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Talking Peace, Making Weapons: IAEA Technical Cooperation and Nuclear Proliferation

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Abstract

A growing literature suggests that nuclear assistance from other countries is an important determinant of whether states pursue nuclear weapons. Existing work does not consider, however, the most widely available source of assistance—the Technical Cooperation (TC) program administered by the International Atomic Energy Agency (IAEA). IAEA assistance is an important piece of the nonproliferation regime's central bargain: member states enjoy nuclear assistance in exchange for agreeing not to seek nuclear weapons. Using a data set of TC projects since 1972, we examine whether international nuclear assistance is associated with the pursuit of nuclear weapons. We hypothesize that some TC assistance reduces the cost of pursuing nuclear weapons, making weapons programs more likely. We find that receiving TC related to the nuclear fuel cycle is a statistically and substantively significant factor in state decisions since 1972 to seek nuclear weapons, with important implications for existing theories of nuclear proliferation.

Keywords

nuclear proliferation, international organizations, IAEA, nuclear power

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The grand bargain of the nuclear nonproliferation regime promises states without nuclear weapons access to peaceful nuclear technologies in exchange for their commitment to forgo nuclear weapons and accept safeguards against the misuse of nuclear technologies for weapons purposes.[1] This bargain dates from the 1950s promise of the United States, as part of the Atoms for Peace program, to allow unfettered access to peaceful nuclear technologies with assurances against misuse. Other nuclear-capable countries, seeing potentially large commercial benefits, were already beginning to sell their nuclear wares abroad, providing recipient states with turnkey nuclear reactors, training, and expertise.

When international organizations (IOs) also became involved in the provision of civilian nuclear assistance, foremost among them was the International Atomic Energy Agency (IAEA). Since 1958, the IAEA has administered tens of thousands of nuclear assistance projects under its Technical Cooperation (TC) program, including the provision of facilities, equipment, fellowships, training, and technical studies for fuel cycle development, radioisotope production, and health and resource applications for nuclear materials.[2] TC usually fulfills substantively different needs than does commercial supply, promoting the nuclear advancement of developing countries. While bilateral nuclear cooperation often appears more substantial than international assistance, the IAEA must be considered a major supplier of nuclear assistance over the last fifty years by consistency and sheer volume.

The promise of peaceful nuclear energy is in perpetual tension with the threat of nuclear weapons proliferation because civilian uses of nuclear technology rely on the same materials, infrastructure, and knowledge base as nuclear weapons development. Nuclear supplier states historically have struggled to balance dual-use commerce and nonproliferation goals, often relying on bilateral assurances, known as safeguards, to prevent diversion to weapons programs. Many have worried that state-to-state nuclear cooperation makes countries more likely to proliferate (Fuhrmann 2009a; Kroenig 2009b). States have been aware of this problem for many years, often coordinating self-restraint through informal institutions. For example, the Nuclear Suppliers Group (NSG) agreed in 1975 not to provide "sensitive" fuel cycle technologies involving uranium enrichment or the reprocessing and handling of plutonium (Tate 1990).

Much less attention has been paid to the proliferation risks from international nuclear assistance. The IAEA was created explicitly to promote peaceful uses of nuclear technology, but also to place those efforts under international safeguards to prevent their misuse (Brown 2010). This has left important empirical questions unanswered. Does IAEA peaceful nuclear assistance encourage states to pursue nuclear weapons? Do states with nuclear weapons programs seek out IAEA assistance to help their programs along? The IAEA ultimately followed the NSG in limiting, after 1977, the fuel cycle technologies it would supply or otherwise help states to develop (Fischer 1997). However, if IAEA assistance still contributes to weapons development, this suggests the Agency is at least partly a "runaway agent," engaging in activities that run counter to its principals' interests (Hawkins and Jacoby

2006). It also raises questions about the sustainability of the norm of unfettered access to nuclear assistance that is inherently dual use.

This article builds on studies that identify a link between state-sponsored nuclear cooperation and proliferation to explore whether involvement in IAEA TC projects—particularly those related to the nuclear fuel cycle—is associated with the pursuit of nuclear weapons. We proceed in six parts. First, we discuss the rich and expanding literature on the drivers of nuclear proliferation. Second, we describe the IAEA's TC program and theorize about a potential connection between fuel cycle–related TC and nuclear weapons programs. Third, we introduce a quantitative analysis of the effect of participation in fuel cycle–related TC efforts on states' proliferation behavior. Fourth, we present our central finding—that fuel cycle–related TC is strongly associated with nuclear weapons programs. Fifth, we separately analyze the effects of TC on the initiation and continuation of weapons efforts. Finally, we conclude with a discussion of the implications of this argument for ongoing efforts to limit the spread of nuclear weapons.

Nuclear Supply and Nuclear Proliferation

Most of the literature on nuclear proliferation focuses on why states seek nuclear weapons (Jo and Gartzke 2007; Powell 2003; Quester 2000; Rublee 2009; Sagan 1996/1997; Solingen 2007) and whether their acquisition has any effect (Beardsley and Asal 2009; Gartzke and Jo 2009; Rauchhaus 2009; Waltz and Sagan 2002). New scholarship is subjecting the broad set of causes and consequences of proliferation proposed by these studies to detailed scrutiny (Gartzke and Kroenig 2014)—from the role of security guarantees and forward deployed weapons in preventing proliferation (Bleek and Lorber 2014; Fuhrmann and Sechser 2014), to the trade-offs among different types of weapons of mass destruction (Horowitz and Narang 2014), to the factors that lead states to choose particular types of nuclear weapons (Gartzke, Kaplow, and Mehta 2014). A growing literature has focused in particular on the strategic construction of nuclear capacity, from why states build nuclear power plants and export sensitive nuclear technologies (Fuhrmann 2008, 2009b; Kroenig 2009a), to how nuclear assistance contributes to nuclear weapons proliferation (Fuhrmann 2009a; Kroenig 2009a). This body of work, however, deals almost exclusively with *state-to-state* nuclear supply. Kroenig (2009a, 2009b), for example, looks at six supplier countries that provide twelve recipient countries with "sensitive nuclear assistance": help with the design and construction of nuclear weapons, transfers of significant quantities of fissile materials, and participation in uranium enrichment or plutonium reprocessing facility construction. Fuhrmann (2009a) focuses more broadly on 2,470 cases of nuclear assistance, the vast majority of which are bilateral.[3] Fuhrmann and Kroenig largely do not address, however, the hundreds of annual nuclear assistance agreements occurring outside the state-to-state context. While the modal case of IAEA technical assistance is not "sensitive," the explicit purpose of the TC program is to "transfer nuclear and related technologies for peaceful uses to countries throughout the world" at below-market rates (IAEA 2011). That is, a key pillar of the IAEA mandate is to develop indigenous nuclear capacity, not political security or commercial revenue.[4]

The IO literature has focused heavily on institutional design (Downs 2000; Fortna 2003; Koremenos, Lipson, and Snidal 2001; Simmons 2000) and the extent to which states comply with their multilateral agreements (Chayes and Chayes 1993; Downs, Rocke, and Barsoom 1996; Hafner-Burton 2005; Hathaway 2002; Simmons 2002). However, few have examined variation in the exploitation of the optional benefits that IOs sometimes provide. There is little analysis of whether these benefits have the intended effect on states, in the context of either international development or international security.

