10-2009

The Response to Nuclear Proliferation

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Paper presented at the ISSS/ISAC Annual Conference, Monterey, CA, October 15-17 2009

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Abstract: This paper uses the methods of social network analysis to discover the structural patterns of cooperation that arose in response to a global traditional security problem. It does this by mapping compulsory and institutional power relations (Barnett and Duvall 2005) among actors responding to the proliferation of nuclear weapons since the end of the Cold War. For the institutional power measure, I use treaty and international agreement membership; and for the compulsory power measure, I use contractual obligations for nuclear expertise, materials, and technology. By mapping the relationships at the system level of world politics, including individual states as well as intergovernmental organizations (IGOs), transnational nongovernmental organizations (NGOs), and transnational corporations (TNCs), this paper finds a third relation among these actors, namely, structural power. It also demonstrates how a network approach to the constitution of system level world politics can produce knowledge not available to traditional methods.

An Untenable Situation

They spoke so often of the dead
in the Ostrogodo family
that a strange thing happened,
one worthy of being recorded.

They used to speak of the dead
all day around the fireplace,
of cousin Carlos, of Felipe,
of Carlota, the deceased nun,
of the entombed Candelario,
in short, they never stopped recalling who was not
alive.

Then, in that house of dark patios and orange trees,
in the sitting room with the black piano,
in the hallways like crypts,
the many dead settled in
and made themselves at home.

Slowly, like drowned souls
in gardens of ashen light
they swarmed like bats,
they folded like umbrellas
to sleep or to meditate
and left on the armchairs
the acrid odor of a tomb,
a soft breeze that invaded the house,
an insufferable silken fan
the color of a shipwreck.

The Ostrogodo family rarely if ever dared to
breathe:
so pure was their respect
for the appearances of death.

And if the dispossessed suffered,
nobody heard a whisper.

(After all, speaking of economics
that silent invasion
didn't cost them a cent:
the dead do not drink or smoke,
and no doubt this was a plus:
but in truth they began to occupy
more and more parts of the house.)

They hung from the draperies,
they sat in flower vases,
they fought over
don Filberto Ostrogodo's easy chair,
and they occupied the bathrooms
for hours, perhaps polishing
the teeth in their skulls:
the fact is, the family
retreated from the fireplace,
from the dining room, from the beds.

And to keep their dignity
they all went into the garden
without complaining to the dead,
a sad cheer on their faces.

In the shade of an orange tree
they ate like refugees
from the perilous front
of a lost battle.
But even there they came
to hang from the branches,
those serious and circumspect dead
who considered themselves superior
and never stooped to speak
to the goodly Ostrogodos.

Until from all their dying
they joined the others,
becoming silent and passing away
in that mortal house
that one day was left with no inhabitants,
without doors, or house, or light,
without orange trees or the dead.

- Pablo Neruda, translated by William O'Daly

Introduction:

It could be considered standard procedure to begin a piece on nuclear weapons with an apocalyptic quote from the Bhagavad-Gita or some other religious work. However, the poem "An Untenable Situation" from Pablo Neruda, written during his final battle with cancer, strikes me as more appropriate. It describes the half-hearted battle fought against an insidious invader; yet in the final scene, once the battle is lost, no one has actually won—without the living to remember, the dead are gone as well. Similarly, "nuclear proliferation" as a subject is more subtle while still being sinister, unlike "nuclear weapons," which is fairly spectacular.

President Obama called for total nuclear disarmament in his April 2009 Prague speech; but many observers believe that proliferation is inevitable (Andelman 2009). A key question for policy makers then is can proliferation be managed, as one would manage a deadly disease? To switch metaphors, a pessimist would agree with O'Neil (2005) and insist it is better to learn how to prune than to try to slash and burn one's way through the forest. To that end, studies such as Newnham (2004) suggest that intentionally manipulating ties bears fruit for states.

Before one can ask if proliferation can be managed, it is important to understand what is meant by "proliferation," and what actors are involved. Proliferation should be understood as encompassing the acquisition of fission bombs delivered by missiles, improvised nuclear devices (IND) and radiological devices or "dirty bombs," conventional explosives that spread radiological material on detonation (US Nuclear Regulatory Commission 2007). Proliferation therefore includes not just states, which are to date the only entities capable of creating nuclear weapons, but also terror groups such as al-Qaeda. Building a bomb is well within the capabilities of terrorist groups, whereas enrichment is not. What they need is highly enriched uranium (HEU) from the fuel cycle, which is available from both research reactors and medical use isotopes (Kahn 2008, Hansell 2009).

As Hansell points out about nuclear treaties, "it is not clear how the international agreements interact, thus gaps or overlaps are possible. Further, not enough has been done to implement the agreements domestically" (Hansell 2009, 158). This paper therefore seeks to make the interrelationships explicit and visible, because lack of connection as well as duplication of effort can be seen with greater precision, thus allowing decision-makers to concentrate their efforts.

Networks in Nuclear Nonproliferation

The response to nuclear proliferation embodied in many treaties involving hundreds of states demonstrates global governance in microcosm—how a global problem is addressed in a decentralized world. States cooperate, exchanging information and expertise, in order to prevent the spread of nuclear weapons and the threat of nuclear terrorism. Despite the fact that this is the highest of "high politics" of military and security affairs (Keohane and Nye 2001), this network also involves actors that are more usually thought of in terms of the "low politics" of a human security political frame (MacFarlane and Khong 2006). The official nuclear "haves" attempt to halt nuclear proliferation—a case of traditional national security, where states have attempted to control knowledge that has both peaceful and deadly uses. In a way, it is the highest of high politics: nuclear weapons are the subject of the most powerful taboos in international relations (Tannenwald 2005). The outing of the A.Q. Khan network in Pakistan has demonstrated that it is no longer enough to rely on the difficulty of the process of enriching and weaponizing uranium (or reprocessing and weaponizing plutonium), nor on the idea that only states can (currently) command such resources to prevent proliferation. While both are true, it is also true that customers need not make the product from scratch, they need only buy or steal it in order to use it.

Such "heteropolarity," (Der Derian 2004) or different types of actors, is also seen in global nuclear networks. Globalization has made this process easier and speedier than it was

previously, and it has introduced new actors: it is no longer a question only of rogue states gaining access to these weapons through espionage or the weakness of state supervision and management, but also criminal groups and terrorists gaining access (Russell 2008).

