Codebook

Proliferation and the Logic of the Nuclear Market

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This codebook explains the coding decisions that helped determine which countries qualify as proliferators (aspiring nuclear weapon states, aspiring hedgers, hedgers and nuclear weapon states), and suppliers (of reactors and Enrichment and Reprocessing – ENR - facilities) from 1939 until 2014. I first describe the general rules I developed to code the two proliferation tracks (acquiring nuclear weapons or becoming a nuclear hedger) and the status of supplier. Then I illustrate the coding logic case by case, supporting it with secondary sources or primary documents, where available.

Rules for coding proliferators

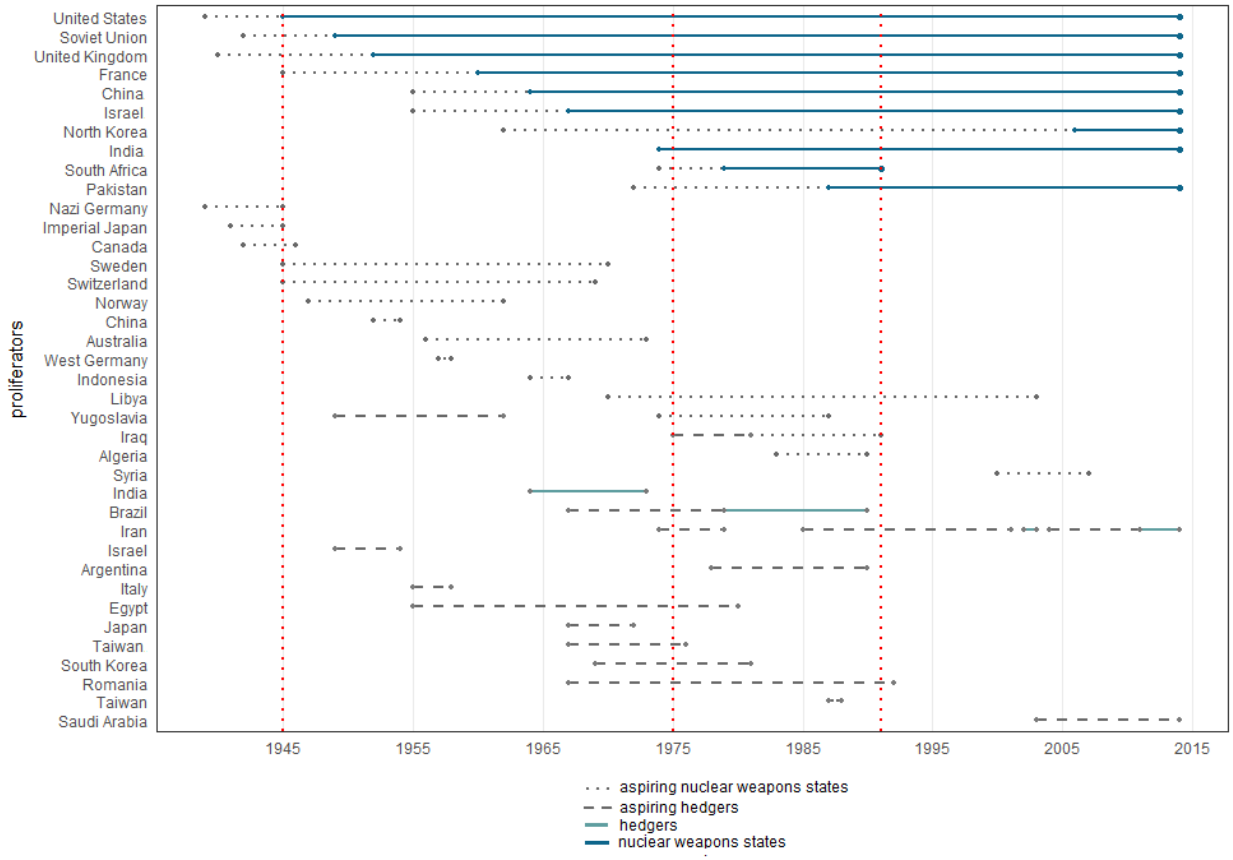
I distinguish between four types of proliferators: aspiring nuclear weapon states, aspiring hedgers, hedgers and nuclear weapon states. This classification reflects the two objectives a state can pursue: becoming a nuclear weapons state or becoming a nuclear hedger.

- *Aspiring hedgers* are countries that seek to develop a robust infrastructure comprising the full nuclear fuel cycle. They want to keep the nuclear option open without making a firm commitment to getting an atomic bomb. When states express their desire to become hedgers but acquire only laboratory-scale ENR facilities, they qualify for the status of aspiring hedgers.
- *Hedgers* are countries that wants to keep the nuclear option open and manages to acquire a pilot or industrial-scale ENR facility.
- *Aspiring nuclear weapon states* are countries that seek either to acquire the necessary materials and technology to build a nuclear weapon or to use their existing nuclear capabilities to achieve that objective.
- *Nuclear weapon states* are countries that have "exploded a nuclear weapon or other nuclear explosive device,"[1] or have assembled a nuclear bomb.

I build on the work of Phillip Bleek, Matthew Fuhrmann and Benjamin Tkach, and Vipin Narang to identify which countries aspired to become nuclear weapon states or hedgers, and which countries reached these objectives. Any differences between their datasets and my coding derive from the expansion of the timespan or from new archival findings. A visual representation of the trajectory of every proliferator can be found in Figure 1.

[1] See Article 9 in United Nations Office for Disarmament Affairs (UNODA), Treaty on the Non-Proliferation of Nuclear Weapons (New York: UNODA, July 1, 1968).

Figure 1 - The Nuclear Proliferation Timeline, 1939-2014



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Phillip C. Bleek, "When Did (and Didn't) States Proliferate? Chronicling the Spread of Nuclear Weapons" (Cambridge, Mass.: Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School and the James Martin Center for Nonproliferation Studies, Middlebury Institute of International Studies, Monterey, Calif., June 2017).

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Sonali Singh and Christopher R. Way, "The Correlates of Nuclear Proliferation: A Quantitative Test," *Journal of Conflict Resolution* 48, no. 6 (December 1, 2004): 859–85.

The United States of America (1939-2014)

Between 1939 and 1944, the United States was an aspiring nuclear weapon state. In 1945, I code the United States as a nuclear-weapon state as that year it not only successfully tested its first atomic bomb on July 19, 1945 at Alamogordo, but also used it against Hiroshima and Nagasaki a month later.

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The Soviet Union (1942-2014)

While scientists in the Soviet Union had been concerned with the defense uses of technological advancements such as nuclear fission and with the "uranium problem" since 1939-1940, it was not until 1942 that the State Committee for Defense, chaired by Joseph Stalin, recognized the necessity for organizing "work on the creation of the atomic weapon." At that point, the Soviet Union can be regarded as an aspiring nuclear weapon state. Following the bombing of Hiroshima and Nagasaki, the Soviet leadership accelerated its efforts to acquire the bomb. They captured nuclear scientists from Germany and brought them to the Soviet Union, built facilities for the extraction of fissile materials, and developed bomb designs. Even if the Soviets reached latency in 1941, this dataset does not code the USSR as a hedger, given that they had a clear intention to acquire nuclear weapons. I code the Soviet Union as a nuclear weapon state in 1949, when it carried out its first nuclear test, RDS-1.

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The United Kingdom (1940-2014)

I code the United Kingdom as an aspiring nuclear weapon state between 1940 and 1951, and as a nuclear weapon state between 1952 and the end-year of the dataset, 2014. The beginning date of 1940 is warranted given British participation in the Manhattan Project. Moreover, in 1945 the Atomic Bomb Committee in the UK conducted a feasibility study for an independent nuclear weapons program, which further supports coding the UK as an aspiring nuclear weapon state. Subsequently, the Atlee government ordered the development of nuclear piles for the extraction of Pu-239 and nuclear bomb designs. In 1952, after having its requests for nuclear weapons rebuffed by the US, the UK decided to acquire nuclear weapons on its own.

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Andrew Pierre, *Nuclear Politics. The British Experience with an Independent Strategic Force, 1939-1970* (London: Oxford University Press, 1972).

France (1945-2014)

I follow Bleek's coding of the French nuclear weapons program, which takes the creation of the Atomic Energy Commission (CEA) as the first step France takes towards atomic weapons. In my study, the establishment of the CEA represents the moment France became an aspiring nuclear weapons state, given CEA's responsibilities in the area of military uses of atomic energy. France becomes an NWS in February 1960, after it carried out its first nuclear test (Gerboise Bleue) in the Algerian Sahara Desert.

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Maurice Vaïsse, "Le choix atomique de la France (1945-1958)," *Vingtième Siècle. Revue d'histoire* 36, no. 1 (1992): 21–30.

People's Republic of China (1952-2014)

I follow Bleek's coding of the nuclear weapons program of the People's Republic of China, according to which in a May 1952 meeting, the members of the Central Military Commission discussed the inclusion of non-conventional weapons development in the first Five Year Plan. I interpret that meeting to mark the moment when the PRC becomes an aspiring nuclear weapon. In 1955 Mao Zedong, the Chairman of the Chinese Communist Party, following a meeting with experts, declared that China would put the building of a nuclear bomb at the top of its priority list. I count the PRC as an NWS after October 1964, when the Chinese carried out their first nuclear test at Lop Nur.

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Israel (1949-2014)

Israel became an aspiring hedger in 1949, shortly after its creation as an independent state. That year, Prime Minister David Ben Gurion gave the greenlight for a variety of measures meant to evaluate the feasibility of a nuclear weapon option. The Israeli Prime Minister's decision stemmed from his desire to prevent another Holocaust and to ensure the survival of the newly created state. He therefore ordered the creation of various organizations which proved instrumental in the efforts to acquire the A-bomb, such as the Israel Defense Forces Science Corps (HEMED GIMMER). Engineer Meir Rabinowitz, one of the most important figures in the Israeli nuclear program, recalls a meeting around the time HEMED was created where the top Israeli experts discussed the linkage between atomic energy and victory in war. HEMED's tasks, although innocuous in appearance, included a geological survey to find uranium ores, and recruiting the human resources needed for the program. In 1949, HEMED sent six physics graduates to the United States for further specialization under Enrico Fermi. That same year, another group of Israeli scientists attended Saclay, the French national atomic research center, and take part in the construction of a small experimental reactor. I then follow Bleek's coding of Israel's nuclear weapons program, which draws on Avner Cohen's work to argue that 1955 marked the year when Ben Gurion, now "determined that the time had come for Israel to launch a national nuclear energy project, with the objective of developing nuclear weapons." I therefore code Israel as an aspiring nuclear weapon state from 1955 until 1966. Israel's decision to assemble nuclear devices right before the Six Day War qualifies it for NWS status from 1967 until 2014.

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Seymour M. Hersh, *The Samson Option: Israel's Nuclear Arsenal and American Foreign Policy* (New York: Random House, 1991).

Ori Rabinowitz, *Bargaining on Nuclear Tests: Washington and its Cold War Deals* (Oxford University Press, 2014), Chapter 5.

