appear to play some role in shaping the likelihood that a state will acquire nuclear weapons, but a state's relationship to the international economy does not.[22]

Table 3 interprets the substantive effect of the variables that were statistically significant in all of the above models on *nuclear proliferation*, using the results from the uncensored hazard model reported in Table 2, model 2, and the censored hazard model reported in Table 2, model 4 (see Table 3). The entries represent the percentage change in the baseline hazard ratios of nuclear acquisition for a given change in the independent variable. Focusing my comments on the results from the uncensored model, Table 3 reveals that providing a state with sensitive nuclear assistance increases the risk that it will acquire nuclear weapons by more than 700 percent. *Sensitive nuclear assistance* has not just a statistically significant effect but also a substantively significant effect on nuclear proliferation. Turning now to the substantive effect of the control variables, Table 3 shows that *industrial capacity* has a substantive effect on *nuclear proliferation.* States above a certain threshold of industrial capacity have a hazard ratio of nuclear proliferation that is more than twenty-nine times greater than the hazard ratio for similar states below the industrial-capacity threshold. In contrast, *regime type* has a smaller substantive impact. Increasing a state's level of democracy by one point on the twenty-point scale increases the risk that it will acquire nuclear weapons by only 12 percent.

The hazard analysis is only the first step, however. To address problems related to nonrandom assignment of the treatment, I use nonparametric, matching techniques as recommended by Ho et al. (2007).[23] It is possible that the findings presented above are biased, because states that receive sensitive nuclear assistance are quite different from those that do not. Sensitive nuclear assistance is not randomly assigned. If countries that received sensitive nuclear assistance and those that did 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.

are very different, the above findings could be largely the result of extrapolations from the available data.

To correct for this problem, Ho et al. (2007) recommend preprocessing data using matching techniques in which treated cases are matched with similar untreated cases. Observations within the control group (in this study, states that did not receive sensitive nuclear assistance) are matched as closely as possible with the treated cases (states that did receive sensitive nuclear assistance) to form a matched subsample of data. This allows the researcher to make inferences about the causal effect of sensitive nuclear assistance based on a comparison of the most similar cases. Matching reduces the role of functional form and specification assumptions of the parametric model, resulting in more reliable causal inferences. When comparing cases in which other causal variables are as similar as possible, any remaining differences between the cases can be attributed to the treatment. To adjust for any remaining imbalances, Ho et al. (2007) recommend using the same parametric model one would have applied to the entire data set on the matched subsample of data.

To begin the analysis, I first identify the confounding factors on which to match observations. Confounding factors are those variables that may influence the dependent variable conditional on treatment, may be correlated with the treatment variable, and are causally prior to treatment. According to Ho et al. (2007, 216), "All variables in $X_i$ that would have been included in a parametric model without preprocessing should be included in the matching procedure." I include, therefore, as confounding factors, the control variables detailed above: *GDP*, *GDP squared*, *rivalry*, *alliance*, *regime type*, *openness*, and *liberalization.*

Next, to preprocess the data, one-to-one nearest neighbor matching with replacement was used, using GenMatch (Sekhon forthcoming; Sekhon and Diamond 2008; Sekhon and Mebane 1998). Table 4 presents the before and after balance statistics, using five standard indicators of balance: the difference in means; the *p* values from a *t*-test on the difference of means; where possible, the *p* values from a K-S test of

**Table 4**
**Balance Statistics**

| Variable | | Mean Treated | Mean Control | $t$-test $p$ value | K-S test $p$ value | Var. ratio (Tr/Co) | Std. 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.

similar distributions; the ratio of the variances of the treated and control samples; and the mean standardized differences from the QQ plot (Imai, King, and Stuart 2006; Sekhon and Diamond 2008).

The balance statistics indicate that excellent balance was achieved. The *p* values on all *t*-tests are greater than .56, with the exception of the *t*-test on *alliance*, which is still well balanced at .111. QQ statistics improve in all cases except *alliance* and *regime type*, which were both well balanced before matching ($p = .915$ and .647 on the *t*-tests, respectively) and continued to be well balanced after matching ($p = .111$ and .860 on the *t*-tests, respectively).

Next, I analyze the preprocessed data, using a Cox proportional hazard model. Table 5 presents the effect of sensitive nuclear assistance on nuclear acquisition as estimated by the Cox regression in the matched sample. I only present the coefficients for the treatment variable in Table 5. The coefficients for the confounding factors are substantively meaningless because I matched on those variables. The results of the Cox estimation on the matched subsample provide further support for Hypothesis 1. The sign on the coefficient is positive and statistically significant, which demonstrates that states that receive sensitive nuclear assistance are more likely to acquire nuclear weapons. Furthermore, the analysis on the matched data suggests that *sensitive nuclear assistance* may have an even larger substantive effect than indicated by the analysis performed on the unmatched sample. On the unmatched sample, we saw that *sensitive nuclear assistance* increased the risk of *nuclear proliferation* by more than 700 percent. In the matched sample, however, *sensitive nuclear assistance* increases the risk of *nuclear proliferation* by more than 1,200 percent (not shown). If anything, it appears that not correcting for the nonrandom assignment of sensitive nuclear assistance underestimates the effect of sensitive nuclear assistance on nuclear proliferation.