The organization of these actors is for the most part, not self-organized, which has implications for its effectiveness. In a human security frame, the network is more likely to be self-organized, meaning the number of actors, as well as the type of actor involved could be increased, allowing for an openness and transparency that could be met by communication among the actors. This in turn allows accountability: progress, or lack thereof, could be openly tracked through the media as in the case of the Indian Ocean tsunami of December 2004 (Telford and Cosgrave 2006), or through nongovernmental organizations such as the World Nuclear Association. A network that is more formally organized, by treaties and executive agreements, may be more stable and permanent, but it is likely to be less open, and more rigid in responding to new attempts at proliferation.

States in the nonproliferation network, by attempting to hold onto their *de jure* authority, may be denying the network as a whole the flexibility and transparency it needs to counter proliferation: "The relationships between the DPRK [North Korean] and Khan networks show the shifting roles that ring members may play, with the DPRK acting on different occasions as a buyer, seller, and supplier to mutual partners" (Braun and Chyba 2004). Stopping or at least controlling proliferation is important; as Sagan explained, more nuclear states will be worse for the world. Novice nuclear states lack either adequate military or civilian political organizational controls, and therefore have a high risk of either deliberate or accidental nuclear war. Deterrence strategy took the U.S. and U.S.S.R. years to work out; many new nuclear states seem completely unaware of the depth of thinking necessary. Furthermore, deterrence may not work, because novice nuclear states' capability may not survive to make a second-strike (Sagan and Waltz 1995).

Today, the world sees the convergence of three interrelated trends. First is the global international political economy trend toward privatization at the expense of state authority known as the Washington Consensus (Williamson 1990, Crouch and Streek 1997, Cerny 1997, Crouch 2004, Bremmer 2009). The second trend is a rise in the price of energy from traditional sources, and the consequent renewal of interest in nuclear energy—the "nuclear renaissance" (Carey, et al 2004, Thakur, et al 2008). The plans for new nuclear power plants in the UK demonstrate these two trends: they are intended to be private industry, not state-controlled or even state-subsidized (Smedley 2008). The third and final trend is the existence of actors that are structurally similar to reputable companies in the nuclear fuel cycle in terms of the contracts they have with others, but that do not adhere to a code of conduct. The tacit knowledge gained from civilian nuclear activities (Montgomery 2008) is likely to encourage the proliferation of nuclear weapons to states (Fuhrmann 2009), and may also enable the acquisition of WMD by terror groups. These actors are weak links in the fuel cycle, and the most likely place for terrorists to deal, whether by attack or through the black market.

Nonstate Actors in Nonproliferation Networks

State behavior may be the beginning of the nuclear story, but it is not the end. For example, the World Association of Nuclear Operators (WANO) was formed following the Chernobyl accident, in order to create a "culture of openness" (http://www.wano.org.uk) between operators—thus ensuring best practices are developed and adhered to, and that nuclear power continues to be profitable. Nuclear power will not be profitable if the perceived threat to people's security is so great as to preclude its use. However, recent events in global finance have called into question the ability of many companies to strategically plan in such a way as to not poison the well from which they drink. When it comes to the bottom line, in other words, too many companies think only of the short term bottom line.

Not everyone is as willing to provide public goods as Warren Buffet apparently is. Peter Singer wrote in *The New York Times* that Buffet had pledged $50 million to assist in the establishment of the International Atomic Energy Agency's "fuel bank," which would supply nuclear-reactor fuel to countries that meet their nuclear-nonproliferation commitments. The theory behind the fuel bank is that it will dissuade countries from building their own facilities for producing nuclear fuel, which would make it easier to reroute it to weapons production. "It is, Buffett said, 'an investment in a safer world.' Though it is something that governments could and should be doing, no government had taken the first step" (Singer 2006).

Authors such as Eilstrup-Sangiovanni (2005) have noted that states are increasingly cooperating in network forms as a response to such "dark" networks. However, anecdotal evidence suggests that networks composed merely of states will not be enough to prevent proliferation – they are not flexible or innovative enough. Moreover, they do not target the weak points of state proliferation networks, because their solutions are one-size-fits-all and not based on network topography (Montgomery 2008).

States will always be playing catch-up to other, networked, actors that are capable of penetrating or co-opting the state (Naim 2005). In order to gain the upper hand, they must coordinate their efforts with other actors with the same goals. This would mean working with other actors, and not just in a hierarchical relationship, such as that existing between states and the businesses involved in building and/or exporting nuclear-industry components, or IGOs such as the IAEA. It would also mean collaborating with NGO watchdog groups such as the Federation of American Scientists, and even individuals such as Mark Hibbs, a reporter for Nucleonics Week and Nuclear Fuel (Langewiesche 2006). Both Naim and Langewiesche point out the importance of including nonstate actors in networks: they do not face the same constraints as states, so their efforts can be complementary to those of states.

Nonstate actors in the nuclear nonproliferation network either provide information, as do the groups and individuals indicated above, or the actual materials required in the manufacturing process; including transnational corporations such as General Electric and Toshiba. As Apanasenko writes, "the term 'nuclear security' needs to be treated more broadly, with the understanding that it includes real security as it relates to the production and utilization of nuclear components both in the military and in the civilian sectors, as well as security in general" (Apasenko 2009). Mowatt-Larssen writes: "Developing a collective security consciousness demands an acknowledgement that there is no such thing as nuclear security, and thus, a fatal lapse of security at any site in any country would affect everyone" (Mowatt-Larssen 2009).

Six brief examples, of varying importance, will serve to demonstrate the issue.

- In Uranium: war, energy, and the rock that shaped the world, Tom Zoellner details the ludicrously poor security at uranium mining sites such as Shinkolobwe in the Democratic Republic of the Congo, source of much smuggled uranium (Zoellner 2009).
- In 2007, South Africa's Pelindaba nuclear research site was attacked by four armed intruders. They penetrated several layers of security in a facility "that contains an estimated 25 bombs' worth of weapons-grade nuclear material," shooting and wounding one worker (Zenko 2007).
- In the United States, Florida Power & Light was fined by the Nuclear Regulatory Commission when their security subcontractor Wackenhut failed to report or equip employees as required at the Turkey Point plant (Agency Group 05 2008).
- Prosecutors in New York have indicted an executive from the Limmt Economic and Trade Company, a Chinese company, for selling tungsten, high-strength steels and exotic metals to the Defense Industries Organization, a subsidiary of the Iranian military, from 2006 to 2008 (Eligon and Broad 2009).
- The West Valley Nuclear Services Company's website (www.wvnsco.com) has been vandalized. (WVNS was a subsidiary of Washington Group International, which is now part of URS and known as URS Washington.)
- And most recently, a French nuclear physicist at CERN has been arrested on suspicion of links to al-Qaeda. His work, however, reportedly did not bring him in contact with dangerous materials (Spotts 2009).

