Commercial Nuclear Trading Networks as Indicators of Nuclear Weapons Intentions

JENNIFER HUNT MORSTEIN & WAYNE D. PERRY

Jennifer Hunt Morstein is a graduate of the doctoral program at The School of Public Policy at George Mason University in Fairfax, Virginia. Wayne D. Perry is a Professor of Public Policy and Operations Research in The School of Public Policy. *Funding for this work was provided by George Mason University and the work was completed as part of Dr. Morstein's dissertation under the guidance of Professor Perry.* *Dr. Morstein is currently an analyst with the US Department of Defense. However, the views contained herein are the authors' alone and not intended to represent those of the US government.*

One of the nuclear proliferation lessons of the last decade has been the extent to which proliferant nations have used the commercial nuclear energy market to procure the materials and technologies needed to develop nuclear weapons. Gaining a clear understanding of the global dual-use trade has been challenging. Spreadsheets, link-analysis diagrams, and descriptive statistics can be useful tools to begin to simplify and manage the trade data. However, the vastness and complexity of nuclear trade make comprehending the overall impact of the market on weapons proliferation extremely difficult. What has been missing from the analysis is a means to understand the *relationships* among all the nations in order to *forecast* which nations will emerge as proliferants in the future and to *determine critical nodes* that may offer a way to target nonproliferation efforts more precisely.

The trade in nuclear materials and technologies is a "system" formed by national actors and by commercial entities that can be seen as nationally based.[1] Within the system, these actors form relationships defined by nuclear trade. Not surprisingly, some exert more power over the behavior of that system than do others. Determining which nations have positions that exert the most influence in the network can add to the understanding of the sensitivities of the system and identify the actors towards which policies should be more focused.

It is a fallacy to say that nations that trade with the greatest frequency or quantity of transactions in the market always have the greatest effect on the behavior of that market. Frequency and quantity of trade are most easily determined by the traditional means of data tracking and spreadsheets. Traditional statistics can show that there is a relationship between the type of nation, e.g., industrialized or nuclear-aspiring, but it cannot show exactly how that group of nations participates in the overall market. Analysis of the system requires a methodology specifically designed for understanding relationships and the subsequent position of nations in a complex network. This article applies a methodology known as Social Network Analysis (SNA) to data on nuclear transactions compiled by the Monterey Institute's Center for Nonproliferation Studies (CNS).

This article will examine 10 years of real world nuclear dual-use transactions, most of which were transacted on the open commercial energy market, to show the utility of a macro-level systemic approach for revealing patterns of trade. The analysis will identify empirically and in a replicable manner critical nations in the proliferation of goods for nuclear weapons. This study shows that nations seeking nuclear weapons trade fundamentally differently on the open market than do nations with solely energy intentions. In many cases, the systemic analysis reveals results consistent with what is already known, which helps prove the methodology's reliability. The value added is a macro-level description of the nuclear trade environment that was not previously available. This macro-level view of the system allows for the identification of patterns that can be used as predictive factors in the future. Furthermore, the systemic approach allows for a ranking of importance of actors in the system of trade, which provides additional factors for consideration in the formulation of efficient nonproliferation and counterproliferation policies.

Understanding the relationships among nations is important because the position of a nation in the network of commercial transactions affects the availability of the commodity to others in the network. How a nation is linked to the participants in a market has implications for the individual nation as well as for the entirety of the network. Furthermore, analysis of these relationships has shown that nations seeking nuclear weapons programs will create patterns of connections that are distinct from the patterns of those nations simply trading commercial energy products. The implication here is that this trade pattern recognition helps the forecasting of which nations have nuclear weapons intentions.

THE NEED TO UNDERSTAND TRADING SYSTEMS: THE CASE OF IRAQ

What was learned from Iraq's former nuclear weapons program supports the need for understanding the systemic nature of the commercial nuclear market. Inspections following Operation Desert Storm uncovered an extensive trail of Iraqi purchases made on the global civilian nuclear energy market to support its weapons program. Seized papers revealed inside information about the actions of this nuclear-aspiring nation and the way in which Iraq interacted with suppliers of nuclear technologies and materials.[2] Baghdad had a well-designed plan to use multiple suppliers; make small purchases to avoid suspicion; and purchase components and non-obvious technology instead of the most current technology. Though Western powers had indications that the Iraqis were developing nuclear weapons, including knowledge of some procurement activity, the West was surprised to learn the extent of the program and the lengths to which the Iraqis went to conceal their intentions.

Two key elements of Iraq's strategy were to use many suppliers and to make multiple purchases of materials and technologies that cumulatively far exceeded its non-weapon needs. If Iraq were caught purchasing from any of its suppliers, it might have been assumed that Iraq had only a sole supplier of that commodity. This assumption would lessen the suspicion of a grand effort to acquire a nuclear weapons infrastructure. Additionally, if a source were cut off, Iraq could rely on its many other suppliers. By using many small purchases of a needed material from a variety of suppliers, the quantities Iraq obtained were low enough to avoid attracting attention to its nuclear program. Even if a small amount of material were detected and thought to be intended for a nuclear program, it would be assumed that the amount was relevant only to an embryonic nuclear program and not yet a true threat.[3]

In addition, Iraq took advantage of Western naivete. There was a belief in the export control regimes that certain systems were less dangerous from a nuclear proliferation perspective if certain critical components were removed. Iraq capitalized on the belief that it lacked the ability to successfully integrate the legally acquired equipment with the missing components. Yet, Iraq proved that it could successfully integrate foreign-acquired technology to create the systems it needed. Computer Numerically Controlled (CNC) machine tools were exported legally as long as they were not combined with laser alignment systems. Iraq acquired each component from different suppliers and successfully integrated them to create higher-level systems.[4]

Uncovering Iraq's nuclear weapons strategy provided a valuable lesson. Inspections allowed the world to see inside a nuclear aspirant's program, which can serve as a model for how certain states seek to acquire a nuclear arsenal. Iraq's behavior, when viewed at the systemic level, provides an illuminating pattern of behavior that distinguishes it from nations not interested in nuclear weapons and not trying to conceal their intentions. This behavior is a network "footprint" of proliferation intention that can be seen and measured using the appropriate analytic approach and tools. Although Iraqi imports were tracked prior to Desert Storm, there was no reliable analytic model that was used to evaluate these activities.

The imperatives that drove Iraq to behave the way it did still exist today for other nuclear-aspiring nations. It can thus be hypothesized that other nations are likely to behave in the same general manner as Iraq. This suggests that an analytic approach that can identify these similar patterns can alert the global community to other nations' emerging weapons programs. The systemic approach can help spot three aspects of a weapons program: (1) procuring components via frequent, small purchases that span the stages of the nuclear weapon development cycle; (2) purchasing indirectly through illegal smuggling, deceptive middlemen, and transshippers if nuclear-aspiring nations cannot purchase directly; and (3) obscuring procurement endeavors in the much larger market of legitimate nuclear energy trade. A comprehensive understanding of that global commercial nuclear energy marketplace can reveal much of what is being obscured. Since all trade is two-way, both demand and supply sides of the market must be examined. Study of the market as a system improves upon the traditional method of examining the nuclear proliferation problem as one only of the imports of sensitive materials and technologies to a few so-called rogue nations. The identification of these patterns of trade can provide insight into nations' nuclear programs by helping to distinguish between commercial energy programs and nuclear weapons programs.

The study presented here identifies pathways that nuclear-aspiring nations develop to maximize their access to desired materials and technologies. By better identifying the dynamics that encompass these areas, a more complete picture of the proliferation world can be developed. This more comprehensive picture is a foundation on which improved export control regimes and other future unilateral and multilateral nonproliferation policies may be implemented more efficiently. Because a systematic analysis of the nuclear market can show where leverage over proliferation-relevant trade would be greatest, it can pave the way for a more focused and tailored policy effort.