India (1964-2014)

India enters the dataset directly as a hedger, in the context of China's first detonation of an atomic bomb and India's acquisition of the full nuclear fuel cycle, the Indian Prime Minister, Lal Bahadur Shastri, declared that "we are capable of developing nuclear weapons." Many claim that India started out as an aspiring hedger much earlier, because its scientists set out to establish a nuclear program that harnessed both the peaceful and the military potential of the atom. Prime Minister Jawaharlal Nehru entrusted this dual mission to the Atomic Energy Commission, created in 1948, and headed by Homi Bhabha, the father of the Indian nuclear program. Yet, the most recent scholarship on the topic argues that India pursued only the peaceful uses of the atom, before and even after its first nuclear test in May 1974. With regard to the latter aspect, scholars and some direct participants in the events argue that because India did not build an atomic arsenal immediately after May 1974, it should not be considered a nuclear weapon state until 1998, when it conducted five nuclear tests. While I agree with the assessment that India's early nuclear pursuits were peaceful in nature, I disagree with the interpretation of the 1974 test. I therefore code India as a hedger from 1964 until 1974, at which point I consider it an NWS, in line with the interpretation provided by the Treaty on the Non-Proliferation of Nuclear Weapons, which draws no distinction between testing a nuclear weapon and detonating a nuclear explosive device.

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Sumit Ganguly, "India's pathway to Pokhran II: the prospects and sources of New Delhi's nuclear weapons program," *International Security* 23, no. 4 (1999): 148-177.

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Bhumitra Chakma, "Toward Pokhran II: Explaining India's Nuclearisation Process," Modern Asian Studies 39, no. 1 (2005): 189–236.

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South Africa (1974-1991)

I follow Bleek's judgment on Pretoria's pursuit of nuclear weapons when I code South Africa as aspiring to nuclear weapons. Until that point, South Africa claimed to have had a peaceful nuclear program, although some high-level officials advocated the acquisition of atomic bombs much earlier (1965). Since these policy-makers' opinions were not unanimously espoused by the South African government, I chose to date the beginning of Pretoria's nuclear weapons program to the mid-1970s. I count South Africa as a NWS starting in 1979, when an American satellite reported a double flash of light, which some interpret as a South African nuclear test, possibly with Israeli assistance. Pretoria dismantled its nuclear arsenal in 1991.

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Pakistan (1972-2014)

Pakistan had maintained a peaceful nuclear program for over a couple of decades before it became a nuclear weapons aspirant in 1972. The event to precipitate this change was the Indo-Pakistani War, which ended in a strategic and political victory for India. According to Samina Ahmed, in its aftermath, Zulfikar Ali Bhutto (then Minister of Foreign Affairs, who later became Prime Minister) warned that if India acquired a nuclear weapon, Pakistan will get one of its own, "even if Pakistanis have to eat grass." Pakistan became capable of producing fissile materials with the help of uranium enrichment technology stolen by Abdul Qadeer Khan from the Netherlands. Pakistan can be considered a nuclear weapon state 1987, when it is thought to have assembled a nuclear weapon.

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North Korea (1962-2014)

I code North Korea as an aspiring NWS starting in 1962. North Korea became interested in the military uses of the atom soon after the United States deployed nuclear weapons to South Korea in the late 1950s. But the first signs of Pyongyang's nuclear ambitions appear only in 1962, when the North Korean Minister of Foreign Affairs, Pak Seong-Chol, expressed disapproval towards American non-proliferation proposals, which would have allowed the US to maintain its stockpile but forbade other countries "even to think about the manufacture of nuclear weapons." Pyongyang had been requesting nuclear assistance from the USSR since the mid-1950s, but it was only in 1962 that the Soviets helped the North Koreans set up the Atomic Energy Research Center in Yongbyon, where, a year later, the USSR started building an IRT-2000 research reactor. Despite being privy to the North Koreans' musings about nuclear weapons, the Soviets did not completely cut off assistance, possibly to maintain a modicum of monitoring and control over Pyongyang's atomic program. The North Koreans requested nuclear weapons from both the Soviet Union and the People's Republic of China, only to be rebuffed by both. In 1975, North Korea acquired the capability to extract fissile material (Pu-239) from spent fuel, using hot cell technology provided by the Soviet Union. North Korea later acquired uranium enrichment technology with the help of Pakistani scientist A.Q. Khan. Although Pyongyang stopped operating some of its ENR facilities between 1993 and 2003 per the Agreed Framework signed with the United States, it never completely stopped its military nuclear pursuits. I therefore code the DPRK as a continuous aspiring NWS until 2006, when it carried out its first nuclear test. North Korea remains in the NWS club until the end of the dataset.

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Nazi Germany (1939-1945)

I follow Bleek's coding of the German nuclear program from 1939 until 1945. For that period, I code Nazi Germany as an aspiring NWS. Due to its defeat at the hands of the Allies, Nazi Germany saw its program come to a halt in 1945. Some experts and direct participants in the events claim that Germany had sufficient potential to create an atomic bomb. German scientists had carried out work not only on nuclear chain reactions, subcritical assemblies, and reactors, but also on isotope separation and atomic weapons designs. The victors of World War II dismantled the German nuclear weapons program.

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Pis'mo Gosplana SSSR v Osobyy komitet pri GKO G. M. Malenkovu o vyvoze iz Germanii oborudovaniya i materialov, neobkhodimykh dlya rabot Laboratorii No. 2, May 8, 1945, in L. D. Ryabeva (ed.) Atomnyy proyekt SSSR: dokumenty i materialy, Tom 1, Chast' 2 (Moskva: MFTI, 2002), 286.

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Imperial Japan (1941-1945)

I follow Bleek's coding of the Japanese nuclear program during World War II. I code Imperial Japan from 1941 until 1945 an aspiring NWS. Japan developed a two-pronged nuclear weapons program, with the Army in charge of "Ni-go research" and the Navy in charge of "F-Research. In the closing days of the war, the Japanese military put an end to the program and destroyed most of the relevant documentation. Shortly after Japan's surrender, the US authorities ordered the destruction of the facilities built by the Japanese for the atomic bomb project.

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Canada (1942-1946)

I code Canada as an aspiring NWS between 1942 and 1946, due to its involvement in the Manhattan Project, alongside the United States and the United Kingdom. Canada's participation had less to do with an independent desire to acquire nuclear weapons than with its wartime alliance with Washington and London, but the Canadian contribution to the multinational effort to acquire nuclear weapons cannot be denied.

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Sweden (1945-1970)

I code Sweden as an aspiring NWS, starting in 1945, when, according to Thomas Jonter, the first seeds for manufacturing nuclear weapons were planted. The head of the Chemistry Department at the Swedish National Defense Research Agency (FOA) proposed a "nuclear power cum atomic weapons" strategy for Sweden, whereby the production of fissile materials resulted from the

nuclear power generation, instead of being the primary aim, as in the United States. In 1951-1952, following the shooting down of Swedish aircraft by Soviet fighter jets, the Chief of the Swedish Air Force, Bengt Nordenskiöld, espoused the option of buying nuclear weapons from the United States, given that it would take a long time for Sweden to build its own arsenal. According to the archival record, this proposal was overridden and instead, the authorities in Stockholm followed an indigenous path to the bomb, developing what became known as the "Swedish line." In addition to nuclear power reactors, Swedish scientists (under the leadership of Theodor Svedberg) also invented a type of ultracentrifuge. Work on uranium enrichment, however, did not advance much further, as Sweden opted for the plutonium path. Sweden exits the dataset in 1970, when, following domestic pressure, it ratified the NPT.

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Switzerland (1945-1969)

I start coding Switzerland as an aspiring NWS in 1945, when the top military echelons in Switzerland commissioned studies on the feasibility of developing a Swiss nuclear force, a task which fell upon the Study Commission on Atomic Energy, appointed in 1946. The Swiss authorities' interest in nuclear weapons waxed and waned over the next two decades, leading to what Ursula Jasper calls an "indecisive, contingent, and non-linear" path toward nuclearization. In 1963, another study conducted at the request of the government reached the conclusion that Switzerland had the technological capability to build nuclear weapons, yet instead of implementing a full-scale program, the Swiss decided to merely keep the option open. The Swiss nuclear power program, which would have both justified the acquisition of industrial-scale ENR facilities and provided spent fuel for the extraction of fissile materials for a weapon, started showing signs of weakness in the late 1960s. The Lucens NPP, built by Swiss scientists in 1962-1968, suffered a partial core meltdown in 1969, resulting in its premature shutdown. The Swiss were left dependent on HEU imports from the US and West Germany. Left without their own plutonium-producing reactor, the Swiss ended their nuclear weapons program in 1969.

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Andreas Nidecker, "The Swiss Nuclear Bomb Dream," *Medicine, Conflict and Survival* 30, no. sup1 (July 31, 2014): s64–70.

Norway (1947-1962)

I start coding Norway as an aspiring NWS in 1947, when the Norwegian Defense Research Establishment completed several reports on the civil and military uses of atomic energy. The Norwegians already started building an indigenously designed nuclear research reactor, which provided a foundation for a nuclear weapons program. Yet, the military-industrial-scientific establishment in Norway proved indecisive about focusing exclusively on the military uses of the atom. As Astrid Forland shows, Norway experienced severe difficulties in making its nuclear industry "profitable and competitive in the international market" which led to the abandonment of its nuclear program in 1962.

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Yugoslavia (1949-1962; 1974-1987)

I code Yugoslavia as an aspiring hedger beginning in 1949, when according to William Potter, Djuro Miljanic, and Ivo Slaus, Josip Broz Tito decided to "develop the capability to build nuclear weapons." The main driver behind this decision appears to be the 1948 Tito-Stalin split and the successful test of a nuclear weapon by the USSR in 1949. The rationale behind the program changed from security to international prestige with the thaw in Soviet-Yugoslav relations, brought about by Khrushchev's ascent to power. To patch things up, the Soviet Union provided Yugoslavia with nuclear assistance, which contributed to Tito's nuclear program. In 1954, Yugoslavia started operating a laboratory-scale reprocessing facility built with Norwegian

assistance, a capability which is below the threshold for hedger status. Following the Indian peaceful nuclear explosion carried out in 1974, the leadership in Belgrade intensified its procurement efforts, focusing on creating a nuclear power program to provide cover for a nuclear weapons program, which warrants coding Yugoslavia an aspiring NWS. After Tito's death in 1980, Yugoslavia maintained its military and civilian nuclear programs. Admiral Branko Mamula, the new defense minister, headed the nuclear weapons program until its termination in 1987.

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Egypt (1955-1980)

I start coding Egypt as an aspiring hedger in 1955, when the newly-created Atomic Energy Establishment (AEE) was tasked with the development of both peaceful and military applications of the atom. The leadership in Cairo displayed a long-standing interest in peaceful nuclear explosions, requesting West German assistance to carve out a canal connecting the Mediterranean Sea to the Qattara desert. In 1980, Egypt ceases being an aspiring hedger after it ratifies the NPT.

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Italy (1955-1958)

Italy has a long tradition in the study of nuclear physics, having produced some of the most important figures in the field, such as Enrico Fermi, Bruno Pontecorvo or Edoardo Amaldi. Although Italian scientists and military experts displayed an interest in atomic weapons soon after the end of Second World War, the Italian government refrained from taking any concrete steps down the nuclear road until 1955, when it created the Center for the Military Application of Nuclear Energy (CAMEN). The establishment of this organization marks the moment when Italy became an aspiring hedger. Soon after, the Italian authorities joined forces with France and West Germany in a technological cooperation project which included, among other aspects, the military applications of nuclear energy. This scheme collapsed in 1958, with Charles de Gaulle's ascent to power in France and his prioritization of a national nuclear weapons program (although other protagonists suggest that Italy pulled out "worried by general de Gaulle's authoritarian reputation"). This move marked the end of Italy's status as an aspiring hedger, although until the mid-1970s, politicians in Rome maintained an ambiguous posture regarding the ratification of the NPT, primarily for political reasons.

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Australia (1956-1973)

Australia enters the dataset as an aspiring NWS in 1956 when it started demanding nuclear weapons from the British and the Americans. After its requests got rejected, the Australian government started exploring an indigenous path to the bomb, using nuclear facilities imported from abroad (the UK, the US, and France). In the mid-1960s, Australia started developing centrifuge enrichment technology at Lucas Heights. The small size of this facility does not warrant coding Australia as a hedger. Australia leaves the dataset in 1973, when it ratified the NPT.