The United Nations Security Council's Resolution 1540, with its attendant committee and follow-up procedures, is a good start at making sure states are held accountable for the business conducted within their borders (Nuclear Threat Initiative 2009). But sovereignty is only absolute in a perfect world; in this one, states will never be able to police everything, all the time. Reacting quickly and appropriately after the fact is not enough—prevention is key.

Because there is such heteropolarity in actors, these networks are better studied by looking first at the relationships among actors. By focusing on the type of tie, rather than the type of actor, one can get a more complete picture of the ecosystem. This is analogical to ecological studies that, for example, study trophic roles (feeder/food relationships) and positions in food webs. Rather than simply studying one species at a time, ecology studies holistic systems (Luczkovich et al 2003, Ostrom 2007). Mapping these relationships among actors is best done with the methods of social network analysis.

Social Network Analysis Methodology

Networks are complex systems -- a type of relationship among multiple actors. They are composed of actors who have agency: the ability to act and react. Depending on the framing of the issue area (peace and security, human rights, international trade, economic development, and environment are all examples of issue areas in world politics), network actors include states, sub-state governmental units (such as a ministry or provincial government), IGOs, NGOs, TNCs, social movements, and individuals. Complex systems are also subject to interaction effects. In systems that are tightly coupled, processes happen very fast, they cannot be turned off, and the failed parts cannot be isolated from other parts, making recovery from initial disturbance

impossible – it spreads quickly and irretrievably. This is called a "normal accident," meaning that the system will inevitably produce such accidents. The opposite is a loosely coupled system, in which elements are involved in the same production sequence, but one element does not cause the other (Perrow 1984). Such a system is robust. If networks are tightly coupled, they will exhibit dense, strong links among actors. For example, interactive complexity and tight coupling in nuclear weapons leads to "normal accidents," a situation that will be made worse by small, weak and unstable states (Sagan and Waltz 1995).

"Network" refers to both interorganizational structure and function. The relationship between actors may be financial, legal, social, or whatever. (The actor need not be aware of a particular relationship for the link to exist.) The number of actors varies, but cannot be infinite: there is a practical limit to how many discrete actors can interact without some form of aggregation.

In order to model global networks, mathematical tools are necessary. Social Network Analysis (SNA) is the best method for exploring the social structures that result from global interactions because it makes possible the measurement of interactions, rather than of actor attributes. Network theory is an ontological question; network analysis is an epistemological stance. The social network analysis perspective includes the following aspects: actors and their ties are interdependent rather than independent, autonomous units; ties between actors are channels for the flow of information and resources; network ties both enable and constrain actions; and structure is viewed as enduring patterns of relations among actors (Wasserman and Faust 1994). The most important aspects of the social network paradigm are that it is concerned with structure, which is relational; it is based on empirical evidence; it is graph theoretical, which is visual; and it embodies a formal, statistical model.

SNA allows analysis of both the big picture, as well as local conditions. Techniques such as blockmodeling in particular can map the way different actors may play structurally similar roles in networks (White, et al 1976, Luczkovich, et al 2003). SNA also allows the tracking of multiple relationships among different types of actors and among different levels of analysis, without losing coherence. SNA may reveal properties of networks that are not visible through other methodologies, such as gaps and overlaps. Without forgetting that each individual relation is a demonstration of agency on the part of the actors in the dyad, a network map as a whole can be "the starting point from which strategic planning for social transformation has to begin" (Cox 1999). Knowing the structure of the prevailing social forces (which both enable and constrain action) allows actors more freedom of agency: knowing *where* to influence is vitally important to being able to exercise influence at all. Furthermore, social network analysis methods allow the dynamic mapping of networks over time.

In order to use SNA, there must be evidence of specific interactions and relations among actors. In the following section, the two power relations measured in this study, institutional and compulsory, are explained.

Power Relations

Network terms can be translated into international relations via the measures of power in global governance described by Michael Barnett and Raymond Duvall. They divide types of power into a matrix with two core dimensions: the kinds of social relations through which power works, and the specificity of the social relations through which power's effects are produced (Barnett and Duvall 2005).

The first kind of power, familiar to realists, is compulsory power that represents direct control of one actor over another. This can be measured in network terms in many ways: as a regulatory relationship with one party making and enforcing rules, as a contractual relationship with an exchange of goods or services for payment, or a conflictual relationship with one party using violence against another. Institutional power is more diffuse because actors exert control over others that are socially distant. Membership in an alliance, attendance at UN conferences and other types of affiliations are network relations that measure this type of power. Structural power represents the capacities of actors—in other words, what they are depends on where they are in the network. Finally, productive power is the production of subjects through the diffuse social relations of discursive practices. To paraphrase, an actor's "self" is a creation of discourse, or negotiation with and against multiple others. This can be measured longitudinally by process tracing that links diffusion of norms and ideas to actor constitution—that is, it is helpful to track the progress of an idea through the network, and then look for evidence that the actors' identities have changed as a result.

Networks could thus be demonstrated by treaties, executive agreements, and interorganization agreements, etc., to share resources and information. They could also be demonstrated by presence at decision-making meetings, and influential publications. The evidence of relationships can be quantified and directed. For example, in the case of contractors: the amount of the contract is interval data, and it flows from a source to a recipient (not the other way around). Such information is available in contemporary media reports. This paper maps two types of power relations, in hopes of discovering interesting information about the structural power relationship.

Each treaty accession, contract, and agreement is a painstakingly negotiated political activity; however, the goal here is not to look at the negotiations themselves but at the structure or international environment that together they create. For this study, I will be using the following sources of network information: the non-proliferation treaties and international agreements, and contracts among nuclear energy suppliers. The first is an example of institutional power through the sharing of information, while the second is an instance of the compulsory power of financial contracts.

A. The Institutional Power Relation

For this investigation, I will be using treaty and agreement ties among states where the primary purpose of the agreement is the nonproliferation of nuclear weapons. For this paper, a selection of organizations and treaties has been made in the interests of probing the plausibility of the argument. The inventory provided by the CIA World Factbook will be considered the authoritative source for agreements between states. These interactions were recorded as undirected ties, because they did not have a beginning and end. They indicate the sharing of

information and cooperation to coordinate activities. Furthermore, these ties were recorded as dichotomous, and not weighted in any way—either two actors cooperated by participating in the same organization, or they did not. These treaties and agreements are detailed in Box 1.