THE SYSTEMIC VERSUS THE ATOMISTIC APPROACH

The study of an international market is the study of a system. The nuclear trade system is composed of nations and other international actors that are connected through the trade of nuclear materials and components primarily used for peaceful purposes such as nuclear power, research, and medical purposes. The market is large and extremely complex due to the many permutations of connections between participants. This complexity is further exacerbated by the large number of different nuclear-related materials and components that are dual-use, meaning they can be used for energy or weapons. The complexity of the system makes tracking the indirect connections especially difficult. Determining the causes and effects of a nation's trading behavior requires an understanding of the entire market—not just those pathways that are predetermined to be important for the supply of a nuclear aspirant.

Traditionally, proliferation has been analyzed in terms of the attributes of those countries thought to be interested in nuclear weapons acquisition. Frequently analysts have used a case study or regional approach to proliferation that can be labeled as "atomistic." One of the most authoritative voices from this perspective has been Leonard Spector, whose books on nuclear proliferation are excellent accounts of individual nations' internal capabilities to build an infrastructure for the acquisition of a nuclear weapon arsenal.[5] These accounts include some mention of transactions of nuclear materials from one nation to the next, but interactions between nations are not the focus.

Similarly, Mitchell Reiss and Robert S. Litwak[6] apply the case study approach to the problem of horizontal proliferation. They divide their analysis into sections on Iraq, the Middle East, Israel, the former Soviet Union, North Korea, China, India, Pakistan, South Africa, Brazil, and Argentina. Then they examine nuclear technology and provide an analysis of the role of the International Atomic Energy Agency (IAEA) and other nonproliferation efforts in the New World Order. While this type of work combines detailed histories of troublesome nations with analyses of technological concerns and the existing nonproliferation regimes, it fails to provide a coherent macro picture of nuclear transactions.

These types of analyses lead naturally to a categorization of nations into nuclear classes such as the original nuclear "haves," "have nots," and the "rogue" nations. Richard Betts takes this type of categorization further by focusing on how nations perceive themselves in the world order and using this to categorize nations by their relationships to other nations.[7] Betts moves beyond simple geographic and nuclear capability definitions to assign nations to categories based on other, less obvious concepts, such as status. He places much emphasis on the position of nations in the world system as the primary reason for nations to aspire to an arsenal. In Betts' analysis, "pygmies," "paranoids," and above all "pariahs" are the most likely proliferants.

Although they have varying perspectives on the problem, Spector, Reiss and Litwak, and Betts all focus on nations that seek nuclear weapons. Only these states are monitored and their capabilities and intentions analyzed. Analyzing the history of past acquisition attempts allows for some forecasting as to which states will be the future nuclear aspirants. There is consensus that dual-use nuclear materials and technologies feed these future threats, but the focus remains on the nations that receive these commodities, i.e., the demand side.

Although useful, this approach remains fundamentally atomistic. What is missing is a fuller understanding of the context in which the nation operates; in this case the overall nuclear trade system offers important additional information. This critical part of proliferation analysis examines not just the motivations, capabilities, and intentions of nations seeking nuclear weapons, but also of those willing to help their cause. It examines how nations behave within the international system of nuclear trade and use that system to their advantage. The difference between the "systemic" approach and the atomistic is that the systemic approach uses the entirety of the global marketplace to define the roles and positions of nations; it is the system that is the starting point for the analysis and not the nation.

Although atomistic approaches acknowledge the existence of a market for the trade of nuclear weapons material and that non-nuclear weapons states and non-rogue nations participate in the proliferation of such materials, they lack quantitative analysis aimed at understanding the dynamics of the market and how the supply of materials or components by one nation affects the demand strategies and actions used by others. Atomistic analyses under-represent the vastness and complexity of the global nuclear proliferation problem. Systemic analysis recognizes that the position a nation holds in a connected group of nations would be influenced by and would also influence other nations.

In addition to its value in describing a nation's nuclear efforts in historical and geo-strategic terms, the atomistic approach was pursued because the systemic approach proved too difficult and complex without the development of appropriate analytic methods and modern computer software. However (as described in the next section), appropriate methods and computer programs for systemic analysis now exist.

The systemic analysis of nuclear materials described below reveals that all suspected nuclear-aspiring nations shop for nuclear dual-use goods in a similar manner—developing for themselves trade connections designed to obscure their intentions while securing their access. This strategy was employed by Iraq and revealed in the United Nations Special Commission (UNSCOM) inspections of Iraq. The systemic analysis contributes to the understanding of the nuclear proliferation problem, in general, because it shows that Iraq's strategy was not unique. In fact, it shows that other nuclear weapons-aspiring nations have also followed this pattern. The analysis also reveals some interesting findings regarding the role of key nuclear suppliers, particularly the United States. The United States is found to be one of the central suppliers for virtually all nuclear commodities. This finding is not surprising because the United States is a major producer of many nuclear commodities that are sold on the world market for commercial peaceful purposes. While this is not a new revelation, it shows that the systemic approach could identify new power centers in the market and the degree of their importance, and could also be used to trace initially legitimate commercial trade as it passes through the system toward more nefarious ends. The systemic approach thus validates certain important past insights of the atomistic approach while also providing important new insights. Therefore, changes in the global proliferation problem and improvements in systemic analytical methodologies, as described below, make the systemic approach worthy of pursuit at this time.

ELEMENTS OF THE SYSTEMIC APPROACH

A system is defined by the positions, or roles, of the actors and the patterns of their relationships. Within the system, as Betts' analysis suggests, statuses are the formally defined positions of the actors where the statuses of some actors help to define the statuses of other actors. For example, the existence of a "declared" nuclear nation is necessary before designating the existence of an "undeclared" nuclear nation. Conversely, roles are defined by actors' positions and functions in the system. The result is a classification of nations for the purpose of policy construction as "central exporters" or "central importers" rather than as "declared," "undeclared," or "weapons-aspiring nations." By focusing on demand and supply roles instead of statuses, the systemic approach can provide new impetus and justification for nonproliferation policies, especially regarding the emphasis placed on export controls.

Social Network Analysis is a generic systems analysis methodology that provides the analytic rigor needed to capture the dynamics of the global nuclear market. It is a quantitative methodology that originated in the field of sociology and was designed for the study of power relationships within social networks. This methodology evaluates a system by identifying all of the actors (or nodes) and all of the connections (or transactions) between them. In every system, some nodes are going to be more dominant than others and some connections between nodes will be more heavily used than others. These are key pieces of information that define the system and the relationships between the actors. In sociology, this method has been used to examine patterns of communication and trust in organizations. This study helps demonstrate SNA's direct applicability to economic transactions between actors as well.[8]

SNA relies heavily on the use of graphical depictions or maps to present the configurations of connections between actors in the network. This graphical approach allows the analyst to identify visually key relationships between specific nations and groups of nations in the system. This mapping is the most critical initial step for showing the degree to which the trade of nuclear materials and technologies is complex and interdependent. For simple networks, the maps can be enlightening on their own, but for more complex networks the maps are more difficult to interpret. In those cases, SNA "centrality" measures provide a means to interpret the data. Indeed, mapping alone cannot determine the most influential nations in the system—that is the purpose of the SNA centrality measures. The maps allow for a snapshot view of the complex system while the centrality measures are used to simplify the system.