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Federal Republic of Germany (1957-1958)

I code the Federal Republic of Germany (FRG) as an aspiring NWS between 1957 and 1958, when it engaged in the technological cooperation project with Italy and France. When the collaboration scheme collapsed after de Gaulle's withdrawal from the joint effort, the FRG exits the dataset. Some authors claim that the FRG sought an independent nuclear deterrent from 1956 until 1963 and then tried to retain a nuclear weapons option from 1964 until 1969. Because in 1960 West Germany scientists started looking into closing the nuclear fuel cycle, focusing primarily on uranium enrichment, namely the gas centrifuge, scholars argued that Bonn displayed an "eagerness during the 1960s to preserve some option of access to nuclear weapons." Nevertheless, the FRG ran into technical difficulties when it tried to develop the gas centrifuge on

its own, so it had to join forces with the UK and the Netherlands, which together created Urenco – a multinational fuel group. Therefore, the FRG could not have developed an independent nuclear weapons option, which is why I do not code it as a hedger from 1964 until 1969.

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Japan (1967-1972)

I code Japan as an aspiring hedger between 1967 and 1972. I do not consider off-hand remarks made by various politicians to indicate the nation-wide endorsement of a nuclear weapons program or pursuit of hedging. I therefore discount Prime Minister Nobusuke Kishi's 1957 statement before the Diet that Japan's constitution did not forbid the acquisition of an atomic bomb, since nuclear weapons only served defensive purposes. The ensuing public outcry forced Kishi to resign. Similar statements were made in the aftermath of China's successful nuclear test in October 1964. Once again, the Japanese leadership called for a revision of Tokyo's stance on nuclear weapons. In December 1964, Prime Minister Eisaku Sato said that if other countries had nuclear weapons, it was only common sense "to have them oneself." Japan's nuclear restraint was confirmed on multiple occasions. For example, in January 1965, in a conversation with US President Lyndon Johnson, Sato explained that "although he could see why it might be argued that if China has nuclear weapons, Japan should also, this was not Japan's policy." If Tokyo signaled that China's nuclear test was not enough to push Japan over the brink, by 1966, the Japanese leadership indicated that its nuclear restraint was conditional on keeping India out of the NWS club, and on forcing middle powers (such as France and the UK) to give up their independent nuclear deterrents.

I follow Bleek's assessment of Japan's nuclear ambitions during the Cold War when I code Japan as an aspiring hedger from 1967 until 1972. Starting in 1967, Japan conducted studies assessing

the pros and cons of nuclear weapons. Prime Minister Sato enshrined its aspiration to become a hedger into the country's Four Nuclear Principles, adopted in February 1968, which expressed Japan's commitment to non-proliferation as long as its national security was not threatened. The Japanese leadership, facing US pressure to sign the NPT, realized that the treaty would not prevent it from maintaining the technical capability to produce a nuclear weapon in a relatively short period of time, should Tokyo deem necessary to do so. As a consequence, Japan signed the NPT in 1970 but refused to ratify it right away. Japan exits the dataset in 1972 when it concludes that the best strategy was to maintain its reliance on the US nuclear deterrent. I do not code Japan as a hedger between 1967 and 1972 because during this period, Japan did not have a pilot or industrial-scale ENR facility.

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Fintan Hoey, "Japan and Extended Nuclear Deterrence: Security and Non-proliferation," *Journal of Strategic Studies* 39, no. 4 (2016): 484-501.

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Indonesia (1964-1967)

Indonesia enters the dataset as an aspiring NWS in 1964, when an Indonesian Army spokesman alluded to the possibility that Indonesia would carry out its own nuclear test, although he later conceded that "Indonesia's nuclear weapons program existed only on paper." Days after the

Chinese nuclear test in October 1964, Indonesian diplomats sent a congratulatory note to the leadership in Beijing, and the Chief of Staff at the Indonesian Ministry of Foreign Affairs mentioned that "Indonesia could send personnel to China to learn about nuclear technology." Although the archival record indicates that the Indonesian official was joking, a year later, Jakarta sent a special team (including members of the military) to China to understand the status of China's research on atomic energy. One of the goals of this team was "to see how atomic energy is used for military purposes." Indonesia was interested in developing its nuclear infrastructure, which in 1965, comprised a US-supplied research reactor, which, according to American analysts, "could produce one bomb per century." The visit of the special Indonesian team to China gave birth to rumors that Sukarno was on the verge of detonating a borrowed Chinese bomb. In October 1965, Mao Zedong, the Chairman of the Chinese Communist Party, met with Chairul Saleh, the Indonesian Vice President, and asked him if Jakarta wants to build an atomic bomb. The Indonesian official replied in the affirmative, explaining that Jakarta was carrying out a geological survey to identify uranium ores. Sukarno's nuclear ambitions, however, failed to materialize, as his government was toppled in March 1967. His successor, Suharto, scaled back Indonesia's procurement efforts, refraining from acquiring the full nuclear fuel cycle and putting an end to the nuclear weapons program.

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"Minutes of Chairman Mao Zedong and Chairman Liu Shaoqi's Meeting with the Indonesian Delegation," October 30, 1965, History and Public Policy Program Digital Archive, PRC MFA 105-01917-02. Obtained and translated by Taomo Zhou. http://digitalarchive.wilsoncenter.org/document/118047

Taiwan (1967-1976; 1987-1988)

I start coding Taiwan as an aspiring hedger in 1967, when the Taiwanese leadership decided to pursue both the peaceful and the military uses of the atom. That year, the government allocated $140 million to the development of nuclear weapons but the program was placed under a civilian oversight body. Subsequently, Taiwan acquired an NRX-type research reactor from Canada (1968). In 1970, with French assistance, Taiwan started building a laboratory-scale reprocessing facility at the Institute for Nuclear Energy Research. According to US intelligence assessments, "Taipei conducts its small nuclear program with a weapon option clearly in mind, and it will be in a position to fabricate a nuclear device" in 1979. To prevent Taiwan from acquiring an independent nuclear deterrent, the US applied pressure on Taipei to halt work on extracting plutonium from spent fuel and end all efforts to secure a larger reprocessing facility from European suppliers. The Taiwanese authorities complied with this request, terminated its reprocessing research, and put an end to its search for reprocessing technology from foreign suppliers. This decision marks Taiwan's exit from the dataset between 1977 and 1987. Taipei re-enters the dataset as an aspiring hedger between 1987 and 1988. The Taiwanese tried to re-build the reprocessing facility at INER on their own, but failed to put it into operation.

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Brazil (1967-1990)

Brazil enters the dataset in 1967 as an aspiring hedger, as it pursued a policy which maintained its freedom of action with respect to the uses of atomic energy. During the negotiations of the Treaty of Tlatelolco, Brazil and Argentina insisted on preserving the right of signatory countries to carry out peaceful nuclear explosions. A year later, when the military government of General Artur da Costa e Silva came to power, the defense of the right to develop peaceful nuclear explosions became the cornerstone for Brazil's opposition to the NPT. In a meeting laying out the guidelines for Brazil's nuclear policy, several ministers defended the option of using nuclear energy for international security reasons, although there was no clear commitment to a nuclear weapons program. Brazil brought this issue before the Eighteen-Nation Committee on Disarmament, stating that "we shall not waive the right to conduct research without limitation and eventually to manufacture or receive nuclear explosives." Brazil set off to master the full nuclear fuel cycle (both reprocessing and enrichment), which would have allowed it to keep the nuclear option open. The government in Brasilia signed a deal with West Germany for a transfer of the full nuclear fuel cycle,

which materialized only in part. Instead of receiving a plutonium reprocessing plant and ultracentrifuges, Brazil acquired only the jet nozzle enrichment method from the Germans. Concomitantly, the three branches of the Brazilian Armed Forces created a secret nuclear program (called the "parallel program") through which they developed an indigenous ultracentrifuge technology for uranium enrichment. I code Brazil as a hedger between 1979 and 1990 because in this interval, Brazil operated pilot- and industrial-scale ENR facilities. Brazil renounced the right to carry out peaceful nuclear explosions in 1990, which is when it exits the dataset.

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Argentina (1978-1990)

Argentina has pursued a policy of nuclear ambiguity, which qualifies it for aspiring hedger status. As Ambassador Julio Carasales points out, Argentina's peaceful nuclear status was conditional on the atomic restraint of its neighbors. If Brazil manufactured a nuclear weapon or set off a peaceful nuclear explosion, "Argentina would have no option but to do the same." Argentina also showed support for the use of peaceful nuclear explosions, which would have allowed it to keep the nuclear option open. I follow Bleek's assessment of Buenos Aires' nuclear ambitions when I code Argentina an aspiring hedger between 1978 and 1990. In 1978, the Argentinian authorities started planning a secret enrichment plant that would serve two purposes: to produce fuel for research reactors; and to "permit the country to acquire capacity for international negotiation in a sensitive national security area." The size of the ENR facilities Argentina operated would not have permitted the extraction of enough fissile material to weaponize in a short period of time. The Argentinians encountered technical difficulties when operating with these technologies, which further limited their ability to produce a nuclear weapon. Argentina exits the dataset in 1990, when it renounces the right to carry out peaceful nuclear explosions, "until this technology can be differentiated from military related efforts."

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Romania (1978-1992)

I code Romania as an aspiring hedger from 1978 until 1992. A case can be made for coding Bucharest an aspiring hedger much earlier. Bucharest's interest in nuclear weapons dates back to the early 1960s, when the Soviet Union decided to deploy nuclear-tipped short-range missiles to Western and Eastern Romania. When Moscow changed its mind, the Romanians persisted and even tried to introduce a nuclear sharing arrangement inside the Warsaw Pact. Since multinational nuclear schemes are not considered as evidence of an atomic weapons program, I do not code Romania as an aspirant in the early 1960s. Since the mid-1960s, Romania had been opposed to the NPT, claiming initially that the treaty should be resisted because it was not far-reaching enough. But in March 1967, in a conversation with Leonid Brezhnev, the General Secretary of the Communist Party of the Soviet Union, the Romanian Prime Minister, Ion Gheorghe Maurer, admitted that Romania did not want to sign the NPT because it would have tied its hands in the nuclear weapons arena. Maurer told Brezhnev that Romania would try to develop an atomic bomb if it had the necessary means to do so. In 1971, the General Secretary of the Romanian Communist Party, Nicolae Ceaușescu, told Glenn Seaborg, the Chairman of the US Atomic Energy Commission, that Romania did not have a military program yet, but the continuation of the arms race by the superpowers might push Bucharest to pursue nuclear weapons on its own. After India carried out its peaceful nuclear explosion, Romania became even more vocal about keeping the nuclear option open. In a 1975 conversation with the a member of the executive committee of the Palestine Liberation Organization (PLO), Ceaușescu expressed his disdain for the NPT and his nuclear hedging strategy: "Romania has greatly praised the Nuclear Nonproliferation Treaty, though this treaty did not solve anything, and internally, we disapproved of it, but for political interests we thought that with or without us, the treaty would have been signed anyway; we did not yet intend to produce nuclear weapons and so we thought to ourselves: when we have the capability to produce them, with or without the treaty, if we decide to produce them, we will produce them. In politics you cannot always applaud what you like." A year later, the US Department of State registered Ceausescu's provocative statement that "no state need refrain from a weapons acquisition," but no action was taken. I code Romania an aspiring hedger only in 1978 because that is when the Romanian government bought a laboratory-scale reprocessing facility from France. The Romanians then tried to assess the feasibility of obtaining fissile material in this facility. In this respect, in December 1985, Romanian scientists carried undeclared experiments aiming at extracting Plutonium. With the experiments successfully carried out, the Romanian leadership turned its attention to the construction of the heavy water nuclear power reactors imported from Canada, whose spent fuel could have been used to extract plutonium. In 1989, when Ceausescu was toppled, the first reactor was almost completed, a second one under 50% done, and the remaining three in incipient stages of construction. In 1992, unable to advance its nuclear program, the new leadership in Bucharest decided to report its violations of the NPT to the IAEA, which marks Romania's exit from the dataset.