Box 1: Selected Treaties and International Agreements Concerning Nuclear Nonproliferation

Name	Organization Type	Purpose
Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (OPANAL)	Regional international organization	Aim - to encourage the peaceful uses of atomic energy and prohibit nuclear weapons in South America
Antarctic Treaty	Regional regime	Aim - to encourage the peaceful uses of atomic energy and prohibit nuclear weapons on the continent of Antarctica
Comprehensive Test Ban Treaty (not yet in force)	Multilateral treaty	aim - to prohibit nuclear (weapon) test explosions
Group of 6 (G-6)	International organization	Aim - to achieve nuclear disarmament
International Atomic Energy Agency (IAEA)	International organization	Aim - to promote peaceful uses of atomic energy
Nuclear Suppliers Group (NSG)	Nonproliferation export control regime	Aim - to establish guidelines for exports of nuclear materials, processing equipment for uranium enrichment, and technical information to countries of proliferation concern and regions of conflict and instability
Treaty of Bangkok	Regional treaty (nuclear-weapon-free-zone)	Aim - to encourage the peaceful uses of atomic energy and prohibit nuclear weapons in Southeast Asia
Treaty of Pelindaba (not yet in force)	Regional treaty (nuclear-weapon-free-zone)	Aim - to encourage the peaceful uses of atomic energy and prohibit nuclear weapons in Africa
Treaty of Rarotonga	Regional treaty (nuclear-weapon-free-zone)	Aim - to encourage the peaceful uses of atomic energy and prohibit nuclear weapons in the South Pacific
Nonproliferation of Nuclear Weapons Treaty (NPT)	Multilateral treaty	Aim - to encourage the peaceful uses of atomic energy and prohibit the spread of nuclear weapons globally
Zangger Committee (ZC)	Nonproliferation export control regime	Aim - to establish guidelines for the export control provisions of the Nonproliferation of Nuclear Weapons Treaty (NPT)
Proliferation Security Initiative	International Agreements	Aim – to interdict trafficking of weapons of mass destruction (WMD), their delivery systems, and related materials

The resulting network is a snapshot of all the treaties and agreements that are pending or are in force at this time. Since treaties are so difficult to negotiate, states rarely disengage from treaties; so in a very important sense, this network is also cumulative. The information on membership per treaty or organization was put into a two-mode state-by-treaty matrix, with a dichotomous tie/no tie relationship recorded. This network was then transformed into an affiliational state-by-state matrix (meaning that if states were participants in the same treaty, they were recorded as having a tie to each other).

B. The Compulsory Power Relation

An organization that has control over material resources such as nuclear plant, materials and expertise is influenced by an organization that is requesting the use or ownership of the resources. Perhaps even more important to international life than *pacta sunt servanda* ("treaties must be obeyed") is the principle that contracts must be enforced. After all, there are far more contracts negotiated and signed than treaties. The tacit knowledge gained from civilian nuclear activities (Montgomery 2008) is likely to encourage the proliferation of nuclear weapons to states (Fuhrmann 2009), and may also enable the acquisition of WMD by terror groups.

For the purpose of this investigation, it was also important to count only signed contracts, and not pledges or agreements on future cooperation. However, the data sources for contracts are less comprehensive than for treaties; as a starting point, I have used information culled from the Business Source Premier (now called Business Source Complete) database maintained by EBSCO. The search terms were "nuclear power" and "contracts" and the search was limited by time period (between January 1989 and May 2009), and by the availability of full-text articles. The following types of contracts were recorded as ties: construction, supply, reprocessing, enrichment, decommissioning, decontamination, operation (including software), and transportation of spent fuel or waste.

Network Measurements

All calculations were performed with Ucinet 6 and all images were created using Netdraw (Borgatti, et al. 2002). The compulsory power network consisted of 575 records of financial transactions among 454 distinct actors. These actors were states, companies, state-owned corporations, joint action agencies (joint-action agencies are owned by their members, which are electricity cooperatives), partnerships, joint ventures, academic institutions, nongovernmental organizations (NGOs), intergovernmental organizations (IGOs), and unknown. Actors were coded as state-owned if they were more than 50% owned by a state. The institutional power network consisted of 196 distinct actors related by twelve treaties or agreements. These actors were all states as recognized by the United Nations, with the exception of Taiwan (Republic of China).

Institutional Power Network

The network created by affiliation in treaties is depicted in Figure 1, with a spring embedding layout based on geodesic distances. A spring embedding layout uses iterative fitting starting from a random layout to locate the points in such a way as to put those with smallest path lengths to one another closest in the graph. This graph also uses node repulsion to separate objects enough to read them, and equal edge length to standardize the distances among adjacent objects.

[insert Figure 1 here]

A careful study of the graph will show several promising aspects to nonproliferation treaties: first, most states, even those that do not belong to the major treaties (NPT, IAEA, or CTBT), belong to at least one regional treaty that has as its goal nonproliferation. Second, most

states belong to at least one of the major treaties. However, the pessimistic would note several equally unpromising aspects: there are nuclear weapons states, in particular North Korea, India, Israel, and Pakistan, which do not belong to major treaties with their attendant strengthened enforcement; and there is a state, Taiwan, that is fully capable of developing nuclear weapons and is not party to any treaty at all.

For a valued network such as this (with the value of ties between actors determined by the number of treaties in which both participate), density is defined as the sum of the ties divided by the number of possible ties. The density (matrix average) of the nuclear treaty network is 2.4210, with a standard deviation of 1.3299. According to Hanneman and Riddle (2005) "A social structure in which individuals were highly clustered would display a pattern of high densities on the diagonal, and low densities elsewhere." This indicates that the speed at which information diffuses among the actors is relatively quick, and the extent to which actors have levels of social constraint is relatively high.

The geodesic distance of a network is the number of relations in the shortest possible walk from one actor to another; a walk is a sequence of actors and relations that begins and ends with actors (Hanneman and Riddle 2005). In other words, it measures how "reachable" the actors in a network are to each other. The average distance between reachable pairs is 1.027, and the distance-based cohesion of the graph is 0.976 out of a range from 0 to 1 (larger values indicate greater cohesiveness). This indicates that the network is cohesive. This result has implications for effectiveness at responding to a security threats: networks that are cohesive are likely to communicate well, and should therefore be more likely to share expertise and resources.