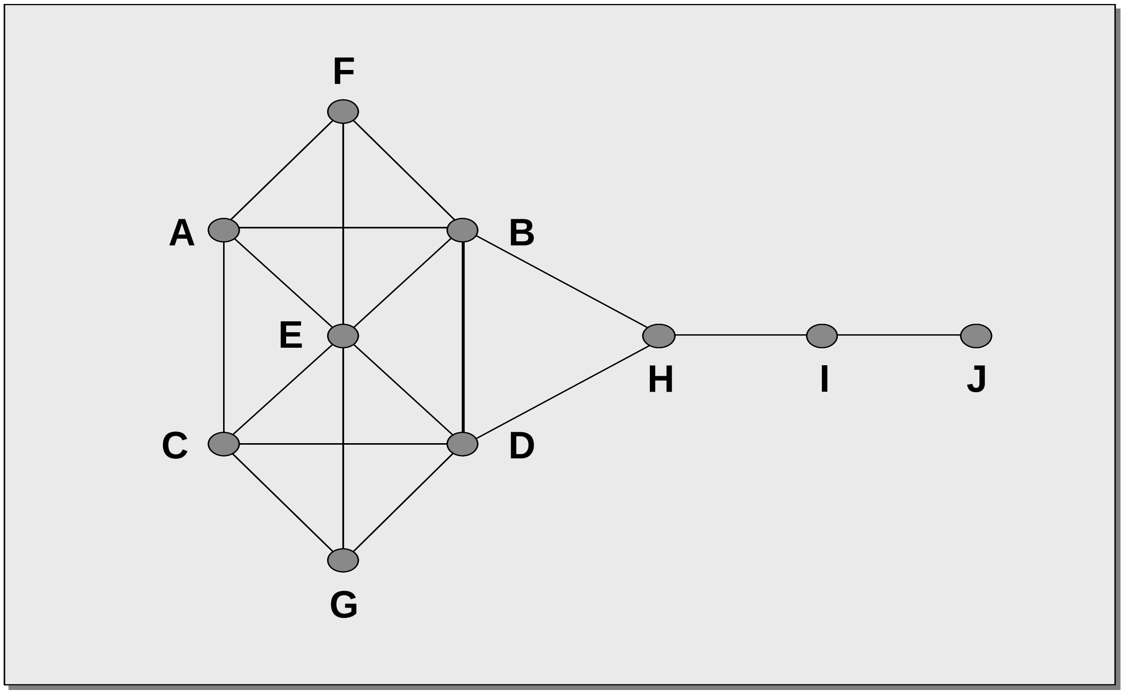
Since the number of actors and transactions in a system can grow large, SNA relies on a set of statistical techniques to assess the state of the system and evaluate the roles of key actors. In general, the statistics examine the number of connections that exist against the total number of permutations possible for all actors. Centrality measures in SNA are thus determined through algorithmic means based on matrices of binary data representing connections between pairs of actors.[9] Actors who have more connections to other actors—are better "plugged in"—are more "central" to the system. However, centrality can be measured in three standard ways. A nation that is:

- most central in terms of *Degree* is the most frequent trader, i.e., the actor with the most connections to others;
- most central in terms of *Betweenness* is the gatekeeper, i.e., the actor that is the key middleman with the power to control trade between the most other actors; and
- most central in terms of *Closeness* is the actor that is most directly connected to every other actor, i.e., the actor who is the fewest steps away from everyone else.

Each centrality measure is an indicator of power and dominance, but the three forms of centrality work in concert. Actors that rate highly on all of the measures simultaneously are clearly dominant players with a high degree of impact on the system. Taken individually, each centrality measure helps to inform us of a different element of network power and, in this case, proliferation policy concern.

A simpler way to illustrate the difference between the three types of centrality is with the "kite diagram," as shown in Figure 1. The kite diagram is a representation of a small set of actors and their relationships. The actor with the highest Degree centrality is 'E' since it has six direct connections to other actors—more than any other. Actors 'H' and 'I' have the highest Betweenness centrality since they control the only pathway connecting 'J' to the rest of the actors. In this regard, they are gatekeepers to connect 'J' to the rest of the network. Actors 'B' and 'D' have the highest Closeness centrality as they have the minimum number of steps to take to reach all other actors. Either 'B' or 'D' can reach any other actor except 'J' in two or less steps, and they can reach 'J' in three. On average, this is the fewest for any actor in the system.[10]

Figure 1: The Kite Diagram Showing Different Types of Centrality



The nation with the most connections (i.e., the highest degree centrality) is not necessarily the nation that is most influential over the trade of the network. Often, nations have multiple pathways from which they can receive their goods. If a nation most central in terms of degree were removed from the network, it is possible that its trading partners would simply resort to other established pathways.

However, there are nations that do control trade simply by being connectors between groups of actors. These nations with high Betweenness do not necessarily have the most connections in the network but are strategically positioned between groups or between a group and another critical nation. If a central nation in terms of Betweenness were removed from the network, a critical part of the network would be cut off from trade because there are few or even no established alternate pathways to pick up the trading.[11]

Finally, a nation most central in the context of Closeness is the actor with the smallest average number of steps to all other nations in the network. The closer a nation is to all other nations, the more its involvement in the behavior of the network increases. It is important to note that this measure depends on direct as well as indirect ties between actors.[12]

Since SNA's measures of centrality are quantitative, they allow for the relative numerical ranking of important actors. Therefore, those that emerge as most "central" for a given commodity in a given timeframe represent the nations of highest proliferation concern. This seemingly basic fact should not be taken for granted: By understanding which nation poses the greatest threat to nonproliferation efforts on a given commodity, more focused and more efficient allocation of nonproliferation or counterproliferation resources can be made. Previous studies of proliferation have not been able to make this distinction clearly. The focus on the capability of a nation allows for an estimate of a stage of a nation's nuclear weapons development. The ranking of a nation's importance in a network allows for a deeper understanding of the criticality of certain policies, such as export controls.

In summary, when the most influential nations *in terms of their effect on overall supply to the trade network* are identified, policies can be developed to address these nations. This identification yields a better understanding of how these nations affect the supply of nuclear materials and technologies to nations seeking to acquire nuclear weapons. Key suppliers, recipients, and middlemen can be identified in a systemic manner using SNA.

DESCRIPTION OF DATABASE

Conceptually, SNA analysis could be undertaken for all nations and all nuclear-related transactions over many years to provide a complete picture of all pathways to trade and of the central actors across commodities and over time. However, such a truly global evaluation was beyond the means of this effort. Instead, this study examines a limited number of nuclear commodities over two five-year intervals to provide a demonstration of the utility of systemic analysis for evaluating the nature of global nuclear trade.

The results reveal that the issue is indeed global; that the many nations involved are highly interconnected; that the system changed following the end of the Cold War; and that there are specific pathways of commodities between nations that form identifiable configurations of trade. Two different types of trade configurations were identified: one specific to commodities less likely to be used for nuclear weapons and one specific to the commodities of highest interest to nuclear-aspiring nations.

Data for this study was retrieved from the Nuclear Abstracts Database created by the Monterey Institute of International Studies' Center for Nonproliferation Studies.[13] This CNS database is the most comprehensive open-source, nonproprietary database related to proliferation issues. It comprises information collected since 1986 regarding nuclear transfers either directly related to weapons or dual-use in nature. CNS analysts systematically search more than 300 publications for articles on nuclear proliferation and generate abstracts of these articles. Sources include trade journals, government publications, defense publications, United Nations releases, IAEA releases, international newspapers, international news services, academic journals, FBIS daily reports, congressional testimonies, monographs, unpublished papers, conference proceedings, book chapters, and gray literature from foreign governments not otherwise available in the United States. The database contains more than 22,000 abstracts.

Despite the comprehensive nature of the CNS database, it is not usable in its original format for a systemic analysis. This empirical study required a distillation of the complex content of the abstracts into a more standardized data format. All CNS abstracts referencing nuclear dual-use transactions for a 10-year period were thus coded and used to populate a new database. This new database is the Coded Nuclear Dual-Use International Transactions (CONDUIT) Database.[14]

The following information was gleaned from the CNS abstracts and was coded to create the CONDUIT Database:

1. source information (original article as cited in CNS);
2. type of commodity (material or technology) transferred;
3. year of transfer (not necessarily the date of the record, because often the CNS database receives articles that report on an incident that took place years before);
4. origin of transfer;
5. destination of transfer (transfers with multiple middlemen were separated by legs into separate transactions);
6. quantity (rare but sometimes available); and
7. status of transaction: completed, attempted, or rumored.