The principal-agent approach to IOs suggests that "agency slack" may be the reason the portfolio of IO benefits does not correspond to the portfolio preferred by individual powerful principals or by the IO's collective (aggregated) principal (Cortell and Peterson 2006; Hawkins and Jacoby 2006; Hawkins et al. 2006). According to this literature, IOs sometimes pursue policies opposed by powerful member states because IO agents can exploit autonomy from their principals to pursue their own interests. Agency loss may be particularly acute at the IAEA, where one subset of states has a strong incentive to push nuclear assistance in a more permissive direction, while another subset would like to restrict benefits and expand the regulation of nuclear supply through safeguards. Being pushed and pulled by the majority of states who receive assistance from the TC program and the minority who fund it may leave IAEA staff in the position of trying to provide a set of benefits that fully satisfy no member state. The political compromise may also result in a willingness by some staff and some member states to ignore the potential risks of certain types of TC, with potentially dangerous consequences for international security.

A Theory of Multilateral Nuclear Assistance

The IAEA's technical assistance program began in 1958 with a series of small, short-term projects (all lasting for less than one year) focusing on the provision of a single instrument, technique, training course, or fellowship (Fischer 1997). Developing states began demanding an expansion of the TC program in the early 1970s to balance the IAEA's expanded regulatory function under the new Nuclear Nonproliferation Treaty (NPT), and as interest in nuclear energy surged following the 1973 oil crisis (Findlay 2012; Loosch 1997). The TC program was expanded and reformed after 1975 to pursue larger and longer term institution- and capacity-building programs.[5] TC spending increased from $1.4 million a year in 1962 to over $36 million in 1985, in real terms, and in 2010 alone the IAEA disbursed $114 million to support 890 active TC projects, including 3,890 expert and lecturer assignments, 4,964 participants at technical meetings, 222 training courses, and 1,838 individual fellowships and scientific visits (IAEA 2010). Individual TC projects vary tremendously across such areas as nuclear safety, human health, food and agriculture, radioisotope production, and the nuclear fuel cycle. Recent projects include radiation oncology training in Latin America, nuclear power feasibility studies in Pakistan, textbooks and laboratory equipment for nuclear physics courses in Macedonia, nuclear power plant site selection studies in Syria, and nuclear science training center construction in Myanmar (IAEA 2010). Not all TC projects receive financial assistance from the Agency; some projects rely on IAEA technical expertise but are funded by other IOs or by the recipients themselves.

TC projects are technically approved by a majority vote of the thirty-five member states represented on the IAEA's Board of Governors. In practice, each year's slate of TC projects is approved by consensus, like almost every board decision. The IAEA secretariat, who selects TC projects to send to the board for approval, thus plays a substantial role in deciding which projects are ultimately implemented. Member states submit an application to the Department of Technical Cooperation, which then takes several months to review and select projects. Since the early 1990s, the TC selection process has officially coordinated with the IAEA's Department of Safeguards to insure there is no conflict with the Agency's nonproliferation goals (Barretto and Cetto 2005). Interviews with former senior IAEA safeguards officials provide some reason to believe, however, that these internal reviews have not been especially rigorous. According to these interviews, the Department of Safeguards conducted only expost reviews of TC projects before 2005. The director general finally insisted that safeguards officials review all TC projects and, even then, such reviews were spotty. One retired safeguards official recalled that, after being shown a set of projects and marking several as a potential proliferation risk, "the reviewers were stunned because no one had ever flagged anything before, and there was no plan for how to handle the problem."[6]

The IAEA secretariat has substantial incentive to downplay the risk of TC to avoid controversy and to further its mission of promoting peaceful nuclear technology. Developing states organized in the mid-1970s to resist the IAEA's shift in financial and normative emphasis to safeguards with the implementation of the NPT. This coalition found some support within the TC department, whose head is always drawn from a developing state.[7] The board's review of projects may also look more effective on paper than it is in reality. The TC department has been criticized for not providing states with enough information or time to allow for rigorous member-state review. Candidate projects often have been distributed as a list with little more than the recipient, title, amount of spending (if any), the project type (which classifies the project as belonging to one of more than thirty fields and subfields of assistance), and sometimes a two- or three-sentence description. The GAO found that of the 1,565 TC projects flagged by the US government for possible proliferation risk from 1998 to 2006, only 3 percent included more than a title in their descriptions (Aloise 2011). States also receive this information only a few weeks before the November meeting of the board and therefore have little time to investigate the projects or discuss them with other member states before voting.[8]

The Board of Governors has acted, however, to address some proliferation concerns related to TC. As early as 1960, it began requiring states to certify that IAEA assistance would not be used to "further any military purpose." The Agency then decided in 1977, following India's 1974 test of a "peaceful nuclear explosive," not to provide "sensitive nuclear assistance"—technologies and facilities for enriching uranium, reprocessing spent fuel for plutonium, or handling plutonium (Fischer 1997). Further, because energy production has never been interrupted by a blockage of nuclear fuel supply, because efficient fuel production requires large economies of scale beyond the need of almost every country, and because world production is expected to meet projected demand for decades, the IAEA and major nuclear suppliers have asserted that there is little economic logic to developing new fuel cycle capacity (Kazimi, Moniz, and Forsberg 2010; Nikitin, Andrews, and Holt 2011). The IAEA's continuing fuel cycle assistance therefore implies some agency slack, at least from the perspective of the agency's major TC donors.

TC and Nuclear Weapons

States considering a nuclear weapons program are likely to weigh its substantial costs and its prospects for success against the perceived benefits of acquiring nuclear weapons. Any factor that lowers the cost of a program or makes it more likely to succeed will increase the chances that a state will initiate or continue a nuclear weapons program (Fuhrmann 2009a). IAEA TC has the potential to both lower the costs of nuclear weapons development and materially improve the odds of success of weapons programs, via three distinct pathways.

First, TC provides fungible resources and can even build some of the infrastructure necessary for a successful program. There are several instances in which the IAEA has supported infrastructure and resource development projects that contributed, at least indirectly, to nuclear weapons development. In North Korea, the IAEA has supported twenty-nine projects since 1978, including about $400,000 in technical assistance for two projects on uranium prospecting and exploration between 1987 and 1994 (GAO 1997). Since that time, the Democratic People's Republic of Korea (DPRK) has built a centrifuge enrichment program capable of enriching uranium for nuclear weapons, a program for which the IAEA suspects procurement of materials and technologies began as early as 1987.[9]

In Pakistan, the IAEA has supported 166 projects since 1973. According to a former IAEA safeguards inspector, "all uranium in the weapons program came from sources developed by TC and was processed in a plant backed by TC."[10] While the uranium in the declared nuclear power program is safeguarded by the IAEA, the inspector reported, the unsafeguarded uranium that was then enriched for use in bombs or to produce plutonium in military reactors came from mines that were located with TC assistance.

Second, TC can provide nuclear engineers and scientists in recipient states with knowledge and hands-on experience useful in a weapons effort. Much of the expertise necessary for weapons development is in the form of tacit knowledge based on experience (Montgomery 2005, 2013), the explicit goal of many TC training, fellowship, and scientific visit programs. From 1958 to 2006, the IAEA provided more than 12,570 person-years of training (IAEA 2007). Such expertise, even if not focused directly on sensitive areas of nuclear development, helps build indigenous capacity and lowers the overall cost of a weapons effort.