Transitivity is "a property that considers patterns of triples of actors in a network or triples of nodes in a graph" (Wasserman and Faust 1994). A relation is transitive if every time there is a tie between actor A and actor B, and a tie between actor B and actor C, there is also a tie between actor A and actor C. It is thus a measure of structural balance in a group. 93.09% of all triads in this network are transitive—of all the triad relations that could be transitive in this network, 99.04% are actually transitive. These scores indicate a relatively high level of cooperation among states in this set of treaties; if a state is a participant of one treaty, it is very likely to participate in another.

In a network graph, the degree centrality of the actors indicates the number of direct connections among them (Wasserman and Faust 1994), and the highest and lowest ten scores are given in Table 1. The highest and lowest ten scores for closeness centrality, indicating the shortest paths to all other actors, is given in Table 2 (Wasserman and Faust 1994).

Table 1: Degree Centrality

	Actor	Degree
1	Australia	99.48718
2	New Zealand	99.48718
3	Argentina	98.97436
4	Austria	98.97436
5	Belgium	98.97436
6	Brazil	98.97436
7	Bulgaria	98.97436

Table 2: Closeness centrality

	Actor	Closeness
1	Australia	50
2	New Zealand	50
3	Argentina	49.87212
4	Austria	49.87212
5	Belgium	49.87212
6	Brazil	49.87212
7	Bulgaria	49.87212

8	Chile	98.97436
9	Czech Republic	98.97436
10	Denmark	98.97436
188	Swaziland	96.41026
189	Timor-Leste	96.41026
190	Trinidad and Tobago	96.41026
191	Israel	80.51282
192	India	74.8718
193	Pakistan	73.84615
194	Cook Islands	72.30769
195	Democratic People's Republic of Korea	18.46154
196	Niue	6.153846
197	Taiwan (Republic of China)	0

8	Chile	49.87212
9	Czech Republic	49.87212
10	Denmark	49.87212
188	Swaziland	49.24242
189	Timor-Leste	49.24242
190	Trinidad and Tobago	49.24242
191	Israel	45.66745
192	India	44.52055
193	Pakistan	44.31818
194	Cook Islands	44.01806
195	Democratic People's Republic of Korea	35.58394
196	Niue	34.09091
197	Taiwan (Republic of China)	NA

Closeness centrality approaches emphasize the distance of an actor to all others in the network by focusing on the distance from each actor to all others, so that actors that are locally central (those that are connected to many others, but the others are not connected to the larger graph) do not get as high a score as they do in degree centrality. In this case, it turns out that the measures produce identical results: the same states are at the top and at the bottom of these tables. This is cause for concern, as several of the states with the lowest scores are nuclear weapons states. This suggests that attempts to persuade them to change their behavior through the existing treaty structure will not be successful.

Structural similarity can be determined using regular equivalence. "Actors that are regularly equivalent do not necessarily fall in the same network positions or locations with respect to other individual actors; rather, they have the same kinds of relationships with some members of other sets of actors" (Hanneman and Riddle 2005). In other words, the actors in the equivalence class, or blockmodel (White, et al 1976) share a similar relationship to the actors in the other classes. The actors in one equivalence class have a particular pattern of ties to actors in the other classes, without necessarily having that particular pattern of ties to the *same* actors in the other classes. For example, actor A is the son of actor B, and actor C is the daughter of actor D; with actors A and C in the class of "child" and actors B and D in the class of "parent." The blockmodel results are contained in Table 5.

Table 5: Equivalence Classes in the Nuclear Treaty Affiliation Network

Equivalence Class	Actor
1	Afghanistan, Andorra, Antigua and Barbuda, Bahamas, Bahrain, Barbados, Belgium, Niue
2	Argentina, Australia, Austria, Finland
3	Albania, Brazil, Tuvalu
4	Algeria, Bulgaria, Cook Islands, Nepal
5	Taiwan (Republic of China)
6	Armenia, Chile, Fiji, Lebanon
7	Angola, Azerbaijan, Bhutan, China, Kiribati
8	Bangladesh, Democratic People's Republic of Korea, Nauru
9	Belarus, Cuba, New Zealand, Pakistan
10	Belize, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brunei Darussalam,

	Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Colombia, Comoros, Republic of the Congo, Costa Rica, Côte d'Ivoire, Croatia, Cyprus, Czech Republic, Democratic Republic of the Congo, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Holy See, Honduras, Hungary, Iceland, India, Indonesia, Islamic Republic of Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Latvia, Lesotho, Liberia, Libyan Arab Jamahiriya, Liechtenstein, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Federated States of Micronesia, Moldova, Monaco, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Netherlands, Nicaragua, Niger, Nigeria, Norway, Oman, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Republic of Korea, Romania, Russian Federation, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, Sudan, Suriname, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Thailand, The former Yugoslav Republic of Macedonia, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland, United Republic of Tanzania, United States of America, Uruguay, Uzbekistan, Vanuatu, Bolivarian Republic of Venezuela, Viet Nam, Yemen, Zambia, Zimbabwe

The equivalence classes again point out the danger that many nuclear weapons states are in separate blockmodels. Also, there are states in these blockmodels that have indigenous nuclear capabilities, either for research, power generation, or both.

Problems with the data include the fact that not all treaties are equal, although this analysis has presented them as such. There are significant differences in enforcement, funding, and so on, that have not been accounted for. Also, there are other treaties that might be relevant to nonproliferation endeavors, such as the Convention on Nuclear Safety and the Convention on the Physical Protection of Nuclear Material. To get a more complete picture, these treaties should also be added to the dataset. However, these findings demonstrate that a network analysis of nuclear nonproliferation networks is plausible, as it is capable of showing in quantified form what is already known from more qualitative studies. To find out what else it is capable of, I turn to a different relation, compulsory power.

Compulsory Power Network

The network created by contracts is depicted in Figure 1, again using a spring embedding layout with node repulsion and equal edge length. In this image, the organization types are also visible.