The data was broken into two five-year periods (1985 to 1989 and 1990 to 1994) with the fall of the Berlin Wall as the breakpoint. The periods lend themselves easily to comparisons of the Cold War and post-Cold War orders while keeping the amount of data to a manageable level. The fall of the Berlin Wall in the autumn of 1989 began the transition between the periods that was completed by the dissolution of the Soviet Union at the end of 1991. The Gulf War further altered proliferation concerns: post-war UNSCOM inspections in Iraq revealed the weaknesses of the Cold War nonproliferation regime. Change occurred rapidly and dramatically between the final months of 1989 and 1991. Choosing to end the first five-year period at the end of 1989 and beginning the second at the beginning of 1990 allowed for the inclusion of the major changes. This division created a convenient dichotomy for the analysis of the effects of exogenous world events on the global trade of nuclear materials and technologies.

Overall, more than 3,000 instances of nuclear transactions among more than 100 nations were coded and entered into the CONDUIT database. This number of nations is almost one-half of those existing during this time period, and it shows the wide-ranging international market in nuclear materials. The nations spanned from the United States—which was the single most frequent exporter—to small countries like Mongolia and Sudan. The list of key importers includes Iraq,[15] Pakistan, Japan, France, India, West Germany, and the United States.

The proliferation system was divided into commodities to compare the nature of trade for commodities of different levels of proliferation concern. Six critical commodities[16] were selected because they represent dual-use commodities with differing degrees of danger or risk for diversion to weapons programs. By categorizing dual-use items in terms of "degree of danger," it is easier to understand the nature of the nuclear trade. In the realm of nuclear proliferation, many frequently traded nuclear materials are integral to the commercial nuclear energy market, but these networks are often very complex and involve many nations. Understanding the ramifications of such networks cannot be accomplished without first having a reference for the level of danger of a commodity.

The selected commodities include two that are "lower danger"—low-enriched uranium and lower danger reactors—because they are less important to proliferation but significant in the nuclear power industry, and four that are "higher danger" commodities—highly enriched uranium, plutonium, enrichment equipment and plants, and higher danger reactors—because of their greater value in nuclear weapons programs.

With six commodities and two time periods, 11 separate SNA analyses were performed (there was insufficient data for an analysis of higher danger reactors in the second time period) to create a general picture of the global nuclear market.[17] The most influential nations were identified using the three SNA centrality measures of Degree, Betweenness, and Closeness. The changes in the most influential actors over time reflect the changes in the proliferation market over time. The quantitative results bolster previous knowledge and allow for a view of a macro-level trend not readily visible in other forms of data analysis. Furthermore, the identification of central nations can serve as complementary information to the identification of nuclear-aspiring nations for nonproliferation policy.

OVERVIEW OF SOCIAL NETWORK ANALYSIS RESULTS

Table 1 provides the results of the SNA analysis.[18] By commodity and timeframe it lists the total number of transactions, the number of nations trading that commodity, and the central actors. The uranium commodity has the largest total number of transactions and nations trading for both timeframes. The sheer number of incidents makes determining structure in such a network difficult. This commodity is thus ideal for demonstrating the SNA approach. The SNA centrality measures allow for a simplification of the network through the identification of key importers, exporters, and gatekeepers. The configuration types listed in the right-most column will be defined and discussed below, after the discussion of the centrality results.

For the uranium commodity for 1985-89 there are 296 transactions by 51 nations. The most frequent exporters, those most central in terms of Degree, are Canada, the United States, and France. The most frequent importers are Japan and West Germany. The gatekeepers, those most central in terms of Betweenness, are the United States, West Germany, the Soviet Union, and France. Interesting to note, the nation most directly connected to all others as an exporter (most central in terms of Closeness) is Hungary. This Closeness is due to Hungary's connections as an exporter to the Soviet Union. However, since it is connected by only one transaction, it is not as critical to the system as it may initially appear. The most central importers in terms of Closeness are Pakistan, Iraq, and Libya. The presence of nuclear-aspiring nations as central importers is significant. When a central importer in terms of Closeness emerges in the data, it should be examined carefully as a possible nuclear weapons-aspiring nation.

Overall, the identification of central importers reveals something about the economic and technical attributes typical of such nations. Across commodities, the central importers tend to be either nations with high-level technical infrastructures that traded in lower danger commodities or nations with nuclear weapons aspirations that traded in higher danger commodities.[19]

There are no nuclear-aspiring nations listed as central exporters for any commodity. As was the case with central importers, the declared nuclear nations have a large presence as central exporters because they have an advanced technical infrastructure. It is this technical so-

Table 1: SNA Results by Commodity

Commodity	***Highest Degree Nations*** Exp = Exporter Imp = Importer	***Highest Betweenness Nations***	***Highest Closeness Nations***	***No. of Trans-actions***	***No. of Nations***	***Configuration Type***
Lower Danger Commodities						
Uranium for 1985-89	**Exp-** Canada, USA, France **Imp-** Japan, FRG	USA, FRG, USSR, France	**Exp-** Hungary **Imp-** Pakistan, Iraq, Libya	296	51	Spider Web
Uranium for 1990-94	**Exp-** USA, Russia **Imp-** Japan	Russia	**Exp-** Mongolia, Tajikistan **Imp-** Iran	429	82	Spider Web
Lower danger Reactors for 1985-89	**Exp-** USA **Imp-** Spain	Argentina, PRC	**Exp-** USA, Argentina, France, FRG, USSR **Imp-** Pakistan	55	28	Spider Web
Lower danger Reactors for 1990-94	**Exp-** USA, PRC **Imp-** Iran	PRC, Japan, Russia	**Exp-** USA **Imp-** Even spread across actors	83	36	Spider Web/ Hub-and-Spoke Hybrid
Higher Danger Commodities						
Plutonium for 1985-89	**Exp-** USA **Imp-** FRG	FRG	**Exp-** UK, USA **Imp-** Pakistan	29	15	Spider Web/ Hub-and-Spoke Hybrid
Plutonium for 1990-94	**Exp-** France, USA, Russia **Imp-** Japan	Russia, FRG, USA	**Exp-** S. Africa, Russia, USA **Imp-** Iraq, Algeria, Israel, Syria	137	36	Spider Web/ Hub-and-Spoke Hybrid
Enrichment Equip. & Plants for 1985-89	**Exp-** FRG **Imp-** Iraq	Argentina	**Exp-** FRG **Imp-** Iraq	42	14	Hub-and-Spoke
Enrichment Equip. & Plants for 1990-94	**Exp-** Switzerland **Imp-** Iraq	FRG	**Exp-** FRG, Switzerland **Imp-** Iraq	29	17	Hub-and-Spoke
Highly Enriched Uranium for 1985-89	**Exp-** PRC **Imp-** Pakistan	PRC	**Exp-** India, PRC, USA **Imp-** Pakistan, Argentina	14	11	Hub-and-Spoke
Highly Enriched Uranium for 1990-94	**Exp-** USA **Imp-** Even spread across actors	USA	**Exp-** USA **Imp-** Even spread across actors	57	15	Hub-and-Spoke
Higher Danger Reactors for 1985-89	**Exp-** France, FRG **Imp-** India, Japan	None	**Exp-**FRG, France **Imp-**Japan, India	9	6	Hub-and-Spoke

phistication that allows them to trade these products. The five original nuclear weapons nations—the United States, Soviet Union/Russia, China, France, and the United Kingdom—each emerge as central exporters of higher danger commodities. These five countries are joined by the Federal Republic of Germany (FRG), South Africa, and India.

For lower danger commodities, the United States, China, France, and Russia (but not the United Kingdom) are again key exporters of both uranium and lower danger reactors. Additionally, for the first timeframe, 1985-89, Argentina and West Germany are also central exporters of lower danger reactors. During this period, Argentina began to market itself as a supplier of light-water research reactors. It also entered into numerous data-sharing and research and cooperation agreements regarding reactors.[20] Argentina is the only nation central in the export of lower danger reactors that is a developing rather than technologically highly advanced country.

In general, the lower danger commodities involve a more diverse selection of central actors. Central exporters of uranium include Canada, Hungary, Mongolia, and Tajikistan. Canada is a major miner of uranium. The presence of Mongolia as a central exporter is explained by the fact it sent a large shipment of natural uranium to the United States. Since the United States is most directly connected to all other actors in the uranium network and Mongolia has a major connection to the United States, Mongolia is also closely connected to the network.