Finally, TC connects officials and scientists in weapons-aspirant states to networks of experts, suppliers, and like-minded counterparts that can further facilitate nuclear development. A former safeguards inspector, for example, described a uranium-related project in Syria that ultimately went forward on a smaller scale than Syria had requested. Even at its reduced scale, however, the effort was sufficient for Syria to develop contacts with private actors that could support a larger program in the future.[11] Many TC training and collaboration projects involve participation by multiple countries, creating opportunities to identify and connect with counterparts in other countries that have an interest in similar, and not always peaceful, nuclear technology.

Most of the existing proliferation literature lumps all civilian nuclear cooperation into one large category, concluding that "[a]ll types of civilian nuclear assistance raise the risk of proliferation" (Fuhrmann 2009a), although some recent work reaches a more nuanced finding (Fuhrmann 2012). If nuclear assistance affects proliferation by reducing the cost of a weapons program via the mechanisms described previously, then some kinds of civilian assistance are likely to have more of an impact on proliferation than are others. We focus here on IAEA TC projects related to the nuclear fuel cycle, which offer states the prospect of material assistance in technology areas that are useful to weapons programs. Other categories of civilian assistance, such as the use of radioisotopes for agricultural purposes or the industrial application of nuclear technology, may improve the tacit knowledge of recipient countries, but are unlikely to significantly facilitate a weapons program. Fuel cycle–related TC, however, may lead states to pursue weapons when they would not have otherwise, or may be disproportionally sought after by weapons aspirants. This logic is summarized in the following hypothesis:

> **Hypothesis:** States participating in more fuel cycle–related TC projects will have a greater likelihood of pursuing nuclear weapons.

Note that we do not distinguish here between two possible causal stories: fuel cycle–related TC might *cause* nuclear weapons programs by reducing the anticipated costs of such a program and increasing the chances of success. Alternatively, states already pursuing nuclear weapons could request more fuel cycle–related TC because those projects are most likely to facilitate weapons development. The connection between TC and nuclear weapons programs probably works in both directions if states are behaving strategically, and both causal stories imply that TC contributes to proliferation. We take up the question of the direction of causality in more detail later. We turn first, however, to a quantitative analysis of IAEA TC

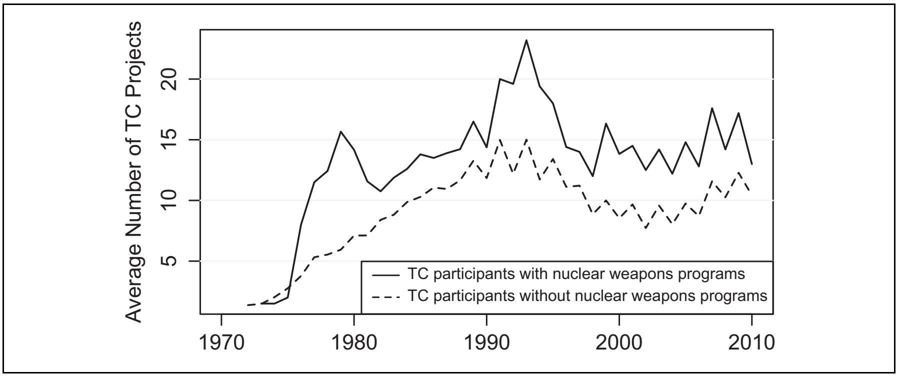

Figure 1. Average number of projects among TC participant states.

and nuclear proliferation, in an attempt to establish the link between fuel cycle–related TC and nuclear weapons programs.

Testing IAEA TC and Nuclear Proliferation

Do states with nuclear weapons programs make greater use of TC? Our analysis employs a new data set of all IAEA national TC projects from 1972 to 2010, assembled using the query tool on the IAEA's TC website from September to October 2011 (IAEA 2011). Figure 1 shows the first step in examining the connection between TC and nuclear weapons, charting the average number of active TC projects (of all types) by year among those states participating in TC.[12] Since the mid-1970s, states with nuclear weapons programs on average have been more active consumers of IAEA TC. This pattern may be the result of a direct link between TC and nuclear weapons programs, or it could be that some states have a generally higher propensity to engage in all nuclear activities, civilian and military, because they increase the state's international prestige, build indigenous technological capacity, or appeal to domestic constituencies. In the latter view, TC does not lead to weapons programs, nor do weapons programs lead to TC—it is an elevated interest in nuclear activities in general that leads to both higher levels of TC and nuclear weapons aspirations.

The overall pattern of TC usage shown in Figure 1, however, obscures significant variation in the types of TC projects chosen by states with and without nuclear weapons programs. Figure 2 characterizes the distribution of TC projects by weapons program status and the type of technical assistance. The boxes in the figure outline the twenty-fifth through seventy-fifth percentiles for each type of TC among states that participate in TC, with the median represented by a solid black line and the mean by a diamond. The vertical lines indicate the range of active projects in that category. Dark gray boxes represent states with nuclear weapons programs; light gray denotes states without weapons efforts.

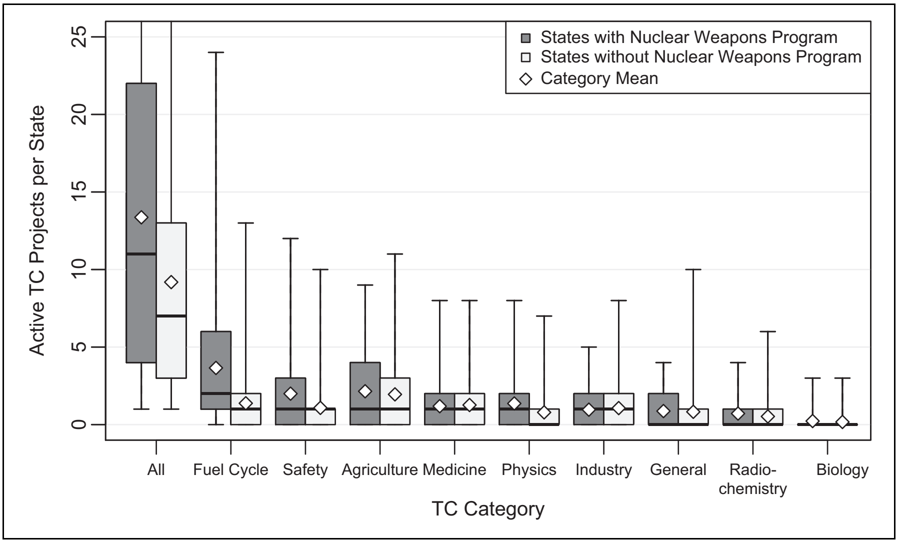

Figure 2. TC projects by category and weapons program status

If there is no direct link between TC and nuclear weapons program status—that is, if TC and weapons programs are related only by virtue of a state's elevated interest in all things nuclear—we would expect that the overall increased propensity for TC among states with nuclear weapons would be spread evenly across TC categories. As Figure 2 shows, however, nuclear weapons aspirants are involved in many more nuclear fuel cycle projects than states without weapons programs.[13] By comparison, non-weapons program states tend to participate in a slightly greater number of industrial and medical projects. The predilection of states engaged in weapons programs for fuel cycle–related TC is the more notable for the fact that the IAEA disburses relatively meager fuel cycle–related funding. In 2010, fuel cycle projects accounted for less than 6 percent of project expenditures, totaling only about $6.6 million, well below other categories of assistance such as nuclear safety (18.4 percent of project expenditures), health and medicine (17.9 percent), and agricultural applications of nuclear technology (14 percent; IAEA 2010).