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South Korea (1969-1981)

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Libya (1970-2003)

I start coding Libya as an aspiring NWS in 1970, when, shortly after King Idris had been toppled, Muammar Gaddafi sent his Prime Minister Abdessalam Jalloud to China to purchase a nuclear weapon prototype. According to John Prados, Beijing refused to sell. While not finding any evidence for the 1970 request, Målfrid Braut-Hegghammer dates the program to the late 1960s-early 1970s, when, "after the coup, the new regime immediately started exploring several options for acquiring nuclear weapons." The Libyan authorities set off to build a nuclear infrastructure with the help of foreign suppliers. In parallel, Libya succeeded in procuring materials, components, and expertise on the black-market to build a small-scale enrichment facility. Gaddafi also bought enrichment technology from the AQ Khan network. The Libyans did not manage to use these facilities to produce fissile materials. The authorities in Tripoli offered to give up the program as early as 1992, but they faced a variety of blockages in their negotiations with the international community. As a result, it was only in 2003 that Libya ceased all work at its ENR facilities, dismantling and shipping the centrifuges it had bought from AQ Khan or other black-market vendors to the US. 2003 marks the year when Libya exists the dataset.

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Iran (1974-1979; 1985-2014)

Iran enters the dataset as an aspiring hedger in 1974, when the Shah laid out an ambitious vision for his nuclear program, vowing to acquire the full nuclear fuel cycle with the help of Western suppliers. Because Iran conditioned its nuclear restraint to that of India, the 1974 PNE carried out by India likely gave reason to Iran to reconsider and possibly "wish to develop a similar capability." The US sought to persuade Iran to adhere to a regional multinational enrichment scheme, which would have limited Teheran's ability to become an independent supplier and curbed its proliferation potential. The Shah, however, turned to the Europeans, with whom he concluded more advantageous agreements. In its first years of existence, the Islamic Republic of Iran put the nuclear program on pause, which is why Iran exists the dataset between 1979 and 1985. In the mid-1980s, Iran resumed work at the Plasma Physics Laboratories in Teheran, where it conducted research on centrifugation for the purpose of enriching uranium. I therefore code Iran as an aspiring hedger again starting in 1985 until 2001 and from 2004 until 2011. Between 2002 and 2003 and 2011 and 2014, I code Iran as a hedger because during these intervals, it was operating pilot- and industrial-scale ENR facilities. The leadership in Teheran has repeatedly denied possessing a military nuclear program, but the rhetoric adopted by Iranian politicians, which subsumes appeals to nationalism, sovereignty, identity, and progress, promotes a hedging strategy, as Wyn Bowen, Matthew Moran, and Dina Esfandiari have shown.

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Iraq (1975-1991)

I start coding Iraq as an aspiring hedger in 1975, when the Iraqis launched a nuclear procurement program aimed at securing the full nuclear fuel cycle. Dating the beginning of the Iraqi nuclear weapons program can be difficult because, as Målfrid Braut-Hegghammer shows, in the early 1970s, "enterprising nuclear scientists began to pursue a mandate from the political leadership to develop a nuclear weapons option." However, there was no mandate for such activities until 1975, when Saddam Hussein ordered the Iraqi Atomic Energy Commission (IAEC) to "prepare a strategy for the introduction of a nuclear power program and aspects of the related fuel cycle… based on turkey projects and the transfer of nuclear technology from abroad." Israel's 1981 military attack on the research reactor Baghdad had purchased from France accelerated the Iraqi nuclear program and pushed it underground. From 1981 until 1991 I code Iraq as an aspiring NWS. As part of its covert efforts to acquire nuclear weapons, the Iraqi first carried out research on processes that would help them obtain fissile material; then they developed the technologies in question; and finally, they launched a crash program meant to produce a nuclear weapon. Many of Iraq's nuclear facilities were destroyed by the US-led military coalition in the First Gulf War. The campaign was not aimed at rolling back Baghdad's nuclear program, but at forcing Saddam Hussein to withdraw from Kuwait. The international community, surprised by the discovery of a crash nuclear program, placed Iraq under a tight embargo. In this context, the Iraqi nuclear weapons program came to a halt in 1991.

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Algeria (1983-1990)

Algeria enters the dataset as an aspiring NWS in 1983. Algeria's nuclear procurement program, combined with its refusal to sign the NPT, qualify it for this status. In 1983, Algiers signed a secret agreement with Beijing for a large research reactor. Recently declassified intelligence documents show that in the early 1990s, US officials worried about the reactor's size, which exceeded the requirements of a nuclear research program, which fueled fears that Algeria was pursuing a nuclear weapons program.

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Syria (2000-2007)

I code Syria as an aspiring NWS starting in 2000. Arguably, Syria may have had an interest in the military uses of the atom earlier. The earliest evidence of Syrian nuclear ambitions dates back to 1978, when the government of Hafez al-Assad sought "bids from the US, UK, France and other European companies to study the feasibility of getting into peaceful nuclear technology" due to concerns about "the nuclear weapons capability potential inherent in Iraq's acquiring a nuclear laboratory and research reactor from France." The source cited for this analysis suggests that this interest in nuclear technology stemmed more from a desire to become a hedger than from a clear penchant for nuclear weapons: the Syrian feasibility study "is not triggered by a desire to develop nuclear weapons but by a feeling that with many ominous developments possible one ought to be taking the first steps toward training people in nuclear technology." In the absence of other sources

to corroborate this interest in nuclear weapon, the aforementioned assessment remains in the realm of speculation. Hafez al-Assad started negotiations with Argentina (from which it sought to purchase a research reactor and a hot cell) and China (from which it ended up buying a Miniature Neutron Source Reactor in 1991). Syria's interest in reprocessing (the hot cell from Argentina) suggests that the leadership in Damascus may have been interested in producing fissile material for nuclear weapons. Sources cited by *Nucleonics Week* warned that the "Chinese assistance to Syria might serve to 'jump start' a nuclear weapons development in that country. I follow Bleek's assessment of Syria's nuclear ambitions when I code it as an aspiring NWS beginning in 2000. In the early 2000s, the regime in Damascus strengthened its ties to other Axis of Evil countries, in particular North Korea and Iran. The regime in Pyongyang reportedly helped Syria build a nuclear facility at al-Kibar (also known as Dair Alzour), which Israel destroyed in the September 2007 Operation Orchard. Since 2007, newspaper reports have claimed that Syria resumed its nuclear weapons activities at a different site (Qusayr). The Federation of American Scientists has produced a dossier which suggests that the revelations about a renewed Syrian effort to acquire nuclear weapons should be "treated with skepticism." As a consequence I code Syria as an aspiring NWS from 2000 until 2007.

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Saudi Arabia (2003-2014)

I code Saudi Arabia as an aspiring hedger, starting in 2003. Saudi Arabia's interest in atomic energy dates to the 1970s, when the leadership in Riyadh reportedly tried to build a nuclear power plant with the assistance of a French firm, spurred by similar developments in Iran. The supposed plan was abandoned after the 1979 Three Mile Island accident. Additional rumors about a Saudi purchase of a Chinese research reactor surfaced in the late 1980s, but the deal in question did not materialize. In the early 1990s, Saudi leaders emphasized that "the Kingdom of Saudi Arabia has the capability of acquiring and developing nuclear weapons but, as is well known, the Kingdom is at the forefront of the states calling to make the Middle East a nuclear-free zone" (statement made by then-Minister of Defense and Crown Prince, Prince Sultan). Such statements simply indicate restraint. They do not contain any warning or threat that Saudi Arabia would go nuclear under different circumstances. Yet since the early 1990s, Riyadh's position on nuclear weapons has experienced significant changes, morphing into a hedging strategy. In 2003, news reports citing a leaked strategy paper indicated that nuclear weapons were listed among the three options that the leadership in Riyadh considered for dealing with its regional rivals (primarily Iran). The other two options included seeking protection from a nuclear-armed country or establishing a nuclear-weapon free zone in the Middle East. This consideration of an independent nuclear deterrence in this strategy paper qualifies Saudi Arabia for hedger status. Since 2003, the Saudis have taken a

variety of steps to develop a nuclear infrastructure, including the acquisition from Argentina of a research reactor in 2013, and entering negotiations with various nuclear suppliers, such as the US, Russia, China, South Korea or France. Riyadh plans to build 16 nuclear power reactors by 2030, at a price-tag of $100 billion. According to Riyadh's nuclear energy strategy, the first reactors should come online by 2022. These plans are accompanied by comments made by various members of the royal family, including Prince Turki al-Faisal who has suggested that Saudi Arabia might seek nuclear weapons if it found itself caught between a nuclear-armed Israel and an Iran possessing atomic weapons. High-ranking officials have repeatedly stressed that the Saudi government would not accept anything less than the level of nuclear development Iran would be allowed to have under the terms of the deal with the P5+1. Saudi Arabia is believed to have financed the Pakistani atomic arsenal, and recent news reports indicate that "nuclear weapons made in Pakistan on behalf of Saudi Arabia are now sitting ready for delivery."

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Rules for coding suppliers

I investigate the role of countries which can sell nuclear research reactors, power reactors, and enrichment and reprocessing facilities (E&R technology). I seek to determine which countries can export these technologies at any given point between 1939 and 2014, by examining approximately 1,500 nuclear facilities.[2] I proceed as follows:

1. For coding suppliers of nuclear research reactors, I use the IAEA Research Reactor Database (RRDB), which contains information about 774 facilities. With the help of RRDB, I established the location of every research reactor in the world and the approximate date when construction began. To determine who built each reactor in the RRDB, I conducted additional research using both primary and secondary sources. When a country starts building its own research reactor or when it does so in cooperation with other countries, it counts as a potential supplier. When a state exports a research reactor to another country, I regard it as an actual supplier. When I add up the number of research reactor suppliers for each year in the 1939-2014 interval, I take into account both potential and actual exporters. If a country temporarily or permanently shuts down all of its research reactors, I stop counting it as a supplier.

2. For coding suppliers of nuclear power reactors, I rely on the Power Reactor Information System (PRIS), which contains information about 671 facilities. Using PRIS, I established where each nuclear power plant (NPP) in the world is located and when it started being built. To determine the manufacturer of each reactor in PRIS, I use the Global Energy Observatory database and conducted additional research using both primary and secondary sources. A country becomes a potential supplier when it builds its own nuclear power reactors or when it joins forces with other countries to build such facilities. When it starts exporting them

[2] It is possible that some countries view others as potential rivals in the nuclear exports arena even before the former develop the technology in question. These perceptions can affect their decision whether to export or not. Determining which countries count as suppliers based on whether other states see them as such or not would be a difficult endeavor for two reasons: not all countries would share the same view – those who are very strong are more likely to dismiss as non-threats those countries that weak actors regard as potential rivals ; even if unanimity was possible, finding evidence of such perceptions for every country in the international systems for every year in the 1939-2014 interval would be challenging, given the limited access to primary sources.

to other states, it counts as an actual supplier. Both types matter in my coding of NPPs suppliers. The moment an exporter shuts down all its nuclear power plants (even if just briefly), I eliminate it from the suppliers' pool.