[insert Figure 2 here]

Organization types represented by color are states, companies, state-owned corporations, joint action agencies, partnerships, joint ventures, academic institutions, nongovernmental organizations (NGOs), intergovernmental organizations (IGOs), and unknown. The arrowheads

indicate the direction of the contract, while the thickness of the tie indicates the number of contracts between those two actors. Finally, circles indicate that the actor is a member of the World Nuclear Association; squares indicate that the actor is not a member. The WNA is a global nuclear energy industry professional organization that has a commitment to nonproliferation in its Charter of Ethics. Actors can become members of the WNA only by a majority vote of the membership, making it more likely that only actors who demonstrate commitment to this principle will be accepted.

Again, density is here defined as the sum of the ties divided by the number of possible ties, with the value of ties between actors determined by the number of contracts in which both participate. For the compulsory power network, the average density was 1.0708, with a standard deviation of 0.3487. This is a lower density than the institutionally power relation; not only should this be expected, but it is probably an over-estimation of density, as the dataset covers a twenty-year period in which not all ties were present at all times.

Again, the geodesic distance is the number of ties in the shortest path between each pair of nodes. For the network of contracts, the average distance was 1.000, while the distance-based cohesion was 1.000 (again, a range from 0 to 1, with larger values indicating greater cohesion). This would seem to indicate that the network is extremely cohesive, with most actors "next" to each other.

The transitivity of this network is much higher than that of the nuclear treaties, with 100% of all triads in this network are transitive—of all the triad relations that could be transitive in this network, 100% are actually transitive.

The degree centrality measure for this network appears to follow a power law distribution (Barabasi 2003), and is shown in Table 3. The lowest ten actors in degree centrality are not given because the lowest score of 0.221239 was shared by 287 actors. Similarly, the lowest score 0.221239 for closeness centrality is shared by 37 actors; however, in this case the graph of scores does not follow a power law. Closeness centrality is shown in Table 4.

Table 3: Degree Centrality

	Actor	Type	Degree
1	Westinghouse Electric Co	company	8.40708
2	Chernobyl Shelter Project	IGO	6.637168
3	US Department of Energy	state	6.637168
4	Framatome ANP	state-owned corporation	6.19469
5	Areva	state-owned corporation	5.309734
6	NNSA	state	4.20354
7	UK Atomic Energy Authority	state	3.539823
8	Russia	state	3.318584
9	Shaw Group Inc	company	3.318584
10	Electricite de France	company	3.097345

Table 4: Closeness Centrality

	Actor	Type	Closeness
1	Areva	state-owned corporation	0.974516

2	Framatome ANP	state-owned corporation	0.973739
3	Exelon Corp	company	0.973634
4	Westinghouse Electric Co	company	0.973446
5	US Department of Energy	state	0.973278
6	Electricite de France	company	0.972273
7	Mitsubishi Heavy Industries Ltd	company	0.971562
8	Electrabel	company	0.971228
9	China Guangdong Nuclear Power Co	joint venture	0.97102
10	Tennessee Valley Authority	state	0.970957

This network shows a very different picture of degree and closeness centrality. Degree centrality (again, the number of direct connections between actors) shows a mixture of states and private corporations, with an IGO thrown in for good measure. Closeness centrality (the number of shortest paths to all other actors) shows a different group; the actors that overlap between the two groups are Areva, Framatome ANP, Westinghouse Electric Co, US Department of Energy, and Electricite de France—only one state actor among them. The implication this has for policy is clear: measures that do not have the support of the business community will be difficult to promulgate and enforce.

Another way to discover structural equivalence is through hierarchical clustering. The algorithm in Ucinet proceeds by initially placing each case in its own cluster. The two most similar cases are then combined into a new class. The similarity of this new class to all others is then computed, and the joining/recalculation process is repeated until all cases are aggregated into a single cluster. The "hierarchical" part of the method's name refers to the fact that once a case has been joined into a cluster, it is never re-classified, resulting in clusters of increasing size that always enclose smaller clusters (Hanneman and Riddle 2005). These hierarchical clusters show that being different organization types does not hamper certain types of similarity. For example, Areva is a vertically-integrated organization with contracts from suppliers and to customers at every stage of the fuel cycle from mining to plant operation. The other actors in Areva's "class" have similar patterns of ties, whether they are state-owned corporations like Areva or not. The result is too large to show with actor names included, but the dendrogram is shown in Figure 3.

[insert Figure 3 here]

Directions for Future Research

The next steps to take would be to extend the analysis to other actors. In a case study of the humanitarian response to the Indian Ocean tsunami, it was discovered that not only did actors with different attributes play similar roles in the network, but that knowledge of attributes was insufficient to predict structural roles (Kamran, 2009). Information on nuclear nonproliferation network membership begins with membership data from treaties such as the Non-Proliferation Treaty (NPT) and other groups of state actors such as the Nuclear Suppliers Group. However, adding the many businesses (many of them Fortune Global 500 members), academic institutions, IGOs, and NGOs that are involved in the construction and operation of nuclear power plants, as well as production and transportation of nuclear materials, duplicates this finding in an entirely different security frame. The existing dataset of nuclear contracts could be used as a seed to start

a snowball using other data sources such as World Nuclear News and the Mergent Horizon database of companies, their suppliers, and their customers. Evidence of their relationship with each other and with states would also include attempts at regulation.

Furthermore, think-tanks/institutes and activist/interest groups should also be taken into account, as they provide much of the information with which decisions are made by others. NGOs include multinational nuclear research institutions such as the European Organization for Nuclear Research (CERN), and the International Association of Lawyers Against Nuclear Arms (IALANA). Information about NGOs can also be found in the International Affairs Contact Network database maintained by the University of Pittsburgh (http://www.ucis.pitt.edu/iacnet/).

The analysis could also be extended to different levels of analysis to include national programs such as the U.S. Nuclear Data Program, and the problem of nonproliferation programs run by different subnational agencies such as those run by the U.S. Department of Energy versus those run by the Department of Defense (GAO 2005), as well as the investigation of those programs individually, such as the bilateral program with Russia known as the Cooperative Threat Reduction (Nunn-Lugar) program or the Proliferation Security Initiative. Also, probabilities for alternative network structures can be modeled (Wasserman and Faust 1994).

Future research should also take into account dynamics: evidence of different types of change should be sought (Holsti 2004). There are questions to be answered about changes in the nuclear treaty network; for instance, what was the structural impact of North Korea leaving the NPT? The speed of proliferation, and the rate at which a response is constructed, is also likely to have structural affects, which could be investigated with longitudinal network analysis programs such as SIENA (Snijders, et al, 2005) and SoNIA (Bender-deMoll 2006). Does longevity of tie make for a stronger or weaker tie? What is the impact of longevity on flexibility of ties? Do states proliferate if their neighbors in the network (not necessarily their geographic neighbors) do so? There is a correlation between ego and alter behavior in studies of individuals and smoking, obesity, and depression (Christakis and Fowler 2007, Christakis and Fowler 2008, Fowler and Christakis 2008). All of these questions have policy implications, from recommending that more authority and control back in the hands of the state, to developing new ways of holding nonstate actors accountable for their actions.