The fuel cycle category merits some explanation. In this article, we consider fuel cycle–related TC to be those projects engaged in what is sometimes referred to as the "front end" of the fuel cycle: the exploration for and preparation of nuclear fuel for use in nuclear reactors (including uranium mining, milling, conversion, enrichment, and fuel fabrication), as well as projects related to the design and management of nuclear research and power reactors. The IAEA also includes in this category projects related to the handling of nuclear waste (the "back end" of the nuclear fuel cycle), but we do not consider such projects because our theory suggests they are likely to have less impact on the cost of nuclear weapons programs and the chances of nuclear weapons success.

Table 1. Top Participants in Fuel Cycle–Related TC, 1972–2010.

State	Fuel cycle–related TC projects	All TC projects	Sample project title
Argentina	59	122	Irradiation and post-irradiation examination of low-enriched uranium very high density fuel assembly in a high-flux reactor
Egypt	50	173	Evaluating selected uranium resources and producing and purifying yellow cake
Brazil	41	198	Structural integrity analysis of nuclear reactor components
Indonesia	40	157	Uranium exploration and development study
Mexico	40	166	Improving the reliability of equipment at the Laguna Verde nuclear power plant
China	34	141	Improvement in self-reliance and the capability to manage nuclear power plant projects
South Korea	33	124	Nuclear fuel cycle technology
Pakistan	31	155	Investigation of uranium sources in sedimentary, igneous, and metamorphic environments
Chile	27	136	Uranium ore processing
Iran	27	81	Data integration for uranium exploration
Romania	23	102	Restructuring of the uranium mining industry
Morocco	22	94	Utilization of a research reactor

The IAEA no longer administers sensitive fuel cycle TC (assistance with uranium enrichment or plutonium reprocessing), so fuel cycle–related projects today address such tasks as identifying potential uranium reserves, building or improving uranium mining and processing capabilities, developing nuclear fuel fabrication expertise, siting and designing nuclear research and power reactors, operating and maintaining nuclear reactors, and managing nuclear infrastructure. Table 1 shows the most frequent participants in fuel cycle–related TC projects from 1972 to 2010, the number of TC projects of all types with which they were involved in this period, and a representative title from one of their fuel cycle–related projects.

Recent work has found a strong relationship between bilateral nuclear assistance and proliferation. The receipt of bilateral nuclear assistance (both sensitive and otherwise) does not seem to have a clear relationship to participation in IAEA TC programs, as shown in Figure 3. This chart plots each state's cumulative number of IAEA TC projects (of all types) as of 2000 (vertical axis) against its cumulative number of bilateral nuclear cooperation agreements in 2000 (horizontal axis; bilateral supply data are from Fuhrmann 2009a).[14] White circles represent states that received sensitive nuclear assistance at some point prior to 2000 (Kroenig 2009b).

That there is no obvious pattern linking bilateral and multilateral cooperation perhaps should not be surprising; the mechanisms by which states come to participate in

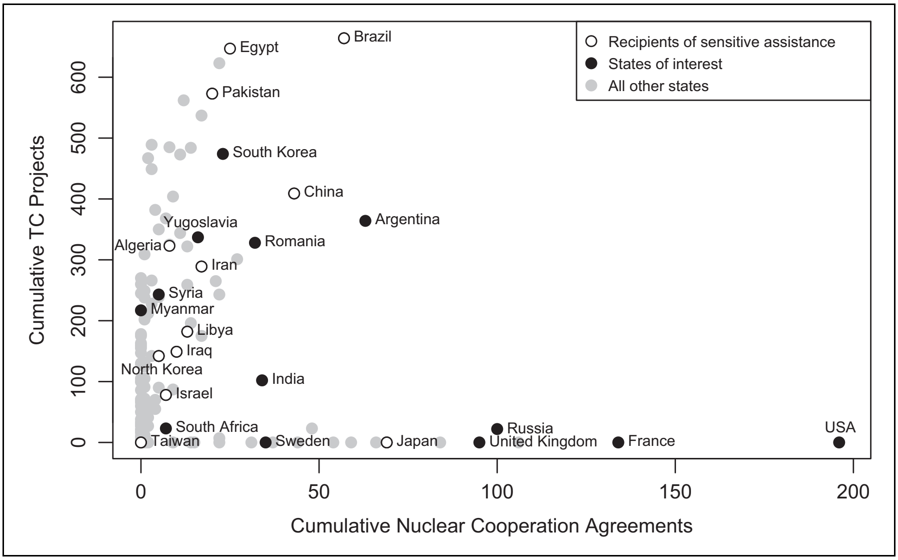

Figure 3. Receipt of IAEA versus bilateral nuclear assistance (through 2000)

these distinct forms of nuclear cooperation are quite different. A principal goal of IAEA TC is to contribute to the development of the least prosperous nations (IAEA 1959). The factors that drive bilateral nuclear supply, such as the strengthening of alliances (Fuhrmann 2009b), should lead to a very different kind of aid recipient. Of the five nuclear weapons states recognized under the NPT, for example, China is the only one to have participated in a significant number of TC projects. The other NPT weapons states participate in almost no TC but are the largest recipients of bilateral nuclear supply. Many of the states that have pursued nuclear weapons during the time period considered here, including Pakistan, North Korea, Iraq, and Iran, are significant beneficiaries of IAEA TC but receive relatively little bilateral nuclear assistance. This may be because the states of greatest proliferation concern are not attractive targets for bilateral nuclear aid. IAEA TC, on the other hand, may be less subject to the political calculations that disqualify states of concern from direct country-to-country assistance.

Statistical Analysis

This initial look at the relationship between TC and nuclear weapons programs is suggestive, and we turn now to a quantitative test of the association between IAEA TC and nuclear weapons proliferation. To facilitate comparisons with the existing literature on the drivers of nuclear proliferation, we adopt the modeling approach of Jo and Gartzke (2007) and employ a subset of the variables commonly used in this literature (Fuhrmann 2009a; Jo and Gartzke 2007; Singh and Way 2004). Our data are structured as a pooled time series, with a country-year unit of analysis. While most existing quantitative studies of proliferation—including work on bilateral nuclear assistance by Fuhrmann (2009a) and Kroenig (2009b)—employ data sets that begin in 1945, our analysis covers a substantially shorter time period, from 1972 to 2000.[15] This is a function of our independent variable of interest: we do not have TC data prior to 1972. As a consequence of our constrained time frame, we are more limited than other studies in the number of cases of nuclear proliferation we address.[16] The TC program, however, was quite small before 1975. Also, the institutional, technological, and security context for nuclear weapons development has changed significantly since the post–World War II period, such that findings that rely heavily on the early decades of the nuclear age may be less relevant to today's proliferation challenges.