3. For coding suppliers of E&R technology, I start from the latency dataset created by Fuhrmann and Tkach, which covers approximately 254 facilities. The dataset provides information on when the construction of each E&R facility began. After determining the manufacturer of each facility with the help of additional primary and secondary sources, I separated potential suppliers from actual suppliers, following the same rules as for RR and NPP suppliers. When a country closes up its E&R facilities, it no longer counts as a supplier.

The following sources were consulted when examining each facility in every country. In addition to these general resources, I used materials from the archives listed below.

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Archives of the Romanian Ministry of Foreign Affairs, Bucharest, Romania

Archives of Social and Political Organizations, Chișinău, the Republic of Moldova

Central State Archives, Rome, Italy

Centro de Pesquisa e Documentação de história Contemporânea do Brasil, Rio de Janeiro, Brazil.

CIA Records Search Tool, College Park, Maryland

Gerald Ford Presidential Library, Ann Arbor, Michigan

The Hoover Institution Archive, Stanford, California

International Atomic Energy Agency Archives, Vienna, Austria

Jimmy Carter Presidential Library, Atlanta, Georgia

Library and Archives of Canada, Ottawa

Library of Congress, Manuscript Division, Washington, D.C.
Glenn Seaborg Papers

Lyndon B. Johnson Presidential Library, Austin, Texas

National Archives and Records Administration, College Park, Maryland

National Archives of the United Kingdom, London, the United Kingdom

National Central Historical Archives, Bucharest, Romania

National Security Archive, The George Washington University, Washington, D.C.

Politische Archiv des Auswartigen Amts, Berlin, Germany

Richard M. Nixon Presidential Library, Yorba Linda, California

Richard M. Nixon Presidential Materials, College Park, Maryland (until 2010)

Russian State Archive for Contemporary History, Moscow, the Russian Federation

The United States

Research Reactors: 1942-2014

I count the United States as a potential research reactor (RR) supplier starting in 1942, when it started building CP-1. The numbers of RR grew rapidly, totaling over 270 research reactors, critical and subcritical assemblies, and zero-power reactors over the seven decades covered by this dataset. In 2014 the US had 42 research reactors in operation, which means that it still counts as a supplier. The US became an actual RR supplier in 1956 when construction on research reactors exported abroad began. Between 1956 and 2014, the US sold research reactors to 32 additional countries.

Power Reactors: 1954-2014

I count the United States as a potential nuclear power plant (NPP) supplier in 1954, when it started building its first nuclear power plant at Shippingport. By the time the first reactor was connected to the grid in 1957, the US had already planned four other NPPs, a rapid growth rate for the early years of the nuclear age. The US Atomic Energy Commission (US AEC) aggressively pursued the expansion of the nuclear electricity share in the domestic energy mix. As a result, in 1978 the US had a record number of 178 power reactors that were operational or under construction. After the Three Mile Island nuclear accident, reliance on atomic power started to decline, which led to more than 70 power reactors being shut down or cancelled. In 2014, the US had 105 atomic power stations in operation or under construction, which means the United States still counts as a supplier. The US became an actual NPP supplier in 1957, when construction on NPPs exported abroad began. Between 1957 and 2014 the United States exported nuclear power stations to 16 countries.

Enrichment and Reprocessing: 1939-2014

I start counting the United States as a potential enrichment and reprocessing (ENR) supplier in 1939, when it started building its Centrifuge Testing Facility at the University of Virginia. The US maintains several facilities open (at Los Alamos, Paducah, Piketon, and Wilmington) despite having banned commercial ENR. The US became an actual ENR supplier in 1961, when it started exporting ENR abroad. Between 1961 in 2014, the United States exported ENR to 5 countries.

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The Soviet Union/Russia

Research Reactors: 1946-2014

I start counting the USSR as a potential RR supplier in 1946 when construction on its first research reactor (F-1) began. By 2014, a total of 130 research reactors, critical and subcritical assemblies, and zero-power reactors had been built, under construction, or operational in the USSR and later on the territory of the Russian Federation and the former Soviet Republics. There are currently 54 operational research reactors on the territory of the Russian Federation, which keeps Russia in the supplier category until the end of the dataset. The USSR became an actual RR supplier in 1955, when construction on Soviet-origin research reactors began Eastern Europe. Over the span of over four decades, the USSR transferred research reactors to over 13 countries.

With the demise of the Soviet Union, the newly independent states inherited a number of research reactors, critical and subcritical assemblies, and zero-power reactors. These facilities do not count as Soviet/Russian exports.

Power Reactors: 1951-2014)

The Soviet Union became a potential NPP supplier in 1951, when it started building its first nuclear power plant (NPP) at Obninsk. The plant began electricity production in 1954. The number of NPPs under construction or built on the territory of the USSR peaked at 72 in 1987, one year after the Chernobyl accident. Thereafter, the Soviet authorities decided to close down or cancel the construction of NPPs, so by the time the USSR dissolved in 1991, the number of power reactors under construction or already built had dropped to 62. The USSR became an actual NPP supplier in 1958, when it started exporting power reactors to Eastern Europe.

With the demise of the Soviet Union, the Russian nuclear industry hit its lowest point 2004-2005, when the number of nuclear power reactors fell to 45. After the mid-2000s, as the economy picked up momentum again, Russia started building more reactors on its territory and resumed construction on several NPPs that had been mothballed. In 2014, there were 53 NPPs in the Russian Federation. Moscow also expanded its customer portfolio, exporting reactors to the Middle East, East and South West Asia. A number of former Soviet republics inherited NPPs built by the USSR on their territory prior to the demise of the Soviet Union. These facilities do not count as Soviet/Russian exports.

Enrichment and Reprocessing: **1941-2014**

The USSR enters the dataset as a potential ENR supplier in 1941, when it started building a centrifuge facility in Khar'kov. After the end of the Cold War, the ENR infrastructure build by the Soviet Union was inherited by the Russian Federation, which still maintains several facilities in operation. The Soviet Union became an actual supplier in 1955, when construction started on a gaseous diffusion laboratory in China. Moscow later withdrew its assistance to China, but the groundwork for several facilities in the PRC was laid by Soviet scientists. The USSR also exported ENR technology to the Czech Republic, Libya, and North Korea. After 1990, the Russian Federation exported enrichment technology to China.

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United Kingdom

Research Reactors: 1944-2014

I start coding the United Kingdom as a potential RR supplier in 1944, when British scientists together with Canadian scientists started building the NRX reactor in Canada. Until 2014, the UK Atomic Energy Authority began construction and/or built close to 36 domestic research reactors, critical and subcritical assemblies, and zero-power reactors. The UK became an actual research reactor supplier in 1954, when it started building a research reactor in Belgium, in cooperation with the host country. Between 1954 and 2014, the UK sold research reactors to a total of 10 countries. Three reactors sold by the UK are still in use (Belgium, Chile, and Switzerland), which means the UK counts as a supplier until 2014.

Power Reactors: 1953-2014

I start coding the United Kingdom as a potential NPP supplier in 1953, when it broke ground for its first nuclear power plants – Calder Hall 1 and 2. The reactors were connected to the grid three years later. In its 50-year history, the UK Atomic Energy Authority began construction and/or built close to 45 domestic power reactors. The number of NPPs in the UK peaked in 1980 at 39, only to be followed by a considerable decline which brought the current number of power reactors down to 10. The UK became an actual NPP supplier in 1958, when it sold a nuclear power station to Italy. For a variety of technical and financial reasons, the UKAEA failed to attract many customers in the subsequent years. Starting in 1998, no British-origin power reactors have been operating internationally, as the NPPs sold abroad were permanently shut down. Nonetheless, the UK continues to be seen as a potential supplier, as it maintains a domestic nuclear infrastructure.

Enrichment and Reprocessing: 1942-2014

I start coding the UK as a potential ENR supplier in 1942, when construction on the reprocessing facility at the Montreal Lab in Canada began. The UK currently maintains several reprocessing facilities in operation which qualifies it for supplier status until the end-year of the dataset. The UK has transferred ENR technology to Pakistan. The UK joined various multinational enrichment consortia, such as URENCO (with the Netherlands and Germany), the Enrichment Technology Company (with France and URENCO).

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Canada

Research Reactors: 1944-2014

I start coding Canada as a potential RR supplier in 1944, when construction on its first research reactor (NRX) began. Over the course of the next seven decades, Canada built and operated 19 research reactors, critical and subcritical assemblies, and zero-power reactors on its territory. The construction on the first Canadian-supplied research reactor, bought by India, began in 1955, which marks the year when Canada became an actual RR supplier. Canada also sold research reactors to Taiwan and Jamaica. The Slowpoke research reactor in Jamaica is still operational which makes Canada an actual supplier until the end of the dataset.

Power Reactors: 1958-2014

I start counting Canada as a potential NPP supplier in 1958, when construction began on Rolphton NPD, the first Canadian nuclear power reactor. The plant was connected to the grid in 1962, by which time, Canada had already started building its second NPP, at Douglas Point. The domestic Canadian nuclear industry kept expanding until 1986 – when there were 23 nuclear power reactors built or under construction. Canada became an actual NPP supplier in 1965, when it concluded its first export to India. Between 1965 and 2014, Canada sold nuclear power reactors to 5 countries.

Enrichment and Reprocessing: 1942-1956; 1990-1993

Canada enters the dataset as a potential ENR supplier in 1942, having developed a reprocessing facility together with the US and the UK at the Montreal Lab and later at Chalk River. Canada first

exists the dataset in 1956, when the Chalk River facility stopped operating. The second time Canada enters the dataset dates back to 1990, when Canada partnered up with the United States to develop the Condensation Repression Isotope Separation by Laser Activation (CRISLA) enrichment process. This enrichment facility was in use until 1993, which marks Canada's second exit from the dataset.

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Sweden

Research Reactors: 1952-2005

Sweden became a potential RR supplier in 1952, when it broke ground for its first research reactor – R1. Over the course of five decades, Sweden built six research reactors, critical assemblies and zero-power reactors. The last reactor to operate in Sweden – R2-0 – shut down in 2005, which is when Sweden ceases to be a potential RR supplier.

Power Reactors: 1957-2014

Sweden joins the suppliers' club as a potential NPP vendor in 1957, when it started building its first power reactor – Agesta. The connection to the grid of this nuclear plant in 1964 was followed by a modest increase of the Swedish nuclear power program, peaking at 9 NPPs in 1998. Sweden became an actual NPP supplier in 1974 when it exported its first nuclear power reactor to Finland, its only customer. As the Swedish nuclear industry maintains both a domestic infrastructure and a presence abroad, Sweden remains a NPP supplier until 2014, the last year covered in this dataset.

Enrichment and Reprocessing: 1943-1972

Sweden enters the dataset as a potential ENR supplier in 1943 when Theodore Svedberg developed the ultracentrifuge, which had important applications in the realm of uranium enrichment. In 1946, Sweden broke ground on a reprocessing laboratory in Stokholm. A second reprocessing laboratory became operational in 1960, and it remained in use until 1972, which marks Sweden's exit from the dataset. Around 1945, Sweden exported centrifuge technology to the Soviet Union, which was installed at the Sukhumi facility.

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France

Research Reactors: 1948-2014

France became a potential RR supplier in 1948, when it started building its first research reactor – Zoe (EL-1). By 2014, France had 39 reactors under construction or in operation. The first French-supplied research reactor was built in Israel in 1958, which is when France became an actual supplier. This reactor is still in use, which makes France an actual supplier until the end of the dataset.