Empirical analysis of centrality is also very useful in determining how the nuclear market changed over time. As Table 1 shows, between the two timeframes—1985-89 and 1990-94—there are profound changes in the most central actors within commodity groups. The changes in world affairs brought about by the demise of the Soviet Union also affected the realm of nuclear proliferation. These geopolitical changes are, in turn, captured in the systemic data analysis.

KEY INSIGHTS ABOUT THE NATURE OF THE GLOBAL NUCLEAR MARKET

The key conclusions from an analysis of the SNA results fall into three areas: (1) the global nature of the nuclear trade network; (2) implications regarding central actors; and (3) configurations of trade.

Global Nature of Nuclear Trade

This study makes it clear that the dimensions of the global nuclear trade network are extensive and that the trade within it reflects a highly developed international system. More importantly, the SNA results provide a method for effectively comprehending the entirety of the market that has not been available previously. This study shows that such tracking is possible and how it might be done.

Rather than print all the maps of the global trading network generated for this study, we present selected maps below in the section on the configuration of trade. These network maps as well as the others not reproduced here reveal that trade is not geographically bounded and that it is highly interconnected. These maps show that many nations are involved in the trade of these commodities and that they are fundamentally interdependent. The SNA Closeness results discussed above clearly demonstrate that the nations are not only interdependent, but also that certain nations are more important to the trade network than are others. The SNA Betweenness centrality measure shows that nations are linked together *indirectly* as well as directly.

The global nature of the network seems intuitive at first glance. For nations to trade there must be more than one nation involved. However, being able to view the network at a macro level reveals *all* the nations that are involved. In the traditional nation-specific or regional focus only a handful of nations are actually studied. A graphic depiction of the complex interdependencies between all nations shows that all nations involved in the trade are deserving of some attention. At the very least, awareness of their involvement is critical so that the choice of nations addressed by analysis is not solely dependent on *a priori* identification.

If the trade of nuclear dual-use materials did not form a system there would not be many interdependencies. Maps would consist of clusters that were not connected, but most of the maps show conclusively otherwise. The maps also help to identify common suppliers even if they are linked only indirectly. There can be little doubt that the market for nuclear materials and technology is a robust, well-connected international network encompassing virtually all of the industrial nations and many developing ones as well.

Implications of Centrality

The second major finding involves the ways in which a complex global market allows and encourages nations to strategically develop connections in the network that optimally position them for importing and exporting desired goods. This strategic behavior is a fundamental element of the nuclear dual-use trade system that is revealed by the empirical analysis.

The Betweenness centrality measure indicates that for the higher danger fuel commodities, plutonium and highly enriched uranium, the system's gatekeepers are four of the de jure nuclear states—the United States, France, China, USSR/Russia—plus a single non-weapon state, West Germany/Germany. There are no nuclear-aspiring nations as key suppliers. The four declared nuclear states just mentioned have a double influence over the system: They are largely responsible for the loading of supply into the network, and they are also able to influence the flow of commodities by behaving as critical gatekeepers or middlemen. Their dominant presence in the exporter and middlemen roles is critical. Particularly in light of the presence of several weapons-aspiring nations of concern in the role as importers, this result implies that the declared nuclear nations may perhaps inadvertently be supporting the aspiring nations.

The importer role, like the exporter role, is defined by the identification of the most central importers in terms of Degree and Closeness. Interestingly, the importers most central in terms of Degree (frequency of trade) are not always nuclear aspiring nations, while, in terms of Closeness, *all the most central importers were aspiring nations* (except for higher danger reactors—a particularly small network—where Japan is the most central importer in terms of Closeness). The implications of this finding are profound. As a nation seeks to acquire an infrastructure to develop nuclear weapons, it will closely connect itself to as many nations in the system as possible.

Nuclear-aspiring nations use the energy trade to help develop their nuclear weapons arsenals in a strategic and goal-oriented manner as did Iraq prior to the Gulf War. Nations wishing to do commercial business for weapons acquisition may create numerous connections to guard against a total cut-off in the event of connections between nations dissolving. Tapping many suppliers means that goods can be traded in quantities low enough to avoid suspicion of their use for a weapons program. The results show that nuclear-aspiring nations try to involve themselves in numerous connections. However, the presence of *all* the nuclear-aspiring nations in the close importer category implies that Closeness is more important than Degree in understanding the strategies of these nations.

The policy implications of these findings are clear. Nations central in Closeness should be monitored carefully, while nations exercising control over the supply side of the network should bear heavy responsibility for the immediate and future direction of their imports—and they may be able to do so unilaterally or in a subset of the Nuclear Suppliers Group. In the commodities of uranium, plutonium, highly enriched uranium, and enrichment equipment and plants, *all* of the most central importers are weapons-aspiring nations. For enrichment equipment and plants, Iraq is the closest nation to all other nations. Iraq seemingly has tried to directly connect to the network as closely as possible in order to maximize efficiency and speed in the acquisition of enrichment equipment.

Configurations of Trade

Perhaps the most intriguing result of the study is that the network maps reveal distinctive commodity-based patterns or configurations of trade. Almost without exception, lower danger commodity maps are defined by a highly interdependent "Spider Web" character with many crosscutting pathways and inter-relationships. They also tend to include many more nations and numbers of transactions. On the other hand, the higher danger commodities involve fewer countries, fewer transactions, and tend to be configured as "Hub-and-Spoke" systems with a small number of dominant suppliers and/or importers.

The importance of these configurations is what they suggest about the intentions of actors in the system. Primarily, they show that s*pecific pathways of trade can be identified in the network.* For example, in a Hub-and-Spoke configuration, the hub receives from or supplies to a multitude of other actors the commodity in question. The map may consist of more than one Hub-and-Spoke cluster in a network. For example, the Enrichment Equipment and Plants commodity for 1985-89 (Figure 2[21]) shows two Hub-and-Spoke configurations that are linked.

Supply-Hub networks are characterized by a cluster of actors centered around a single supplier. In these clusters, the supplier exports to nations that do not have any, or have very few, other suppliers. Supply-Hub nations have a near monopoly on the export of goods to their network, and are obvious targets for nonproliferation policy attention. This study found that Supply-Hub networks existed in higher danger reactors in 1985-89, highly enriched uranium in 1985-89, highly enriched uranium in 1990-94, and enrichment equipment and plants in 1985-89.

The network for higher danger reactors in 1985-89 has two clusters—one supplied by West Germany and one supplied by France. These two groups are linked by a common connection to Japan. The network for highly enriched uranium in 1985-89, although more complex, is predominantly a Hub-and-Spoke network in which two clusters exist. One cluster is centered by China and the other is centered by the United States—both as suppliers. They are not linked together but rather are isolated from one another. The network for highly enriched uranium in 1990-94 is a Hub-and-Spoke arrangement, and the single cluster is centered by the United States as the supplier. France serves as a middleman between the United States and Iran. Enrichment equipment and plants for 1985-89 is a Hub-and-Spoke split between a Supply-Hub sub-network and a Demand-Hub sub-network. The Supply-Hub cluster is centered by West Germany.

By contrast, Demand-Hub networks illustrate systems where numerous exporters are supplying a single recipient. This case is illustrated in Figure 3,[22] the Enrichment Equipment and Plants Commodity for 1990-94. This network actually has two sub-networks, one centered by Iran and one focused on Iraq. These types of configurations, particularly for higher danger commodities, are indicative of a weapons-aspiring nation trying to acquire materials from multiple sources in order to conceal its activities or circumvent international controls. These configurations highlight probable weapons ambitions and indicate countries of proliferation concern.