Our theory suggests that IAEA TC may contribute both to the decision to engage in weapons development and to the maintenance of nuclear weapons programs once established; therefore, we follow Jo and Gartzke (2007) by including in our data both those country-years in which a state has no nuclear weapons effort and those in which a state is pursuing weapons.[17] Some work in this literature takes a different approach, observing states only until they begin nuclear weapons programs (Fuhrmann 2009a; Kroenig 2009a; Singh and Way 2004). However, dropping states from our data set in all years after they have launched weapons programs would suggest TC no longer matters to states once weapons work has begun. If TC does contribute to the decision to start weapons development by reducing its associated costs, as our theory suggest, then access to TC is likely also to contribute to state decisions to continue nuclear weapons programs already underway. The distinction between initiation and continuation of a weapons program, however, can be useful for investigating the causal mechanisms behind proliferation, so we revisit this modeling decision as part of our discussion of the direction of causality in the next section.

Dependent Variable

The dependent variable in this analysis is a dichotomous variable coded one if the state has an active nuclear weapons program in that year and zero otherwise.[18] Dates of nuclear weapons programs are from Jo and Gartzke (2007); they consider a state to have a nuclear weapons program from the time the state's leadership authorized the program or, lacking evidence of such a decision, when the state begins taking noticeable steps toward a nuclear capability.

Explanatory Variables

To analyze the relationship between fuel cycle–related TC and nuclear weapons programs, we draw from our data set of IAEA technical assistance and use a simple count of the number of active fuel cycle–related TC projects a state was involved in for a given year.[19] We include projects that the IAEA categorizes as related to the nuclear fuel cycle or to reactor operations, but exclude nuclear waste management efforts.[20] We consider here only national projects, and so omit efforts that the IAEA considers regional, interregional, or global, as well as those projects administered to the Palestinian territories, about which we lack other covariate data.

Previous work has found a link between bilateral assistance and weapons proliferation. We include in our analysis a dichotomous variable representing sensitive nuclear supply that takes on the value of one when a state receives sensitive nuclear assistance in a given year and zero otherwise (Kroenig 2009a).[21] We also employ a measure of civilian bilateral nuclear supply: the cumulative number of nuclear cooperation agreements that a state has signed, excluding nuclear safety agreements (Fuhrmann 2009a).[22] Fuhrmann (2009a) uses a cumulative measure that implicitly assumes that the fruits of bilateral assistance persist indefinitely without degradation, even though real-life nuclear programs often involve failures, accidents, false starts, the loss of key personnel, and so on. By contrast, our annual count of TC programs assumes the benefits of IAEA assistance are fleeting; many TC programs focus on training or networking opportunities that may or may not have a long-term impact. As a robustness check, we repeated our quantitative analysis using a cumulative version of our fuel cycle–related TC variable and using an annual version of Fuhrmann's (2009a) bilateral nuclear assistance measure, but neither change affected our results.

Our inclusion of these bilateral assistance variables does not constitute a full test of Kroenig (2009b) or Fuhrmann's (2009a) theories. Kroenig focuses on the role of sensitive nuclear assistance in the acquisition of nuclear weapons, not the decision to engage in nuclear weapons programs (although in robustness checks he finds that sensitive nuclear assistance is also associated with nuclear weapons program status). We might expect, however, that sensitive assistance will play a similar role to bilateral civilian nuclear cooperation and multilateral assistance, reducing the costs of weapons work and increasing the likelihood that states will seek nuclear weapons. Fuhrmann's work posits a conditional relationship between the effect of bilateral nuclear assistance and a state's threat environment, a hypothesis not addressed here. Further, both authors engage the full history of nuclear weapons development since 1945, while our analysis begins in 1972. Still, building on this previous work allows us to better understand the effect of bilateral assistance on nuclear weapons programs in the context of multilateral cooperation.

We also use two indicators to control for the possibility, described previously, that both IAEA TC and nuclear weapons efforts are symptoms of a common cause, which we might think of as a general propensity to pursue nuclear technology for reasons of international prestige, domestic politics, or economic growth. The first variable is the total number of non–fuel cycle TC projects that the state engages in for that year, as states with a higher level of nuclear interest would probably also be more active recipients of IAEA assistance in general, not just in the case of fuel cycle–related cooperation. The second measure is a dichotomous variable that takes on the value of one when a state generates any electricity from nuclear sources (World Bank 2008). States with a general interest in nuclear technology should be more inclined to produce nuclear power themselves.

The quantitative literature on nuclear proliferation has highlighted several other determinants of nuclear weapons programs (Jo and Gartzke 2007). To control for other indicators of a state's opportunity to develop nuclear weapons, we include Jo and Gartzke's (2007) composite measure of nuclear capability and update their measure of economic capacity using data from the Correlates of War project (Singer 1987). This index is equal to the average of a state's proportion of energy consumption and coal and steel production in a given year, multiplied by 100. Higher levels of nuclear and economic capacity are likely to be associated with nuclear weapons programs, and may also indicate a greater capacity to accept multilateral TC.

Five variables account for a state's demand for nuclear weapons. States that face a greater risk of international conflict may be more driven to acquire weapons and therefore may also be more likely to participate in TC. To account for security threats to a state, we calculate the five-year moving average of the number of Militarized Interstate Disputes per year in which a country was involved (Ghosn, Palmer, and Bremer 2004; Singh and Way 2004). Similarly, states may seek nuclear weapons to counter nuclear threats, so we include a dummy variable that takes on the value of one if a state has a rival with nuclear weapons and zero if it does not (Gartzke and Kroenig 2009; Klein, Goertz, and Diehl 2006). Conversely, states may feel more secure under the protection of a nuclear umbrella, making them less likely to pursue weapons. We include a dummy variable that takes on the value of one if a state has a defense pact with a nuclear weapons state, using formal alliance data from the Correlates of War Project (Gibler and Sarkees 2004). Finally, states that are more engaged in the international economy may have an added incentive to forgo nuclear weapons and their attendant uncertainty (Solingen 2007). Following Singh and Way (2004), we measure economic openness as the state's total trade (imports plus exports) as a share of gross domestic product (GDP) and economic liberalization as the change in the state's trade ratio over a three-year span, using trade and GDP figures from Gleditsch (2002).

Membership in IOs may play a role in limiting proliferation; the trade-off between the right to peaceful uses of nuclear technology and concerns about proliferation is at the heart of the IAEA and the NPT (Brown 2011). As is common practice in the literature, we include a dichotomous variable that takes on the value of one if a state has ratified the NPT and zero otherwise.[23]

To address temporal dependence in our time-series cross-section data, we incorporate a simple count of the number of years that have passed without the state engaging in a nuclear weapons program, along with its squared and cubed terms (Carter and Signorino 2010). The count of nonnuclear program years is analogous to the peace-years variable commonly used for this purpose in studies of international conflict. Because our data include country-years in which a state is pursuing nuclear weapons, we also include a similar cubic polynomial representing the number of years that have passed in the course of a state's nuclear program.[24] Alternative model specifications that include splines or time dummies yield similar results (Beck, Katz, and Tucker 1998). Because the hypothesized effect of

TC projects and other factors are unlikely to be felt immediately by the recipient state, we follow common practice and lag this and other substantive variables in our analysis by one year.