Power Reactors: 1955-2014

France enters the nuclear power reactor market as a potential supplier in 1955, when construction on its first nuclear power plant – G-2 (Marcoule) – began. The G-2 was connected to the grid in 1959, by which time the Commisariat à l'Energie Atomique (CEA) had quadrupled the number of power reactors under construction. The French leadership placed the development of nuclear power at the top of its priority list. As a result, in 1988, the number of NPPs in operation or under construction in France peaked at 64. Afterwards, the French nuclear industry slightly contracted, stabilizing at 59 nuclear power stations since the late 2000s. France became an actual NPP supplier relatively late compared to the US, UK, and the Soviet Union, transferring nuclear power technology for the first time in 1970 (to Belgium, through a joint venture). Between 1970 and 2014, France exported NPPs to 5 countries.

Enrichment and Reprocessing: 1949-2014

France enters the dataset as a potential ENR supplier in 1949, when construction on its first reprocessing facility (Le Bouchet) starts. France currently operates two ENR facilities which means it counts as a supplier until the end of the dataset. France became an actual ENR supplier in 1957, when it sold a reprocessing facility to Israel. France has transferred ENR technology to 6 countries.

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Norway

Research Reactors: 1951-2014

I start coding Norway as a potential RR supplier in 1951, when construction on its first research reactor – JEEP I, which was built in cooperation with the Netherlands – started. Norway built and operated four reactors between 1951 and 2014. Two reactors are still in use, making Norway a potential RR supplier until the end of the dataset in 2014.

Enrichment and Reprocessing: 1954-1978

Norway becomes a potential ENR supplier in 1954 when it started operating a reprocessing laboratory at Kjeller, built in collaboration with the Netherlands. The year when construction started on this facility remains unknown. Norway stopped being a potential ENR supplier in 1968, when the second facility built at Kjeller was shut down. I code Norway as an actual ENR supplier in 1956 when, together with Czechoslovakia, it transferred a reprocessing laboratory to

[3] , https://doi.org/10.1051/rgn/19784314.

Yugoslavia. I stop coding Norway as an actual ENR supplier in 1978, when the facility in Yugoslavia shut down.

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The Netherlands

Research Reactors: 1951-2014

The Netherlands entered the market as an actual supplier of RRs in 1951, when ground broke on the JEEP I research reactor, built in cooperation with Norway. By the time the Netherlands began building its own RR in 1959, it had imported research reactors from the US and the UK. The Dutch stopped being actual suppliers in 1967, when JEEP I was shut down. Holland designed and built its latest indigenous subcritical assembly in 2001, which became operational in 2004 and is currently in use. Therefore, the Netherlands counts as potential supplier until the end of the dataset in 2014.

Enrichment and Reprocessing: 1954-2014

The Netherlands becomes an actual ENR supplier in 1954 when, together with Norway, it started operating a reprocessing laboratory at Kjeller. In the subsequent decades, the Netherlands contributed to the development of various enrichment facilities in Germany, the UK, France, and the US through URENCO and the Enrichment Technology Company. Since many of these facilities are still in use, the Netherlands remains an actual ENR supplier until 2014.

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Yugoslavia

Enrichment and Reprocessing: 1952-1977

Yugoslavia enters the dataset in 1952, when it broke ground on its indigenously-developed EMIS laboratory at the Rudjer Boskovic Institute. This facility stopped operating in 1977, which marks

the year when I stop coding Belgrade as an ENR supplier. Yugoslavia did not transfer ENR facilities to other countries, which is why I do not code it as an actual ENR supplier.

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Belgium

Research Reactors: 1954-2014

I code Belgium as a potential RR supplier in 1954, when it built its first research reactor – BR-1 – in cooperation with the United Kingdom. The reactor is still in use, which makes Belgium a potential RR supplier until the end of the dataset. Over the course of the next six decades, Belgium built several other research reactors and critical assemblies, one of them in cooperation with the US (BR-02). Belgium also built several reactors in France, but because they are owned by EURATOM, they do not count as a state-to-state transfer.

Power Reactors: 1969-2014

Belgium enters the nuclear market as a potential NPP supplier in 1969, when it starts building the DOEL-1 nuclear power plant, in cooperation with the US. The first NPP Belgium built became operational in 1975. The number of nuclear power reactors remained modest, peaking at 4 projects which Belgium undertook on its own or in partnership with other countries. Despite taking part in several tenders since the late 1960s, Belgium has never managed to seal a deal for exporting a nuclear power reactor to another country, which keeps it out of the actual NPP suppliers' club.

Enrichment and Reprocessing: 1971-1988

The Mol Purex Reprocessing Facility was built in 1960 by the Organization for Economic Cooperation and Development (OECD). Since this study looks at state-to-state nuclear technology transfers, the OECD is not included as a supplier. In 1972, through a multinational collaboration project, Belgium helped Pakistan build the Experimental Reprocessing Plant at Pakistan Institute of Nuclear Science and Technology (PINSTECH). The Hermes hot cell complex at Mol, built in 1980, remained in operation until 1988, when Belgium exits the dataset as a potential ENR supplier.

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Czechoslovakia/Czech Republic

Research Reactors: 1966-2014

Czechoslovakia became a potential RR supplier in 1966, when construction began on its first indigenous reactor – TR-0. Two other research reactors were built before Czechoslovakia dissolved in 1992. Because these facilities remained in use after 1993 on Czech territory, I code the Czech Republic as a potential supplier until 2014. Czechoslovakia or the Czech Republic did not export any facilities to other countries, which means neither of them counts as an actual supplier.

Power Reactors: 1983-1992; 1996-2014

I count Czechoslovakia as a potential NPP supplier starting in 1983, when it began building its own nuclear power plant at Mochovce, years after launching a nuclear power program with the help of the Soviet Union. By the time the Mochovce NPP became operational, Czechoslovakia had split into the Czech Republic and Slovakia. For a brief period of time (1993-1995), the Czech Republic disappeared as a potential supplier, as it had shut down all of its nuclear power plants. Czechoslovakia first became an actual NPP supplier in 1984, when it started a joint venture with Poland for the Zarnowiec-1 and 2 NPPs, which were cancelled in 1990.

Enrichment and Reprocessing: 1956-1978

Czechoslovakia enters the dataset as an actual ENR supplier in 1956 when, together with Norway, transferred reprocessing technology to Yugoslavia. The Vinca Reprocessing Center remained in use until 1978, which marks Czechoslovakia's exit from the dataset.

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Federal Republic of Germany

Research Reactors: 1957-2014

The Federal Republic of Germany (FRG) enters the dataset in 1957 as a potential RR supplier, when it started building its own research reactor – the FR-2 at Karlsruhe. Previously, West Germany relied on imports from abroad. By 2014, the FRG built and operated thirty indigenous reactors. The Federal Republic of Germany joined the market as an actual supplier in 1962, when it began building a first research reactor in Austria. Over the course of five decades, Germany

exported RR technology to 5 countries. Because many of the reactors it built indigenously and the ones it exported abroad are still in use, Germany remains in the dataset until 2014.

Power Reactors: 1958-2014

West Germany became a potential NPP supplier in 1958, when it started building its first nuclear power plant at Van Kahl. By the time the plant was connected to the grid in 1961, West Germany had begun construction on two additional NPPs. The number of nuclear power reactors built or under construction on West German territory continued to expand until 1982-1983, peaking at 24 NPPs. Afterwards the West German nuclear infrastructure began to shrink, dropping to 6 NPPs in 2014. When the Berlin Wall collapsed, the Federal Republic of Germany inherited all nuclear power reactors built by the Soviet Union on East German territory and decided to shut them down for safety considerations. As a result, the number of NPPs does not increase after 1991, but on the contrary, it continues to decline.

I count West Germany as an actual NPP supplier in 1968, when it transferred its first nuclear power reactor to Argentina. From 1968 until 2014, Germany exported NPPs to seven countries. Not all of these facilities became operational: the nuclear power reactor at Zwentendorf in Austria never entered service as a result of a referendum, while Germany withdrew from the construction of the Bushehr NPP after the Islamic Revolution in Iran in 1979. In the aftermath of the Fukushima nuclear accident, the German government announced that it will close down all German NPPs by 2022. Despite the adoption of this policy, I code Germany as a supplier until 2014, since it maintains the capacity to export a nuclear power reactor to another country.

Enrichment and Reprocessing: **1960-2009**

West Germany becomes a potential ENR supplier in 1960, when it started building a pilot-size enrichment facility at Karlsruhe Nuclear Research Center, Institute for Nuclear Process Engineering. There are 5 other ENR facilities in the FRG, two of which have been under construction since 1985 and 2007 respectively. As a consequence, I code Germany as a potential ENR supplier until the end-year of the dataset – 2014. West Germany became an actual supplier in 1971, when it built an enrichment plant at Almelo in Netherlands, in collaboration with its other URENCO partners. West Germany also signed a deal to transfer ENR technology to Brazil, but it came under pressure from the US to cancel the sale. According to some sources, Brazil received only the jet nozzle enrichment technology transferred from West Germany. Several of the ENR facilities Germany built in other countries are still operational, which means it stays in the dataset until 2014.

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Switzerland

Research Reactors: 1957-2014

I code Switzerland as a potential RR supplier starting in 1957, when it built its first indigenous heavy water reactor – Diorit. Switzerland remains a potential RR supplier until 2014 because it currently has one indigenously-built critical assembly in operation, alongside another such facility built in cooperation with the UK.

Power Reactors: 1962-1969

Switzerland enters the potential NPP suppliers club in 1962, when it builds its only indigenously-developed nuclear power reactor at Lucens. The NPP was connected to the grid in 1968 and permanently shut down one year later, in 1969. The Swiss never exported nuclear power plants to other countries, although they were approached by several buyers in the late 1960s.

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H. Pauli, *Dismantling of the research reactor DIORIT* (IAEA-CN--143) (Vienna: International Atomic Energy Agency, 2006).

Argentina

Research Reactors: 1957-2014

Argentina became a potential RR supplier in 1957, when construction on its first research reactor – the RA-1 Enrico Fermi – started. It currently has three indigenously-built reactors in use and one reactor – the CAREM 25 – under construction, which keeps it in the suppliers' category until 2014. I code Argentina as an actual RR supplier in 1977, when it started building a research reactor in Peru. Since then, it exported research reactors to 4 other countries.

Power Reactors: 2014-

I code Argentina as a potential NPP supplier in 2014, when it broke ground for its first indigenously-developed power reactor – the CAREM25. Argentina has not yet exported any power reactors to other countries, which leaves it out of the actual NPP suppliers' category.

Enrichment and Reprocessing: 1968-1973; 1978-1994

Argentina enters the dataset as a potential ENR on two occasions: between 1968 and 1973, when it built and operated a reprocessing facility at Ezeiza; and between 1978 and 1994 when it built and operated an enrichment pilot plant at Pilcaniyeu. Argentina started building a second enrichment facility at Pilcaniyeu, which has not been finished. It can be argued that because construction on this second facility at Pilcaniyeu has not been finished, Argentina can be coded as a potential ENR supplier until the end-year of the dataset. However, given that work on the Pilcaniyeu facility has been postponed indefinitely, Argentina exits the dataset in 1994.

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The People's Republic of China

Research Reactors: 1958-2014

The People's Republic of China (PRC) entered the market as a potential RR supplier in 1958, when it built its first indigenous research reactor – the Swimming Pool Reactor at the Institute of

Atomic Energy in Beijing (SPR IAE). Between 1958 and 2014, the PRC built and operated a total of 18 research reactors, critical and subcritical assemblies. As 15 of those reactors are still in use, China counts as a potential supplier until the end date covered by this study. China became an actual RR supplier in 1988 when it started building a research reactor in Algeria. By 2014, China had sold research reactors to six other countries. As these facilities are currently operational, China remains an actual RR supplier until 2014.