Figure 2: Enrichment Equipment and Plants Commodity for 1985-89

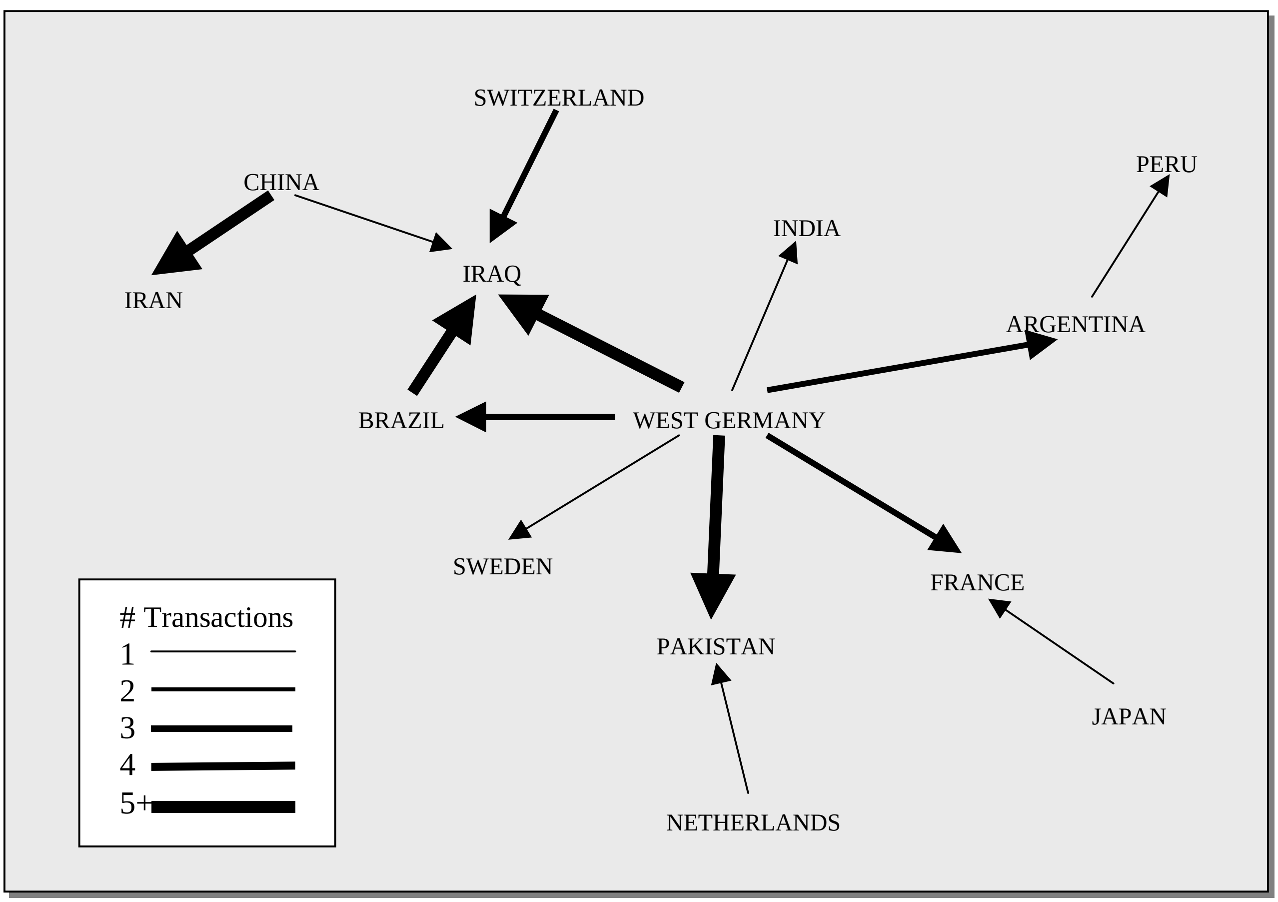
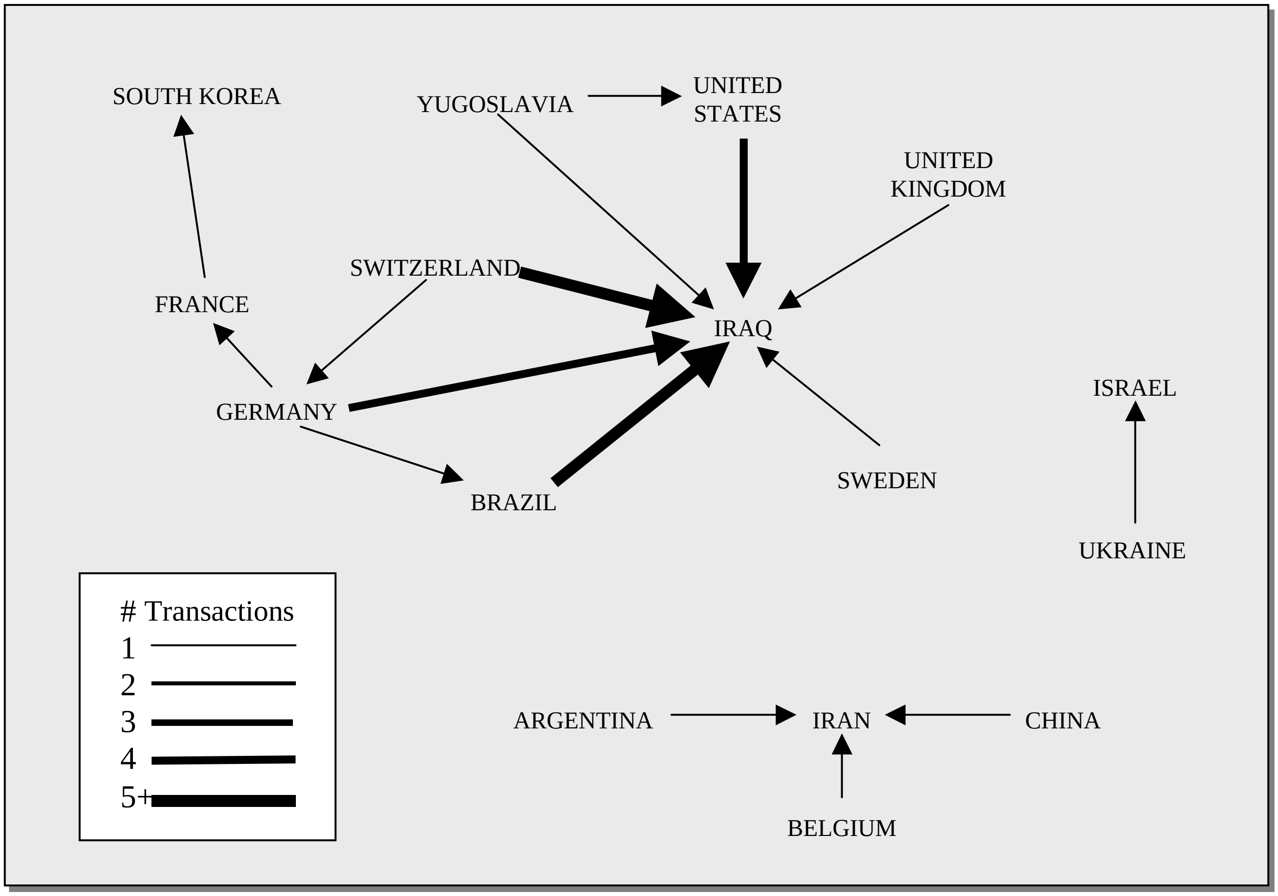