Results

Table 2 shows the results of four logit models that test whether state participation in fuel cycle–related TC is associated with a change in the likelihood of a state pursuing a nuclear weapons program.[25] Model 1 tests the bivariate relationship between fuel cycle–related TC and nuclear weapons programs. Model 2 adds covariates that account for a state's nuclear opportunity, nuclear willingness, and IO constraints. Model 3 adds two measures of bilateral nuclear assistance. Model 4 controls for the possibility that a state's propensity for nuclear technology is the common cause of both fuel cycle–related TC and nuclear weapons programs. All models report robust standard errors clustered by country. Cubic polynomials accounting for time dependence are included and are statistically significant in each model, but are not reported here.

The findings support our hypothesis. In each model, the coefficient on fuel cycle–related TC is positive and significant: an increase in the number of fuel cycle–related TC projects in which a state participates in a given year is associated with an increase in the likelihood of the state pursuing nuclear weapons. This result persists even when controlling for other forms of nuclear assistance, the level of overall nuclear development, and other determinants of proliferation that have been tested in the literature.[26]

In contrast to previous findings (Fuhrmann 2009a; Kroenig 2009b), the measures of bilateral sensitive and civilian assistance, included in models 3 and 4, are not statistically significant. Once we have accounted for states' receipt of IAEA TC, bilateral assistance no longer seems to be a significant driver of proliferation in this time period. Our findings in model 4 suggest that fuel cycle–related TC is itself associated with nuclear weapons programs and is not merely a proxy for a state's general level of nuclear interest. The coefficient on fuel cycle–related TC remains statistically significant even when other measures of nuclear interest—whether or not a state produces nuclear energy and the number of non–fuel cycle–related TC projects—are included in the model.

Contrary to Jo and Gartzke (2007), nuclear capacity has no significant effect on proliferation in our models. This difference in our results is likely explained by the different time periods and inclusion criteria in our respective data sets. By excluding country-years in which states have already acquired nuclear weapons, we omit many cases that involve high nuclear capacity coupled with nuclear weapons efforts. Also, by beginning our analysis in 1972, we cannot capture the latent nuclear capacity that helped the first nuclear states acquire weapons. Our finding suggests that Jo and Gartzke's result may be driven by the early nuclear aspirant states and that latent capacity may be less relevant to an examination of more recent and future proliferation.

Table 2. Analysis of Nuclear Weapons Programs, 1972–2000.

		Model 1	Model 2	Model 3	Model 4
Multilateral assistance	Fuel cycle TC projects	0.362 (0.074)***	0.338 (0.073)***	0.362 (0.092)***	0.504 (0.100)***
Bilateral assistance	Bilateral civilian nuclear cooperation			−0.024 (0.023)	0.000 (0.027)
	Bilateral sensitive nuclear assistance			0.054 (0.742)	0.486 (0.793)
Nuclear development	Other TC projects				−0.091 (0.038)*
	Nuclear energy production				−0.873 (0.884)
Nuclear opportunity	Nuclear capacity		0.177 (0.181)	0.220 (0.179)	0.227 (0.165)
	Economic capacity		−8.262 (13.535)	−0.422 (15.650)	1.084 (16.497)
Nuclear willingness	Disputes (5-year average)		1.411 (0.351)***	1.409 (0.368)***	1.367 (0.387)***
	Nuclear rival		1.047 (0.523)*	0.946 (0.491)^	0.953 (0.512)^
	Defense pact with nuclear state		0.996 (0.604)^	1.149 (0.668)^	0.762 (0.724)
	Economic openness		−0.021 (0.016)	−0.019 (0.016)	−0.031 (0.016)^
	Trade liberalization		0.041 (0.014)**	0.040 (0.015)**	0.050 (0.015)***
IO constraints	NPT ratification		−0.284 (0.467)	−0.434 (0.490)	−0.280 (0.591)
	Constant	−1.726 (0.575)**	−3.528 (1.207)**	−3.369 (1.180)**	−3.143 (1.151)**
	N	4,417	4,241	4,241	4,241

Note: Logit coefficients with robust standard errors, clustered on country, in parentheses. Explanatory variables are lagged one year. Cubic polynomials of the years without a nuclear weapons program and the years since a program was initiated are included in all models but not shown.
*** $p < .001$. ** $p < .01$. * $p < .05$. ^ $p < .10$.

Like other studies, we find that nuclear willingness is strongly associated with the pursuit of nuclear weapons. States are more likely to seek nuclear weapons if they engage in more militarized disputes or have a rival with nuclear weapons. The presence of a defense pact with a nuclear state, however, is associated with an increased likelihood of proliferation at the $p < .10$ level in models 2 and 3. This counterintuitive result adds to a series of contradictory findings in the quantitative proliferation literature on the role of the nuclear umbrella in limiting proliferation and may stem from a poor operationalization of the concept of nuclear assurance.[27]

Models 2 through 4 also show a strong connection between a liberalizing trend in international trade and a propensity to seek nuclear weapons. Although this result runs counter to the expectations of Singh and Way (2004), it parallels findings by Fuhrmann (2009a) and Kroenig (2009b). It may be that trade liberalization functions here less as a demand-side variable and more as an indicator of increasing economic resources and a more prominent role in world affairs. The static measure of economic openness provides the expected result; it is negative and significant at the $p < .10$ level in model 4, suggesting states are less willing to proliferate when they are more deeply connected to the international community through trade ties.

We find no significant effect for NPT ratification upon the propensity to pursue a nuclear weapons program. We caution, however, that this result may not reflect the true constraining power of international law or of international norms because it does not take into account the complex mechanism by which states select into the NPT. Understanding this dynamic would require a more complete treatment of the motivations for NPT accession than we can engage in here.[28]

Substantive Effects

Fuel cycle TC therefore has a positive and statistically significant association with nuclear weapons programs, but it also seems to have an important substantive relationship with state decisions to engage in nuclear weapons programs. Shifting the number of fuel cycle–related TC projects from the mean (.7) to two standard deviations above the mean (4.1) increases the predicted probability of a nuclear weapons program by more than five times (from .14 percent to .75 percent).[29]

Of course, proliferation is not common, and the average state has a very low likelihood of engaging in a nuclear weapons program. Therefore, a country of proliferation concern, such as Iran, might make a more substantively appropriate example of the effect of TC. When all variables are set to match the case of Iran in the year 2000, shifting the number of fuel cycle TC projects from its mean to two standard deviations above the mean has the effect of increasing the predicted probability of a nuclear weapons program by 12 percentage points. Fuel cycle–related TC may not make the average state dramatically more likely to pursue nuclear weapons, but there are select states for which fuel cycle assistance could have a considerable effect.

Initiation versus Continuation of Nuclear Weapons Programs

These results show a strong statistical association between participation in fuel cycle–related TC and nuclear weapons programs, but there are multiple causal explanations for this association. One possible causal story is that fuel cycle–related TC encourages states to pursue nuclear weapons by making weapons programs relatively less costly. If this is true, changes in fuel cycle–related TC should occur prior to changes in nuclear weapons program status: we should observe higher levels of fuel cycle–related TC *before* states begin nuclear weapons efforts, and reduced participation in fuel cycle–related TC *before* states formally end their weapons programs.