## Robustness Checks

I explore the robustness of my findings by examining the extent to which my results depend on the coding of the dependent variable, model specification, and the nuclear-proliferation behavior of a few key states. It is difficult to define precisely when some states acquired nuclear weapons. For states that conduct a nuclear test, the date of nuclear acquisition is quite clear. For nuclear-weapon states that did not conduct nuclear tests, however, the date of the first assembly of nuclear weapons requires an examination of the countries' historical records of nuclear development and some guesswork. Robustness checks performed using alternate codings of *nuclear proliferation* reveal that the results are not sensitive to different measurements of the dependent variable. Next, to ensure that my results were not being driven by the inclusion of specific control variables, I reran dozens of models, omitting right-hand-side variables one at a time. Again, the core results were not affected. Finally, to assess whether the findings are being driven by the proliferation behavior

**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 |

of particular states, I dropped the observations containing certain key countries and repeated the analysis. Sequentially removing the observations containing China, Israel, and Pakistan and reestimating the models did not affect the findings.[24]

## Conclusion

This article sought to explain why states acquire nuclear weapons. I found that in order to explain patterns of nuclear proliferation, one must look to international transfers of sensitive nuclear materials and technology. States that receive sensitive nuclear assistance from more advanced nuclear states are more likely to acquire nuclear weapons than are similar states that do not receive sensitive nuclear assistance. The receipt of sensitive nuclear assistance helps potential nuclear proliferators overcome the common obstacles that states encounter as they attempt to develop a nuclear arsenal. By importing the bomb, states can leapfrog technical design stages, benefit from tacit knowledge in more advanced scientific communities, economize on the cost of nuclear-weapons development, and avoid international scrutiny.

In broader terms, this article provided strong support for the supply-side approach to nuclear proliferation advocated in this issue (Gartzke and Kroenig 2009, this issue). States that have the ability to produce nuclear weapons, either through international assistance or domestic capacity, are much more likely to do so. In contrast, this article found only modest support for key demand-side variables. This may be because nuclear weapons provide states with a variety of security and diplomatic benefits (Gartzke and Kroenig 2009; Gartzke and Jo 2009; Horowitz 2009; Rauchhaus 2009; Beardsley and Asal 2009, all in this issue), which mutes demand-side differences across states. The scholarly study of nuclear proliferation should place less emphasis on understanding which states want nuclear weapons and focus greater analytical attention on examining which states can produce them.

The argument of this article began with the simple insight that the ability to construct nuclear weapons spreads from state to state. As such, this argument about the relationship between nuclear assistance and nuclear acquisition treats nuclear proliferation as a transnational phenomenon. Scholarly approaches to nuclear proliferation have focused largely on the characteristics of individual states and have failed to theorize fully the international dimensions of nuclear proliferation. Academic nonproliferation studies have been criticized for a "tendency to isolate individual states and to examine their unique motives for going nuclear prevent(ing) us from giving due importance to the varieties of international collaboration that were common and indispensable to all early developers of nuclear programs" (Abraham 2006, 55). Indeed, it is somewhat peculiar that studies about the "proliferation," "diffusion," and "spread" of nuclear weapons have not explicitly recognized that nuclear-weapons technologies and materials literally spread from state to state. A complete understanding of nuclear proliferation, therefore, requires further research on the causes and consequences of nuclear assistance.

## Notes

1. See, for example, President Bush's Statement on North Korea Nuclear Test, October 9, 2006, available at http://www.whitehouse.gov/news/releases/2006/10/20061009.html.

2. I define sensitive nuclear assistance as the international transfer of the key materials and technologies necessary for the construction of a nuclear weapons arsenal to a nonnuclear weapon state. A complete list of sensitive nuclear materials and technologies is provided in the data section of this article.

3. Nuclear Threat Initiative (NTI) Web site, "Iraq Country Overview," available at http://www.nti.org/e_research/profiles/Iraq/Nuclear/index.html.

4. Ibid.

5. North Korea received sensitive nuclear assistance in the 1990s, but did not acquire nuclear weapons, as defined here, during the time period under investigation. For data on nuclear proliferation dates, see Gartzke and Kroenig 2009, this issue.

6. Pakistani assistance to Iran, Libya, and North Korea from 1987 to 2002 was state-sponsored, according to any reasonable definition of the term. Recent evidence reveals that senior government officials, including heads of state and Army chiefs of staff, actively supported the policy of nuclear transfer (Corera 2006; Langewiesche 2007; Sagan 2006, 53).

7. Office of the Director of National Intelligence, *Iran: Nuclear Intentions and Capabilities*, November 2007, available at http://www.dni.gov/press_releases/20071203_release.pdf.

8. Nuclear Threat Initiative (NTI) Web site, "Egypt Country Overview," available at http://www.nti.org/e_research/profiles/Egypt/index.html.