Conclusion

Expansion of inclusion in the institutional power network may help to explain why there has not been more proliferation over the years. Even as the size and scope of nonstate actors has increased exponentially, proliferation to states and nonstate actors has been uniformly low. The explanation may be tied to the multiple demand-side motives for nonproliferation (Sagan 1996, Liberman 2001, Hymans 2006) such as the needs of national identity, expense of production, and changes in both external threats and domestic regimes. These motives will change now that there are new types of actors. These new actors are more likely to have motives such as profit (as well as prophet). However, I hypothesize that the structural environment or supply-side (Braun and Chyba 2004, Kroenig 2009, Gartzke and Kroenig 2009, Fuhrmann 2009) will change with the changing environment, as the structure that is the flexible and growing compulsory

power network will make proliferation easier in both the compulsory and institutional networks. It seems likely that these complex networks will have nonlinear interaction effects (Jervis 1997).

Based on these findings, the usual way of thinking about nuclear security should be turned on its head. While it is important that these actors have formed networks for the purpose of cooperating to prevent the misuse of nuclear weapons or materials, it is equally important to look at maps of the networks to reveal exploitable weaknesses. The institutional power relation reveals the fact that there are geographic locations that are loosely policed by nuclear nonproliferation treaties, which, coupled with the knowledge of the location's internal politics, could be useful to groups looking for a place to conduct illicit nuclear activities. The compulsory power relation reveals the fact that there are actors structurally similar to each other, and that not all the actors in an equivalence class will belong to a self-policing organization such as the WNA. Terrorist groups looking for materials or expertise could "shop around" for the best fit with their needs.

Finally, these findings support the call for policy-making to be opened up to multiple types of actors, who should also be responsible for enforcement. Companies, NGOs, IGOs, and academic institutions (and so on) are likely to be on the scene, or to have the information and resources needed to prevent proliferation. Just as in Neruda's poem, "An Untenable Situation," the Ostrogodos must put their own house in order—if they wait until the dead to take over, it will be too late.

Figure 1: “nt spring embedding nuclear powers.jpg”

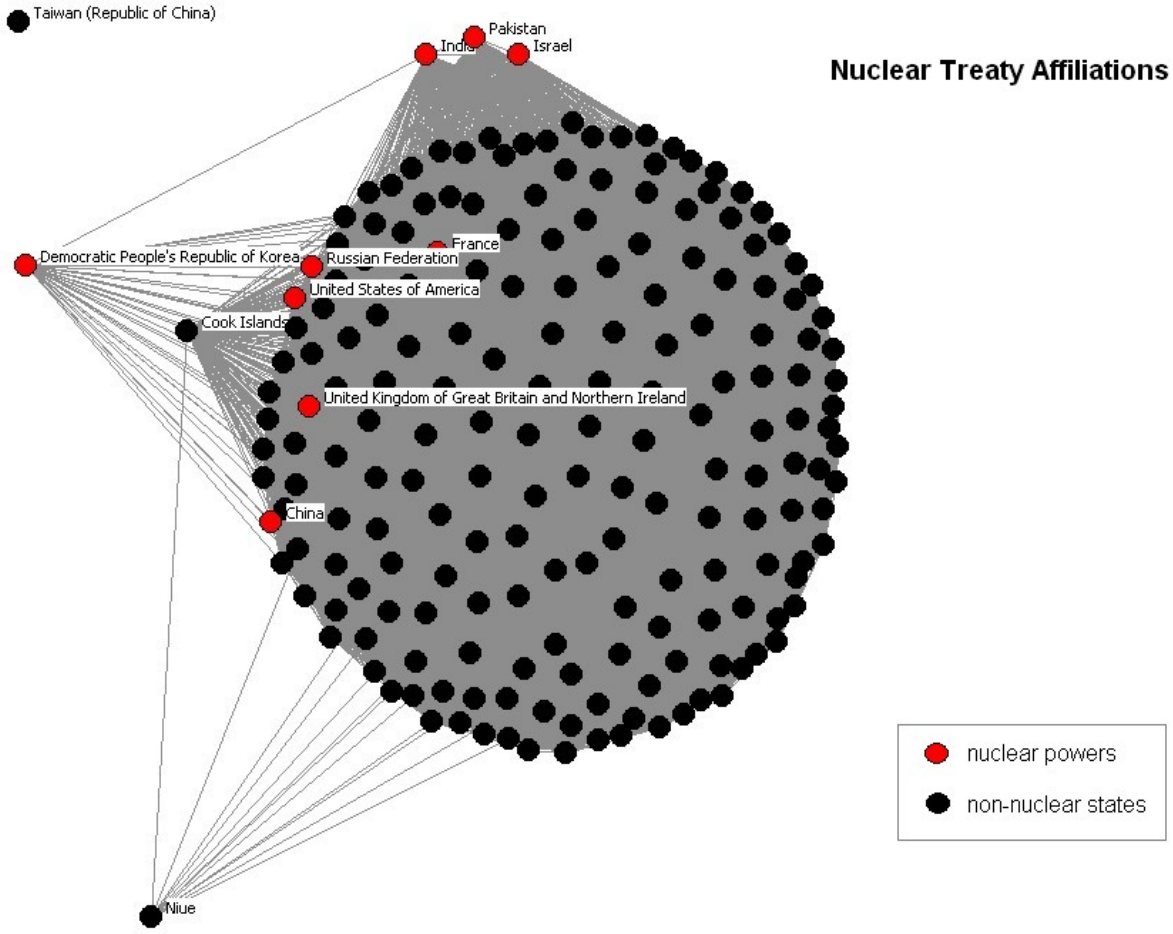


Figure 2: “nc spring embedding type WNA tie strength.jpg”