Alternatively, states already set on pursuing nuclear weapons may seek out more fuel cycle–related TC to reduce the cost of supporting an ongoing nuclear program. If nuclear weapons programs cause an increase in fuel cycle–related TC, then we should observe higher levels of fuel cycle–related TC *after* states decide to begin nuclear weapons efforts, and lower levels of fuel cycle–related TC *after* states end their weapons programs. Of course, it is likely that both effects come into play in real-world decisions by states to engage in weapons work and to seek particular types of TC.

To investigate systematically when fuel cycle TC occurs relative to changes in nuclear weapons program status, we construct separate quantitative models of nuclear weapons program initiation and of nuclear weapons program continuation.[30] This allows us both to explore the potential causal mechanisms at play and to identify whether the effect of fuel cycle–related TC on proliferation varies across different stages of nuclear weapons pursuit. Because events of interest are rare in our data, they are subject to rare event and finite sample biases (King and Zeng 2001).[31] In addition, several of our explanatory variables are excellent predictors of weapons program initiation or conclusion, inducing separation in a standard logit or probit model (Zorn 2005). We thus employ penalized likelihood logistic regression models to estimate binary response models in the presence of separation and to correct for rare event and finite sample biases (Firth 1993; Heinze and Schemper 2002; King and Zeng 2001; Zorn 2005).[32] Each model also includes a cubic polynomial to address temporal dependence (Carter and Signorino 2010). The results are shown in Table 3.

Models 5 and 6 analyze the initiation of nuclear weapons efforts; nuclear weapons program observations after the first year of weapons development are excluded, and states reenter the data set once their nuclear weapons program has ended. Model 6 differs from model 5 only in that the explanatory variables are lagged by three years instead of one to capture the possibility that some drivers of proliferation behavior may precede the decision to seek nuclear weapons. We find higher levels of fuel cycle–related TC are associated with a higher probability of the state initiating a nuclear weapons program. That this variable remains significant at the $p < .10$ level with a three-year lag structure suggests that changes in the level of fuel cycle–related

Table 3. Analysis of Nuclear Weapons Program Initiation and Continuation, 1972–2000.

		Model 5 Program initiation (1-year lag)	Model 6 Program initiation (3-year lag)	Model 7 Program continuation (1-year lag)	Model 8 Program continuation (3-year lag)
Multilateral assistance	Fuel cycle TC projects	0.360 (0.144)*	0.466 (0.208)^	0.647 (0.277)*	−0.035 (0.105)
Bilateral assistance	Bilateral civilian nuclear cooperation	0.022 (0.021)	0.090 (0.031)^	−0.007 (0.026)	0.010 (0.026)
	Bilateral sensitive nuclear assistance	−1.193 (1.331)	−0.312 (1.351)	−0.563 (0.847)	1.572 (1.062)
Nuclear development	Other TC projects	−0.092 (0.066)	−0.109 (0.089)	−0.059 (0.088)	−0.028 (0.062)
	Nuclear energy production	−2.171 (1.229)	−10.274 (3.251)**	−2.056 (1.619)	−0.330 (1.006)
Nuclear opportunity	Nuclear capacity	0.526 (0.197)*	0.436 (0.204)^	−0.317 (0.447)	−0.335 (0.375)
	Economic capacity	15.302 (25.221)	73.991 (36.391)	−11.438 (11.013)	−10.473 (12.840)
Nuclear willingness	Disputes (5-year average)	0.445 (0.388)	0.392 (0.461)	0.805 (0.401)	−0.021 (0.199)
	Nuclear rival	1.783 (0.653)*	1.913 (0.803)^	1.360 (0.839)	0.900 (0.738)
	Defense pact with nuclear state	0.172 (0.832)	1.201 (1.007)	1.776 (1.049)	−0.095 (0.793)
	Economic openness	0.008 (0.003)^	0.012 (0.003)^	0.011 (0.025)	−0.017 (0.031)
	Trade liberalization	−0.004 (0.002)	−0.008 (0.003)	−0.007 (0.029)	−0.015 (0.036)
IO constraints	NPT ratification	0.308 (0.746)	−0.522 (0.760)	−4.737 (1.947)*	−0.983 (1.089)
	Constant	−8.085 (2.023)***	−8.800 (2.137)***	8.633 (3.576)*	7.163 (2.905)*
	N	4,078	3,716	369	344

Note: Penalized likelihood coefficients with standard errors in parentheses. A cubic polynomial of the years without a nuclear weapons program is included in models 5 and 6 but not shown. A cubic polynomial of the years since a program was initiated is included in models 7 and 8 but not shown.
***$p < .001$. **$p < .01$. *$p < .05$. ^$p < .10$; p values calculated using profile penalized likelihood.

TC may occur several years before the initiation of nuclear weapons programs, and thus that this kind of TC makes states more likely to seek weapons.

Models 7 and 8 examine how fuel cycle TC affects the decision to continue already active nuclear weapons programs. In this analysis, only country-years with active nuclear weapons programs are included. States are dropped from the data set when their nuclear weapons programs end, and they reenter the data set if the weapons effort is resumed. In model 7, more fuel cycle–related TC is associated with a greater likelihood of states continuing their nuclear weapons efforts. In model 8, however, for which the explanatory variables are lagged three years behind the dependent variable, none of the included factors are significant determinants of the continuation of weapons programs. Models 7 and 8 provide only limited support for the hypothesis that changes in the level of fuel cycle–related TC are temporally prior to state decisions to continue nuclear weapons programs already in progress.

In short, the models in Table 3 show that increased fuel cycle–related TC is significantly associated with both the decision to start and to continue nuclear weapons programs. They also suggest that fuel cycle–related TC might play a different causal role in program initiation than it does in program continuation. Fuel cycle–related TC seems to contribute to the decision to begin a nuclear weapons program even several years in advance of that choice, providing support for the proposition that this assistance makes proliferation more likely. Fuel cycle–related TC does not precede the decision to continue a weapons program to the same extent. The link between existing programs and fuel cycle–related TC, then, may be due to the decisions of states to seek out the types of nuclear assistance that can best support their pursuit of nuclear weapons, as opposed to TC leading states to continue their weapons efforts.

Conclusion

While policy analysts have long worried about the role that IAEA TC might play in spurring proliferation, this is the first study to systematically examine the link between TC projects and nuclear weapons programs. Our findings suggest these policy concerns are valid: states that benefit from more IAEA fuel cycle–related TC are more likely to engage in nuclear weapons programs. This is bad news for international nonproliferation efforts and has important policy implications.

First, if fuel cycle–related TC leads to weapons programs, as this analysis suggests, then stopping this assistance could reduce the likelihood that some states will pursue nuclear weapons. At a broader level, our findings provide some necessary context to the long-running debate about the sustainability of the basic nonproliferation bargain in which nonnuclear weapon states receive unfettered access to peaceful uses of nuclear technology in exchange for their commitment to forgo nuclear weapons. Fundamentally, dual-use projects that build capacity for a nuclear weapons program—and which are much more likely to lead to weapons programs—may not be appropriate vehicles for peaceful nuclear assistance. States receiving this kind of

TC might reasonably be asked to provide stronger assurances of their peaceful intentions by, for example, acceding to the IAEA Additional Protocol.