Power Reactors: 1993-2014

The People's Republic of China became an actual nuclear supplier before it built its own nuclear power plant. In 1993, China exported a NPP to Pakistan, using a French-based reactor design and a Chinese supplier. In 1997, China broke ground on the first indigenously-designed NPP – at Qinshan 2-2. China has continuously expanded its nuclear power program since the late 1990s, peaking at 30 NPP in operation or under construction in 2014. Given its exports to Pakistan and its domestic NPPs, China counts as an NPP supplier between 1993 and 2014.

Enrichment and Reprocessing: 1960-2014

I start coding China as a potential ENR supplier in 1960, when, after the withdrawal of Soviet adviser, Chinese scientists and engineers took over and finished the construction at the Lanzhou gaseous-diffusion plat (Lanzhou 1). China then built several enrichment facilities on its own, several of which are still operating, which means it counts as a supplier until the end-year of the dataset. Beijing exported a laboratory-scale enrichment facility to Iran and a hot cell facility to Algeria. It also provided assistance to Pakistan in setting up the Kahuta enrichment plant. China can therefore be coded as an actual ENR supplier from 1991 until the end-year of the dataset.

Selected Bibliography:

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Japan

Research Reactors: 1958-2014

Japan joined the nuclear market as a potential RR supplier in 1960, when ground broke on its first indigenously-built research reactor – JRR-3. By 2014, Japan built over two dozen indigenous research reactors, critical and subcritical assemblies, many of which are still in use. Japan therefore

remains a potential RR supplier, although because it never exported research reactors to other countries, it never became an actual supplier.

Power Reactors: 1966-2014

I start coding Japan as a potential NPP supplier in 1966, when it broke ground on Tsuruga-1. This nuclear power reactor was the first instance of Japanese direct involvement in the design of such a facility, in cooperation with American companies. Japan's nuclear infrastructure expanded rapidly, up to 51 nuclear power reactors in 2001. Afterwards, the number of NPPs built or under construction in Japan remained roughly unchanged until 2011, when the Fukushima accident occurred. In the aftermath of the disaster, the Japanese authorities put all nuclear power plants in temporary shut-down.

Japan became an actual NPP supplier in 1985, when it construction started on the first and only power reactor it sold to another country – the People's Republic of China. The Qinshan-1 NPP is still operational, keeping Japan in the actual suppliers' club until the end of the dataset in 2014.

Enrichment and Reprocessing: 1968-1970; 1978-2009; 2011-2014

I code Japan as a potential ENR supplier from 1968 until 1970, from 1978 until 2009, and from 2011 until the end-year of the dataset. Japan built its first indigenously developed reprocessing test facility (JRTF) in 1968, and operated it for two years. It then started building a uranium enrichment pilot plant at Ningyo, which became operational in 1979. Lastly, Japan developed a uranium enrichment plant at Rokkasho which was in use between 1992 and 2009, and then from 2011 until the end-year of the dataset. Japan did not export ENR technology to other countries, so it does not count as an actual supplier.

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Selig S Harrison, "Japans Nuclear Future: The Plutonium Debate and East Asian Security" (Carnegie Endowment for International Peace, Washington, D.C., 1996).

Italy

Research Reactors: 1958-2010

Italy became a potential RR supplier in 1958, when it started building its first subcritical assembly – Struttura Moltiplicante SM-1 – at University of Cagliari. It dismantled and moved it to Pavia

two years later. Italy built less than a dozen indigenous reactors, none of which are currently operating. Italy therefore stops being a potential RR supplier in 2010, when its last indigenously-built reactor shut down. Italy never exported research reactors to other countries, which means it never gets coded as an actual RR supplier.

Power Reactors: 1970-1987

I code Italy as a potential NPP supplier starting in 1970, when a US-Italian consortium broke ground for the Caorso NPP. This nuclear power reactor was connected to the grid in 1978. By the time the Italian nuclear industry began to expand – starting three other projects on its own or in cooperation with other countries – anti-nuclear sentiment, galvanized by the Chernobyl nuclear accident, materialized in a popular referendum calling for the termination of the nuclear power program. In 1987, Italy stops being a potential NPP supplier, as it closed down all of its nuclear power reactors. Italy was never an actual NPP supplier, because it never sold a nuclear power reactor to another country.

Enrichment and Reprocessing: 1962-2012

Italy enters the dataset as a potential ENR supplier in 1962, when it built its first reprocessing pilot plant, ITREC at Trisaia. Italy then indigenously built three other reprocessing plants, which were all shut down by the beginning of the 1990s. Italy therefore stops being a potential ENR supplier in 1990. In 1974, Italy helped France build one of its Eurodif plants. The Eurodif facility shut down in 2012, which explains the coding for Italy's exit from the dataset. Italy also sold a reprocessing laboratory to Iraq in 1979, which was dismantled after the First Gulf War.

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Israel

Enrichment and Reprocessing: 1958-2014

Israel becomes a potential ENR supplier in 1958, when it started building an enrichment facility at the Negev Nuclear Research Center. Israel built two other facilities by itself – one at the Negev Nuclear Research Center and one at the Soreq Nuclear Research Center. All indigenous facilities are still operating, which means Israel counts as a potential supplier until the end-year of the dataset. Israel never exported ENR facilities to other countries, which means I do not count it as an actual ENR supplier.

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Robert Gillette, "Uranium Enrichment: Rumors of Israeli Progress with Lasers," *Science* 183, no. 4130 (1974): 1172–74.

India

Research Reactors: 1960-2014

I code India as a potential RR supplier starting in 1960, when construction on its first indigenously-built research reactor – Zerlina – began. By 2014, India had built 6 more research reactors and a critical assembly. India has not yet exported any RR technology to a foreign country, which means it is not an actual supplier. Because four of its indigenously-built research reactors are still in use, India remains a potential RR supplier until the end of the dataset in 2014.

Power Reactors: 1971-2014

India became a potential NPP supplier in 1971, when it started building its own nuclear power reactor at Madras, after years of relying on foreign nuclear technology. By the time the Madras-1 NPP became operational, India had started work on four other nuclear power reactors. The Indian nuclear power complex has continuously expanded since the 1970s, reaching a total of 21 NPPs in 2014. India has not sold power reactors to other countries, although it has reached an understanding for the supply of NPPs to Kazakhstan. Because construction on these power reactors has not started yet, India remains a potential supplier.

Enrichment and Reprocessing: 1969-2014

I start coding India as a potential ENR supplier in 1969, when construction started at the Power Reactor Fuel Reprocessing facility. Since then, India built 8 other ENR facilities (both reprocessing and enrichment), all of which are still operational, meaning that New Delhi retains its supplier status until the end-year of the dataset. India never transferred ENR facilities to other countries, which means it never became an actual supplier.

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Spain

Research Reactors: 1960-1988; 1990-2010

I start coding Spain as a potential RR supplier in 1960, when construction on Argos and Arbi – two research reactors designed and built by Spanish scientists – started. I stop counting Spain as a potential RR supplier in 1988, when it shut down its last indigenous critical assembly – CORAL I. Spain became an actual RR supplier in 1972 when it started building a research reactor in Chile. Spain remained an actual RR supplier until 2010, with a short interruption between 1986 and 1989 when the RECH-2 reactor in Chile was shut-down.

Enrichment and Reprocessing: 1967-1971

I start coding Spain as a potential ENR supplier in 1967, when it built the Juan Vigon Pilot Reprocessing Plant. This facility remained in use until 1971, which marks Spain's exit from the dataset. Spain did not export ENR technology to other countries, which means I do not count it as an actual ENR supplier.

Selected Bibliography:

A. Romero de Pablos, "Poder político y poder tecnológico: el desarrollo nuclear español (1950-1975)," *Revista iberoamericana de ciencia tecnología y sociedad* 7, no. 21 (2013), 141-162.

Poland

Research Reactors: 1960-1995

Poland entered the nuclear market as a potential RR supplier in 1960, when it starts building its own indigenous critical assembly – ANNA. Poland operated two other indigenous research reactors – AGATA and MARYLA. Poland never exported research reactors to another country, which means I never code it as an actual RR supplier. I stop coding Poland as a potential RR supplier in 1995, when the AGATA research reactor shut down.

Selected Bibliography:

Martin Jirušek et al., *Energy Security in Central and Eastern Europe and the Operations of Russian State-Owned Energy Enterprises* (Brno: Masarykova univerzita, 2015).

South Africa

Research Reactors: 1962-1969

I start counting South Africa as a potential RR supplier in 1962, when ground broke on Pelinduna-0, a prototype critical assembly. The facility became operational in 1967, but it was cancelled two years later, in 1969, which is when South Africa ceases to count as a potential RR supplier. South Africa never exported research reactors to other countries, which means it never gets counted as an actual RR supplier.

Enrichment and Reprocessing: 1960-2014

South Africa enters the dataset as a potential ENR supplier in 1960, when it started building its own enrichment plant at Pelindaba. In the 1970s and 1980s, South Africa developed four other ENR facilities (both reprocessing and enrichment). Only one such facility (a hot cell complex at Pelindaba) is currently operational, which is enough to code South Africa as a potential supplier until the end-year of the dataset. South Africa has not exported ENR facilities to other countries, which means I do not count it as an actual supplier.

Selected Bibliography:

David Fig, "Apartheid's nuclear arsenal: Deviation from development," in *From Defence to Development. Redirecting Military Resources in South Africa*, ed. Jacklyn Cock and Penny Mckenzie (Claremont, SA: David Philip Publishers, 1998), 166.

David Fig, "Political Fission: South Africa's Nuclear Programme," *Energy & Environment* 17, no. 3 (July 2006): 457–67.

Brazil

Research Reactors: 1963-2014

Brazil entered the market as a potential RR supplier in 1963, when it started building Argonauta – the first research reactor built by Brazilian companies, adapted from an American design. In 1984 Brazil built its second indigenous research reactor – IPEN/MB-01. Both reactors are still operational, which means Brazil counts as a potential supplier until 2014. Brazil never exported research reactors to other countries, which means it is never coded as an actual supplier.

Enrichment and Reprocessing: 1960-2014

I code Brazil as a potential ENR supplier in 1960, when construction on a reprocessing laboratory started. Brazil built three other ENR facilities on its own, two of which are still operational. Brazil did not export ENR facilities to other countries, which means it does not qualify for actual ENR supplier status.

Selected Bibliography:

A. P. Leite Cota and A. Z. Mesquita, *Nuclear Research Reactors in Brazil*, Paper presented at 2011 International Nuclear Atlantic Conference - INAC 2011.

A.M. Ribeiro de Andrade, "Átomos na política internacional," *Revista CTS*, Vo. 7, No. 21 (2012).

The German Democratic Republic

Research Reactors: **1961-1991**

The German Democratic Republic (GDR) became a potential RR supplier in 1961, when it built its first reactor – the Rossendorf Research Reactor. East Germany operated three other research reactors until reunification with the Federal Republic of Germany in 1990. They were all shut down in 1991, which is when the GDR ceases to count as a potential RR supplier. Because East Germany never exported its research reactor technology to other countries, it is not considered an actual RR supplier.

Australia

Enrichment and Reprocessing: 1965-2007

Australia becomes a potential ENR supplier in 1965, when it started building its first centrifuge enrichment laboratory at Lucas Heights. This facility was in use until 1983, by which time had already been working on the Separation of Isotopes by Laser Excitation (SILEX) method. Australia ceases to be a potential ENR supplier in 1996, when it sold its SILEX technology to the US. The SILEX enrichment laboratory remained in use until 2007, when Australia exits the dataset.

Selected Bibliography:

Michael Clarke and Stephan Frühling, *Australia's Nuclear Policy: Reconciling Strategic, Economic and Normative Interests* (Abingdon: Routledge, 2016).

Christine Leah, *Australia and the Bomb* (New York, NY: Palgrave Macmillan, 2014).