Figure 3: Enrichment Equipment and Plants Commodity for 1990-94



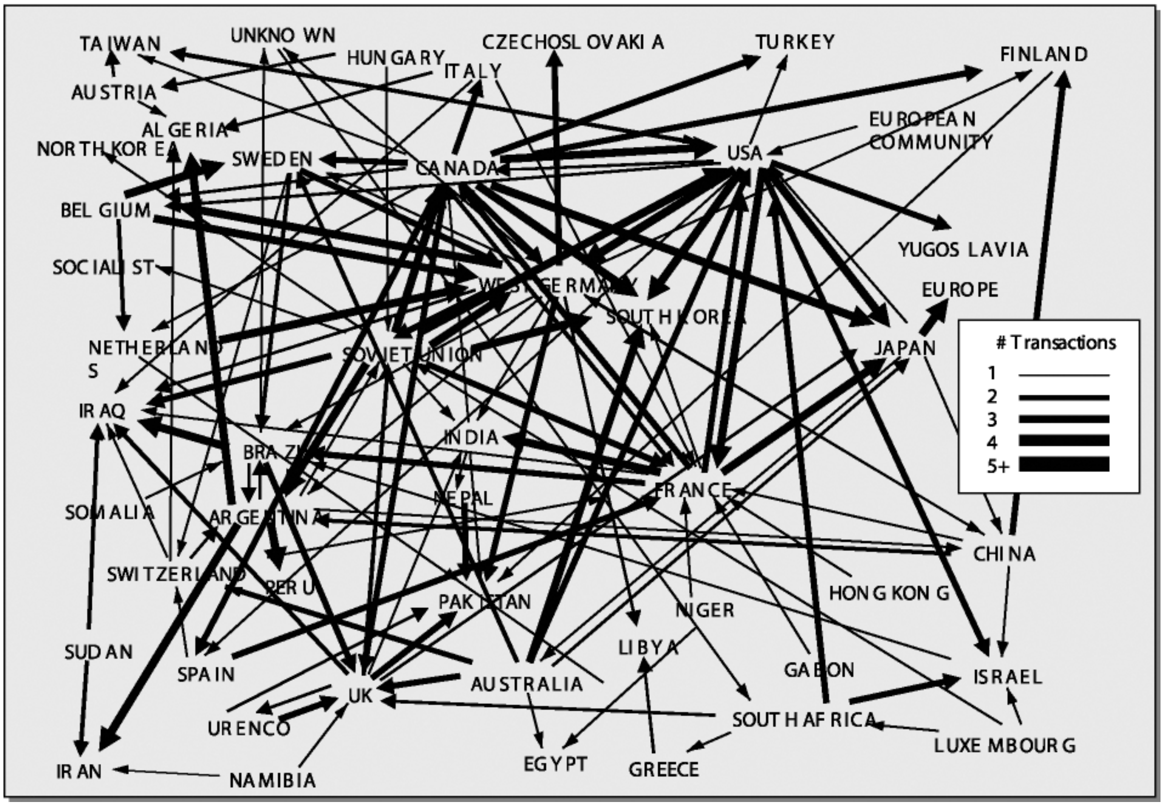
Among the Hub-and-Spoke configured networks, Enrichment Equipment and Plants stands out as being mostly a Demand-Hub network, while the remaining higher danger commodities are Supply-Hub networks. Given that countries on the demand side are the recipients of these higher danger commodities, any Demand-Hub network should be seen as a warning flag of possible proliferation intent.

By contrast, in the Spider Web configuration, most actors have more than one connection and most of them both demand and supply the commodity. There are more alternative avenues of trade and fewer direct linkages to the network on the whole. On the map, the routes of trade are less obvious. It is in the Spider Web networks that the SNA measures reveal the most additional information because the centrality and position of nations are not visually obvious. In contrast to Figures 2 and 3, the Uranium Commodity for 1985-89 (Figure 4[23]) is a Spider Web trade configuration. Maps consisting of several Hub-and-Spoke configurations can easily blur into a Spider Web configuration. Some trade networks are not purely one or the other.

The role of the middleman is also different in the two configurations of networks. The middleman in the Hub-and-Spoke network is not crucial unless it links one Hub-and-Spoke cluster to another or links a nuclear-aspiring nation to the main Hub-and-Spoke cluster. There are very few nations that both receive and supply in a Hub-and-Spoke configuration.

The Spider Web configuration, however, includes many middlemen. Nations usually are both demanding and supplying in the network, resulting in a high level of inter-connectivity and complexity. In the network for uranium there are nearly 300 transactions, connected by a variety of middlemen. For instance, Canada supplies the United Kingdom, which, in turn, supplies Iraq. Sweden supplies Brazil, which, in turn, also is a major sup-

Figure 4: Uranium Commodity for 1985-89



plier to Iraq. However, in a complex system such as this one, identifying important middlemen is difficult. The most central actor in terms of Betweenness is more important in these networks because it ranks the levels of influence of the middlemen. For this system, the most critical middleman is the United States followed by West Germany, the Soviet Union, and France, in that order.

It is significant that the lower danger commodities resemble Spider Web configurations, while the higher danger commodities resemble Hub-and-Spoke configurations. The differences between these lower danger and higher danger commodity maps reflect the dynamics of the supply and demand system in each network.[24]

The lower danger commodities are more interrelated, because of the complex and wide-reaching exchange of these commodities for commercial energy use. Spider Web networks are characterized by more nodes and transactions than the networks for higher danger commodities and by a high level of interaction. The greater number of transactions is likely due to the more open nature of the lower danger networks, which involve fewer restrictions on trade.

The Demand-Hub trade configuration reveals a strategic intention of its central nations. By seeking to acquire goods in component pieces and from many suppliers, there is less likelihood of detection—the strategy seen employed by Iraq. Although in the systemic approach all the trade configurations communicate important proliferation information, the Demand-Hub is possibly the most important as it serves as an indicator of proliferation intent.

CONCLUSIONS

This study shows that the trade of nuclear-related dual-use items is indeed systemic. The nations involved in the system have trading behaviors that are dependent upon the trade behavior of other nations. The supply and demand network is wide-ranging.

In these networks, nations are linked indirectly as well as directly to one another. Recognizing the indirect links is important, because they reveal nations' acquisition strategies. Furthermore, while the frequency of trade is not a necessary element of a nuclear-aspiring nation's acquisition strategy, Closeness—which reflects connections to as many of the other nations in the network at possible—is vital. The trade configurations show that nations strategically develop connections to create for themselves optimal positions for importing and exporting desired goods.

The removal of certain nations from a trade network can drastically alter the supply of nuclear-related goods to aspiring nations. The central suppliers have substantial power over the nature and the outcome of the trade networks. Four of the five de jure nuclear powers—United States, France, China, and USSR/Russia—are largely responsible for supplying higher danger fuel to nuclear-aspiring nations as they have a dominant presence as exporters and middlemen. The only non-nuclear power having similar influence is West Germany/Germany. During the period of this dataset (1985 to 1994), there are no weapons-aspiring nations that appear as central exporters of any commodity.

The higher danger commodities are traded in networks where a small number of suppliers or recipients have established the greatest number of connections, whereas lower danger commodities are traded in networks characterized by many interdependent and complexly connected nations. The role of the middleman is much greater in the lower danger commodities. Finally, the nuclear weapons-aspiring nations dominate the hub in Demand-Hub configurations.

The systemic approach can help to identify emerging trends as they evolve. Iraq's case demonstrated to the world that countries use numerous strategies to acquire nuclear capabilities. Yet, to uncover Iraq's strategy, inside information obtained primarily from extensive, repeated inspections was necessary. These inspections were possible only after defeating Iraq in war. In retrospect, clearer indications about Iraq's intentions could have been gleaned from systemic network analysis such as described here, if only there had been an example to which to compare Iraq's strategy. This study demonstrates that transactions in nuclear dual-use trade networks suggest that Iraq and all of the other nuclear weapons-aspiring nations employ a similar strategy. When the level of danger of the commodity increases, the commercial nuclear energy transactions decrease leaving the nuclear-aspiring nations' strategies visually obvious as Hub-and-Spoke configuration. The shape of trade connections can serve as one early indicator of possible intentions of nuclear weapons development.

SNA can also be used to help strengthen export control regimes. Two regimes focus on nuclear trade: the Zangger Committee and the Nuclear Suppliers Group (NSG). The Zangger Committee's "Trigger List" and the NSG's "Critical Technology List" (CTL) identify items of concern that members are only supposed to export if certain safeguards are in place.