Second, if states with nuclear weapons programs are more likely to choose fuel cycle–related TC to help sustain their nuclear weapons efforts, as we find, then stopping such assistance may also help limit the progress of nuclear aspirant states by reducing their ability to develop a supportive intellectual and physical infrastructure. The fact that states with nuclear weapons programs are more likely to seek particular kinds of IAEA TC also might make this a useful indicator for ferreting out clandestine programs.

Most importantly, the substantive link between fuel cycle–related TC and weapons efforts has policy relevance because, unlike with bilateral nuclear cooperation, the United States and other countries concerned about nuclear proliferation have leverage over whether the IAEA supplies individual TC projects in states of proliferation concern. This is not to say that winning changes to the TC system would be easy. Many nonnuclear weapons states are understandably reluctant to agree to limits on the TC programs from which they benefit. However, as our findings show, further scrutiny of fuel cycle–related TC in the IAEA Board of Governors appears called for. After all, Article XII of the Statute of the IAEA, describing "Agency safeguards," does not call only for monitoring or inspecting but also for much broader rights to ensure any state activity "will not lend itself to diversion of materials for military purposes" (IAEA 1957).

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Notes

1. This bargain is an important element of the Statute of the IAEA (1957) and the NPT (1968).
2. The nuclear fuel cycle refers to the steps by which uranium is mined, milled, converted, enriched, and used to fuel a nuclear reactor, then stored or reprocessed. The nuclear fuel cycle is inherently dual use; it can be used to provide fuel to operate nuclear power

reactors or, using the same infrastructure, to enrich uranium or produce plutonium for nuclear weapons.

3. Fuhrmann's (2009a) data on civilian nuclear cooperation do contain a small number of cases of multilateral assistance provided by the European Atomic Energy Community (Euratom) and the Belgo-Luxembourg Economic Union, but these are broken down into a series of bilateral agreements for the purposes of his quantitative analyses.
4. The first objective of the IAEA, in Article II of its statute, is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world" (IAEA 1957).
5. This change also enabled the IAEA to conduct more careful reviews of TC projects.
6. Interview with retired IAEA safeguards inspector, December 2011.
7. Just as the World Bank president is always an American, IAEA deputy director general positions are assigned to particular nationalities: Administration is always an American, Nuclear Energy goes to the Russians, Safeguards to a developed but nonnuclear weapon state, and TC to a developing state. The multinational nature of the IAEA secretariat means there are also individuals from developing states in the Department of Safeguards, who might favor less strict safeguards, just as there are individuals from pro-safeguards states inside the TC Department.
8. Consulting other governments is crucial to determining how a particular project may fit in with a state's other nuclear activities, particularly in states of proliferation concern. The IAEA has worked for decades to convince states to report their commercial nuclear exports, but the reporting of requests for nuclear supply that have been denied remains voluntary.
9. Presentation by former deputy director of the IAEA, March 2012.
10. Interview with retired IAEA safeguards inspector, December 2011.
11. Interview with former deputy director of the IAEA, January 2012.
12. Weapons program dates are from Jo and Gartzke (2007). The zigzag character of the lines in this figure is due to the biannual approval cycle for IAEA TC.
13. States seeking nuclear weapons also participate in more safety- and agriculture-related projects than states with no weapons program, although the difference is not as large as for fuel cycle–related assistance. This may reflect the fact that safety and agriculture projects make up two of the largest categories of TC projects, and states with weapons programs on average seek more IAEA assistance than states that are not pursuing weapons.
14. Fuhrmann's (2009a) measure of cumulative nuclear cooperation agreements includes only state *recipients* of nuclear cooperation. State suppliers are not captured in this measure.
15. While our TC data set extends through 2010, reliable data for several of our covariates are not available after 2000.
16. The Jo and Gartzke (2007) data include thirteen cases of nuclear weapons development between 1972 and 2000, of which ten were initiated in this time frame.
17. We exclude observations after the year in which a state acquires nuclear weapons. This data choice does not affect our findings: we see substantially the same results when including all nuclear weapons country-years.
18. We do not attempt a test of nuclear acquisition here. With only three cases of nuclear acquisition within the time constraints of our data set (South Africa, India, and Pakistan),

we have too little empirical leverage on this question. Expanding the data set either before 1972 or after 2000 might make such an examination possible in the future.

19. Of course, not all projects have an equal effect on a state's propensity for nuclear weapons programs. A better measure than the count of fuel cycle–related TC projects might be the size of such projects, but this information is not available. We can take some comfort in the fact that no TC project is exceptionally large. The IAEA administered 110 fuel cycle–related TC projects in 2010 for an average cost of about $60,000 per project. At this small size, treating all projects as equivalent probably does not severely bias our results.
20. In terms of the IAEA's TC coding scheme, we include in this variable all of categories three (Fuel Cycle and Waste Management) and four (Nuclear Engineering and Technology), except for the nuclear waste–related subcategories 3H through 3N (IAEA 2011). Our results do not change, however, in robustness checks that incorporate subcategories 3H through 3N.
21. Kroenig (2009b) omits a handful of smaller, nonnuclear states from his analysis that we include. We set these missing country-years to zero by assumption.
22. We exclude nuclear safety agreements because such bilateral assistance seems less likely to influence a state's decision to engage in nuclear weapons efforts, and because the resulting variable more closely parallels our measure of multilateral fuel cycle–related assistance. Including nuclear safety-related agreements in this measure of bilateral cooperation does not affect our results.
23. States need not be NPT members to participate in IAEA TC programs. Pakistan, for example, is one of the most frequent recipients of IAEA technical assistance but remains outside the treaty.
24. While our data set of TC participation begins in 1972, the cubic polynomials representing the count of non-program years and the count of program years use the complete set of nuclear weapons development efforts since 1939. Our controls for temporal dependence, therefore, do not suffer from bias due to left-truncation (Carter and Signorino 2012).
25. Proliferation events make up approximately 4 percent of the observations in the data set. Robustness tests using rare-events logit did not affect the results (King and Zeng 2001). Standard logit models are reported.
26. This result is robust to a variety of model specifications and data changes. The coefficient on fuel cycle–related TC remains positive and significant, for example, when adding or removing a number of marginal cases of nuclear weapons programs or when using Singh and Way's (2004) nuclear weapons pursuit data as an alternative to the Jo and Gartzke (2007) data set.
27. See Bleek and Lorber (2014) for a discussion of the role of the nuclear umbrella in preventing proliferation.
28. See, however, Erickson and Way (2011) and Way and Sassikumar (2004) on the drivers of NPT membership, and Kaplow (2012) on the constraining power of the NPT.
29. These calculations are based on model 4. Other substantive variables are held at their mean while the non-program years variable is set to five and the program years variable is set to zero.

30. Another approach to this question would examine the various drivers of IAEA TC. We plan to pursue this line of research in future work.
31. Nuclear weapons programs begin in .2 percent of observations in the initiation data set of states without nuclear weapons efforts, and nuclear weapons programs end in 2 percent of observations in the continuation data set of states with nuclear weapons efforts.
32. In experiments comparing rare events logit with penalized likelihood regression, King and Zeng (2001) found the methods yield very similar results. We use penalized likelihood regression in place of rare events logit to address problems of separation in the models.

Supplemental Material

Replication materials are available from the authors or on the Journal of Conflict Resolution website at http://jcr.sagepub.com/supplemental.

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