9. See, for example, "The A.Q. Khan Network: Case Closed?" Hearing before the Subcommittee on International Terrorism and Nonproliferation of the Committee on International Relations, House of Representatives, May 25, 2006.

10. From 2001 to 2007 North Korea may have helped Syria construct a nuclear reactor. Nuclear reactors are not considered sensitive nuclear assistance. Some have questioned whether North Korea may have also provided Syria with plutonium reprocessing capabilities, but there is no firm evidence that these countries engaged in any sensitive nuclear cooperation.

11. I do not include variables measuring state decisions to explore, pursue, or possess nuclear weapons, because my theoretical interest is limited to the effect of nuclear assistance on nuclear acquisition. Nevertheless, robustness tests performed using these alternate measures of nuclear proliferation produce similar results.

12. The line between nonsensitive and sensitive nuclear assistance is often fuzzy in practice, yet there is a fairly widespread scientific consensus that sensitive fuel-cycle facilities, such as uranium-enrichment facilities, represent a direct nuclear proliferation threat, while other less sensitive, civilian technologies are relatively resistant to proliferation. By drawing the line between nonsensitive and sensitive nuclear assistance at sensitive fuel-cycle facilities, my definition follows this preexisting consensus.

13. Nuclear-weapons experts have long recognized that a necessary, and the most difficult, step to building a nuclear arsenal is the acquisition of the weapons-grade fissile material that forms the core of the nuclear device. International Agency Atomic Energy regulations assume that 8 kg of plutonium and 25 kg of weapons-grade, highly enriched uranium are sufficient for the construction of a basic nuclear device. Assistance on fuel-cycle facilities includes the construction of complete facilities or the transfer of key component parts for the construction of such facilities, such as centrifuges for uranium-enrichment plants or hot cells for plutonium-reprocessing plants. Assistance on uranium enrichment includes assistance on any of the various types of uranium-enrichment processes including jet-nozzle, gaseous diffusion, gas-centrifuge, and laser isotope enrichment. For a primer on nuclear weapons and their construction, see Jones et al. (1998, 317-22).

14. The secretive nature of sensitive nuclear transfers raises the potential for a missing-data problem. It is difficult, however, for countries to maintain a secret nuclear program, and sensitive nuclear transfers that countries attempt to conduct in secret generally become known within a few years. Given the time frame of this study, which ends in 2000, I assess that missing data do not pose a significant problem to this analysis.

15. See Kroenig (2009) for a description of the cases of sensitive nuclear assistance, a list and description of selected cases that do not qualify as sensitive nuclear assistance according to the above definition, an explanation of key coding decisions, and the sources used in coding the variable.

16. To date, Singh and Way (2004) is the only study that uses quantitative methods to assess the correlates of nuclear acquisition. Jo and Gartzke's study on nuclear proliferation (2007) examines the determinants of nuclear possession, not nuclear acquisition.

17. Including a variable and its squared term in the model is a common method for testing for a non-monotonic relationship (Ramsey and Schafer 2002, 244-45).

18. Using logit or probit estimators or hazard models with a Weibull distribution to characterize the baseline hazard function produces virtually identical results.

19. I conceive of the demand-side and supply-side variables as additive in their effects. In other words, a state that has a strong desire for nuclear weapons will be more likely to acquire nuclear weapons, holding all other factors constant, because the benefits of doing so may be higher. Similarly, a state that has the ability to produce nuclear weapons will be more likely to proliferate, ceteris paribus, because the costs of doing so may be lower.

20. As a robustness check, I replicated the findings of Singh and Way (2004) and Jo and Gartzke (2007) and then added the sensitive-nuclear-assistance variable to their models. In each and every model, sensitive nuclear assistance was positive and statistically significant.

21. To assess whether other less sensitive types of nuclear assistance also contributed to the international spread of nuclear weapons, I created a dichotomous variable measuring whether a country had ever received foreign assistance on the construction of a nuclear research or power reactor. Perhaps surprisingly, the sign on the coefficient of this variable was negative in all of the models in which it was included and was statistically significant in some specifications. This may suggest that countries that receive international help on the construction of a nuclear reactor are actually less likely to acquire nuclear weapons. The other results were unaltered. A possible explanation for this finding is that one of the grand bargains of the Nuclear Nonproliferation Treaty (NPT) may be paying off. Countries may be willing to trade the opportunity to develop nuclear weapons in exchange for international assistance on basic nuclear research and energy production.

22. In various tests, I also included a dichotomous variable gauging whether a state was a member of NPT. The variable was negative and statistically significant in all of the models in which it was included, suggesting that countries that are members of the NPT are less likely to acquire nuclear weapons. The other results remained unchanged.

23. Methodologists disagree about how best to apply matching techniques to time series data. Here, I employ matching analysis merely as an additional check on the robustness of the findings presented above.

24. When I deleted any two of these three states and re-estimated the models, *sensitive nuclear assistance* was no longer statistically significant. This result is not terribly surprising, given that dropping two of these three states leaves only a single positive case of a country that received sensitive nuclear assistance and then went on to also acquire nuclear weapons.

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