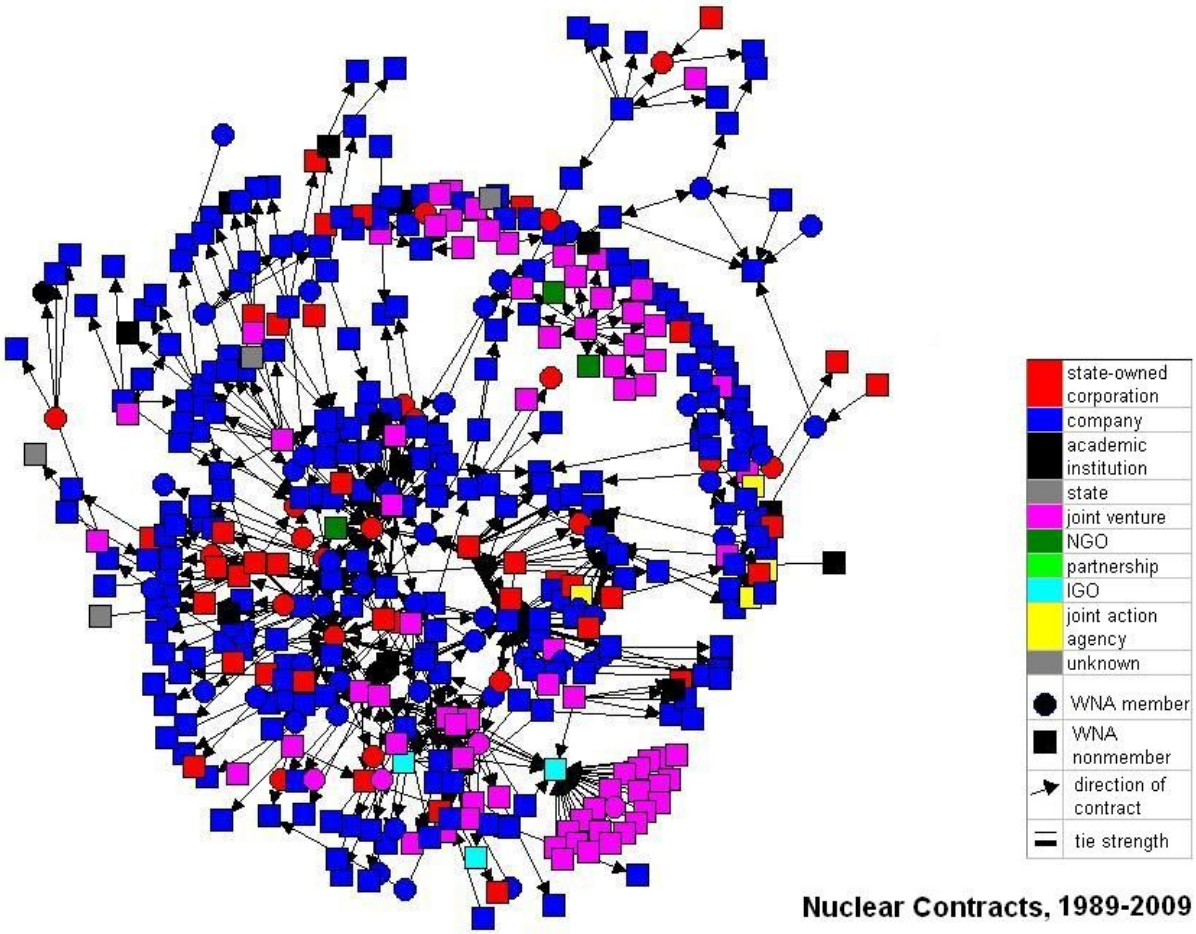
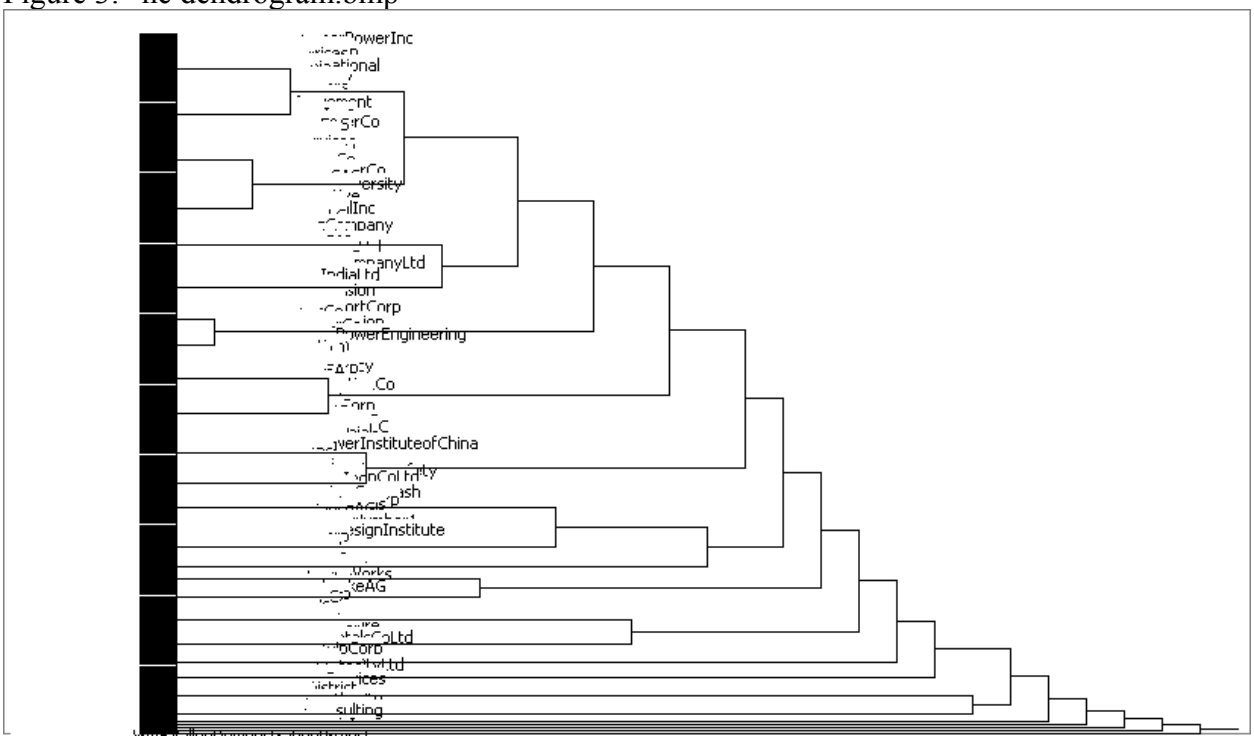


Figure 3: “nc dendrogram.bmp”



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