Roy MacLeod, "The Atom Comes to Australia: Reflections on the Australian Nuclear Programme, 1953 and 1993," *History and Technology* 11, no. 2 (January 1, 1994): 299–315.

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Taiwan

Research Reactors: 1968-2005

I start coding Taiwan as a potential RR supplier in 1968 when it broke ground on ZPRL (the Zero Power Reactor at Lungtan), which it built in cooperation with the US. Taiwan built two other research reactors, and started construction on a third, but cancelled it in 2002. ZPRL was the last indigenous facility to be shut down in 2005, which is the date when Taiwan exists the RR suppliers dataset. Taiwan never exported research reactors to other countries, which means it never gets counted as an actual RR supplier.

Enrichment and Reprocessing: 1975-1977; 1987-1988

I code Taiwan as a potential ENR supplier on two occasions: between 1975 and 1977, when it built and operated a reprocessing laboratory at the Institute of Nuclear Energy Research, and between 1987 and 1988 when it built a reprocessing laboratory at the same institute. The latter facility was never put in use. Taiwan has not exported ENR technology to other countries, therefore it does not count as an actual supplier.

Hungary

Research Reactors: 1969-2014

Hungary became a potential RR supplier in 1969 when it started building its first indigenous research reactor – the Nuclear Training Reactor at Budapest University of Technology and Economics. Because this reactor is still in use, Hungary remains a potential RR supplier until 2014. In 1970 Hungary built a critical assembly on its own – the ZR-6M, which it shut down in 1990. Hungary never exported its research reactor technology to other countries, which means it is does not count as an actual RR supplier.

Pakistan

Enrichment and Reprocessing: 1974-2014

Pakistan enters the dataset in 1974 as a potential ENR supplier, when it started building two centrifuge enrichment facilities, one at Chaklala and another at Kahuta. Construction on the Kahuta plant had already begun when AQ Khan brought back to Pakistan centrifuge designs stolen from URENCO. Pakistan built 3 other indigenously-developed enrichment facilities, two of which are currently operational and one still under construction. Pakistan therefore remains in the dataset until the end-year – 2014. I code Pakistan as an actual ENR supplier starting in 1985, when it transferred its centrifuge technology to China. The pilot centrifuge plant built at Hanzhong, China remained in operation until 1993. Determining the period when Pakistan can be counted as an actual supplier is difficult, given that Pakistani scientist and smuggling ring leader, AQ Khan, sold centrifuges to Iran, Libya, and North Korea with tacit support from the government in some instances. The earliest point at which Pakistan stops being an actual supplier is 1993, and the latest is 2014, as the enrichment facility in North Korea is still operational.

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Gordon Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the AQ Khan Network* (Oxford: Oxford University Press, 2006).

Feroz Khan, *Eating Grass: The Making of the Pakistani Bomb* (Stanford University Press 2012).

The Republic of Korea

Research Reactors: 1987-2014

The Republic of Korea (South Korea) entered the nuclear market as a potential RR supplier in 1987, when construction started on its first indigenous reactor – Hanaro. It is still in use, which makes South Korea a potential supplier until 2014. The ROK exported a research reactor to Jordan – the Jordan Research and Training Reactor – whose construction began in 2013. South Korea therefore counts as an actual RR supplier for 2013 and 2014.

Power Reactors: 1997-2014

The Republic of Korea enters the nuclear market as a potential NPP supplier in 1997, when it started building a nuclear power station based on a Korean design at Hanbit-5 and 6. By the time these two NPPs are connected to the grid (in 2001 and 2002, respectively), South Korea becomes an actual nuclear supplier, signing a deal with North Korea for the construction of a nuclear power reactor. After the deal fell apart in 2002, South Korea found another customer - the United Arab Emirates – where it started building power reactors in 2012. South Korea has expanded the number of indigenously-designed nuclear power stations on its own territory, peaking at 12 in 2014. The existence of domestic NPPs, together with the exports to UAE make the ROK qualify for the status of supplier between 1997 and 2014.

Enrichment and Reprocessing: 1979-1982; 1996-2014

South Korea enters the dataset as a potential ENR supplier in 1979, when a chemical enrichment laboratory at KAERI became operational. The year when construction started at this facility remains unknown so South Korea could potentially be counted as a potential ENR supplier earlier than 1979. Seoul then developed a hot cell laboratory at KAERI in the early 1980s, and a pyroprocessing plant in cooperation with the US in 1996. As a result of the gap between the moment when the chemical enrichment and hot cell laboratories were shut down, and when construction of the pyroprocessing plant started, South Korea loses the status of potential ENR supplier between 1982 and 1996. As the pyroprocessing plant is currently operational, I code South Korea as a potential ENR between 1996 and the end-year of the dataset – 2014. South Korea did not export ENR technology to other countries, which is why I do not code it as an actual supplier.

Selected Bibliography:

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Benjamin K. Sovacool and Scott Victor Valentine, *The National Politics of Nuclear Power: Economics, Security, and Governance* (Routledge, 2012).

Iraq

Enrichment and Reprocessing: 1981-1991

I code Iraq as a potential ENR supplier between 1981 and 1991, when Baghdad built and operated five indigenously developed facilities at Al Tuwaitha, covering both enrichment and

reprocessing. Several of these facilities were destroyed during the First Gulf War, while others were shut-down before the US-led military intervention. Iraq did not export ENR technology to other countries, which means it does not qualify for actual ENR supplier status.

Selected Bibliography:

Målfrid Braut-Hegghammer, *Unclear Physics: Why Iraq and Libya Failed to Build Nuclear Weapons*, Cornell Studies in Security Affairs (Ithaca, NY: Cornell University Press, 2016).

The Democratic People's Republic of Korea

Research Reactors: 2007

I code North Korea as an actual RR supplier in 2007, when it started building a research reactor at Dair Alzour in Syria. An Israeli military strike destroyed the facility in September 2007, marking the end to North Korea's status as a RR supplier.

Enrichment and Reprocessing: 1983-1993; 2003-2009

I code North Korea as a potential ENR supplier between 1983 and 1993 and again between 2003 and 2009, when the indigenously-built Radiochemical Laboratory in Yongbyon was operational. North Korea did not export ENR facilities to other countries, and therefore does not qualify for actual supplier status.

Selected Bibliography:

Joshua Pollack, "North Korea's Nuclear Exports: On What Terms?," *38 North*, Special Report, October 14, 2010.

Belarus

Research Reactors: 2000-2014

I count Belarus as a potential RR supplier starting in 2000, when construction on its first indigenous subcritical assembly – the Yalina-Thermal – began at the Joint Institute for Power and Nuclear Research. Another subcritical assembly – Yalina-Booster – and a critical assembly – Hyacinth – are in use in Belarus, which makes it a potential RR supplier until 2014. Belarus has not exported any RR technologies, which means it is not coded as an actual RR supplier.

Selected Bibliography:

A. Y. Zelinsky et al., NSC KIPT Neutron Source on the Base of Subcritical Assembly Driven with Electron Linear Accelerator, Proceedings of IPAC2013, Shanghai, China.

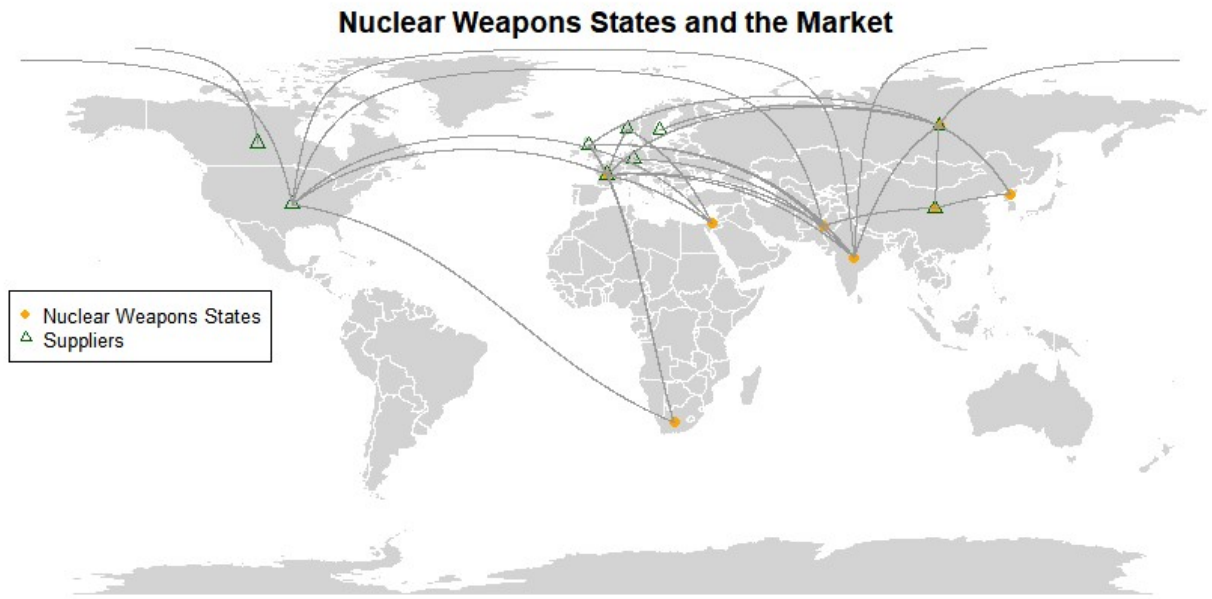
Ukraine

Research Reactors: 2013-2014

Ukraine became a potential RR supplier in 2013, when it started building a subcritical assembly – KIPT Experimental Neutron Source - in cooperation with the United States. The facility, although not yet in use, keeps Ukraine in the potential suppliers category until the end-date covered by this dataset – 2014. Ukraine does not count as an actual RR supplier because it has not yet exported any RR technologies to other countries.

Nuclear Weapons States and Supplier Competition

Based on the primary and secondary materials mentioned above, I identified the NWS which acquired nuclear technology and materials on the global market and traced their efforts to play suppliers against each other. These negotiations are depicted in Figure 2.



A select list of these negotiations, together with those between aspirants, hedgers, and suppliers, can be found in Table 1.

Table 1 - Proliferators vs. Suppliers

Proliferators	***Suppliers***
USSR	US + UK vs. France vs. Sweden vs. Austria vs. Czechoslovakia
France	US + UK vs. Russia vs. Norway
China	USSR vs. France
Israel	US vs. France vs. Norway
India	US vs. USSR vs. Canada vs. France vs. UK
South Africa	US vs. UK vs. France
Pakistan	US vs. France vs. West Germany vs. Belgium
North Korea	USSR vs. China
Japan	UK. vs. US vs. France vs. USSR
West Germany	UK. vs. US vs. France vs. Italy
Italy	US vs. France + Germany vs. Canada
Sweden	Norway vs. US vs. France vs. USSR
Switzerland	US vs. UK
Australia	US vs. UK vs. France
Argentina	US vs. the Netherlands vs. Canada
Brazil	US vs. West Germany vs. France
Iraq	US vs. USSR vs. France vs. Italy vs. Netherlands
Iran	US vs. Canada vs. France vs. West Germany
Libya	USSR vs. UK vs. West Germany vs. France vs. Canada vs. US
Egypt	US vs. USSR
Algeria	Belgium vs. US vs. Argentina vs. France
Saudi Arabia	US vs. Russia vs. China vs. South Korea
Taiwan	US vs. Canada vs. France

South Korea	US vs. Canada vs. France vs. Belgium
Yugoslavia	US vs. USSR vs. Canada vs. France
Romania	US vs. France vs. UK vs. West Germany vs. Sweden vs. Canada
Indonesia	US vs. USSR vs. PRC