In practice, the NSG guidelines are more restrictive. Lessons learned from the UN inspections of Iraq led the NSG to extend the scope of its CTL to encompass a number of dual-use items related to non-nuclear elements of nuclear weapons development. The NSG also decided that all new contracts for trigger list items would require as a condition of export that the recipient have full-scope IAEA safeguards (meaning that all nuclear facilities in the country are under safeguards).[25]

The NSG has limitations. Not all potential supplier nations are members. China, India, Israel, and Pakistan are the most important non-members.[26] Another limitation of the CTL is that it does not cover all potentially nuclear-relevant technologies that could be used to acquire a nuclear arsenal. The CTL includes all key categories of nuclear-related dual-use technologies. But the foundational technologies that are components of these key categories have been simply too ubiquitous to be easily controlled. Although they are commonly used in many industries and were considered too low-level to control in the past, the trade of these items has aided some nuclear-aspiring nations. This phenomenon implies that technology control regimes are still incomplete and, therefore, allow proliferators easy access to certain dual-use technologies.

Even with these limitations, the multilateral export control regimes make an important contribution to nonproliferation. Export controls serve three nonproliferation purposes:

1. to inhibit the progress of a weapons development program by forcing the nuclear-aspiring nation to find another channel for import or to reverse engineer a product;
2. to increase the cost and the length of time to build a nuclear weapon; and
3. to allow nations to exchange information so that

recognizable patterns of proliferation can be observed, if possible.[27]

Using SNA to identify key actors in the trade of dual-use goods and the patterns that emerge can help nations achieve the third goal. The systemic approach emphasizes the identification of macro-level trade patterns and trends. It does so in a manner that is conducive to working with a greater amount and complexity of data than is feasible in traditional analysis assisted with data in a list or spreadsheet format.

The global nuclear trade network is a dynamic system where new actors emerge and cease to be prominent exporters and importers over time. With accurate and timely data on international nuclear transactions, periodic assessments can be performed to identify changes in centrality over time and the development of new trade configurations. Such monitoring can assist the making of timely adjustments in export control policy.

The systemic analysis also reinforces the need for greater unilateral and bilateral efforts at restricting the export of a broad range of critical technologies. Export controls may be enhanced by policy initiatives that focus on individual nations that act as central importers or exporters with respect to the current potentially aspiring states, such as Iraq, Iran, and North Korea, or the newly declared nuclear weapons states of India and Pakistan. A bilateral approach would include expanded agreements and interactions between the United States and Russia, the United States and China, and any other of these countries and other central suppliers. The United States can also continue to develop unilateral nonproliferation strategies. Because the SNA centrality measures suggest that certain suppliers occupy especially influential positions, unilateral policies of export self-restraint could be productive in slowing nuclear proliferation. This study clearly suggests that multilateral agreements are not the only feasible nonproliferation strategy.

With a better understanding of trade information, therefore, more focused policymaking and more efficient implementation of existing nonproliferation regimes can be accomplished. By focusing on nations that wield tremendous influence over the network rather than just the nuclear-aspiring nations, fewer resources might be required to inhibit supply to nuclear-aspiring nations. Although there has always been recognition that supplier nations bear responsibility, the determination of different levels of power in the network can make for a more complete picture of the responsible parties. Greater attention can be paid to nations that serve as gatekeepers, which goes beyond the idea of the middleman to the idea of addressing the most powerful middleman.

Further attention to nations' positions in the global nuclear market can also reveal the nations that are high in Closeness centrality. Such a position suggests an attempt to import a wide scope of nuclear goods in a manner that helps avoid scrutiny. Discovery of such a trading profile can provide a warning that a country may aspire to develop nuclear weapons.

This study has sought to find structure in a complex global system of nuclear-related transactions. With the application of a quantitative methodology designed specifically for determining the structure of and dynamics within networks, the complexity of dual-use nuclear trade was reduced empirically to manageable levels that could be used to better inform nonproliferation policymaking. The results of this study demonstrate that such analysis can be accomplished for nuclear transactions to reveal a structure in trade that is useful for the support of existing nonproliferation policies and the construction of enhanced policy in the future.

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[1] For this study, corporations are treated as part of the country within which they are operating. It assumes that national governments can control corporations operating in their territory.

[2] David Albright and Mark Hibbs, "Iraq's Bomb: Blueprints and Artifacts," *Bulletin of the Atomic Scientists* 48 (January/February 1992); David Albright and Mark Hibbs, "Iraq's Shop-Till-You-Drop Nuclear Program," *Bulletin of the Atomic Scientists* 48 (April 1992).

[3] David Kay, "Denial and Deception Practices of WMD Proliferators: Iraq and Beyond," *Washington Quarterly* 18 (Winter 1995).

[4] Ibid.

[5] Leonard S. Spector, *Going Nuclear* (Washington, DC: Carnegie Endowment for International Peace, 1987) and *The Undeclared Bomb* (Washington, DC: Carnegie Endowment for International Peace, 1988).

[6] Mitchell Reiss and Robert S. Litwak, eds., *Nuclear Proliferation after the Cold War* (Washington, DC: Woodrow Wilson Center Press, 1994).

[7] Richard K. Betts, "Paranoids, Pariahs, and Nonproliferation Revisited," in Zachary S. Davis and Benjamin Frankel, eds., *The Proliferation Puzzle: Why Nuclear Weapons Spread (and What Results)* (Portland, OR: Frank Cass, 1993).

[8] Literature that addresses the background and theory of Social Network Analysis includes: Linton C. Freeman, "Centrality in Social Networks Conceptual Clarification," *Social Networks* 1 (February 1979), pp. 215-239; David Knoke and James H. Kuklinski, *Network Analysis* (Beverly Hills: Sage, 1982); David Krackhardt, "Assessing the Political Landscape: Structure, Cognition, and Power in Organizations," *Administrative Science Quarterly* 35 (June 1990), pp. 342-369; John Scott, *Social Network Analysis: A Handbook* (London: Sage, 1991); David A. Smith and Douglas R. White,

"Structure and Dynamics of the Global Economy: Network Analysis of International Trade," *Social Forces* 70 (June 1992), pp. 857-893; and Stanley Wasserman and Katherine Faust, *Social Network Analysis: Methods and Applications* (New York: Cambridge University Press, 1994).
[9] For a detailed technical explanation of social network analysis centrality measures, see Jennifer Hunt Morstein, *Determining the Structure of the Global Dual-Use Nuclear Trade Network: Analysis for Improved Nuclear Nonproliferation Policy*, (Ph.D. diss., The School of Public Policy, George Mason University, 1999), and Wasserman and Faust, *Social Network Analysis*.
[10] Krackhardt, "Assessing the Political Landscape."
[11] Wasserman and Faust, *Social Network Analysis*, p. 189.
[12] Ibid., p. 190.
[13] Center for Nonproliferation Studies, *Nuclear Abstracts Database* (Monterey, CA: Monterey Institute of International Studies), on-line subscriber access at <http://cns.miis.edu>.
[14] Jennifer Hunt Morstein. *Coded Nuclear Dual-Use International Trade (CONDUIT) Database*, Version 1.2 (Annandale, VA, 1999).
[15] Data on Iraqi nuclear transactions continued emerging after the UNSCOM inspections in Iraq due to an inherent lag in the reporting of data. Since the main data source was news media, as UNSCOM uncovered more Iraqi imports of the past they were reported often without reference to the year of import. To maintain structure in the coding of the data, when a report lacked a date, the year of the report was noted. Therefore, the presence of Iraq as a central actor in the second timeframe must be considered to be a reflection of its activities in the first.
[16] The commodities used in the study were defined as follows:

1. Uranium, including low-enriched uranium, nuclear fuel, uranium hexaflouride (UF6), and natural uranium;
2. Highly Enriched Uranium, including weapons-grade uranium;
3. Plutonium, including spent fuel, reprocessed fuel, and mixed-oxide fuel;
4. Enrichment Equipment and Plants, including plants, major components, and designs for enrichment;
5. Higher Danger Reactors, including heavy water reactors (HWR) and breeder reactors such as LMFBR, FBR, HTGR; and
6. Lower Danger Reactors, including light water reactors (LWR) such as pressurized and boiling water reactors, and research reactors.

[17] Measures of centrality were derived using the SNA software package UCINET IV. Borgatti, Everett, and Freeman, *UCINET IV Version 1.64* (Natick, MA: Analytic Technologies, 1996). Related maps were generated by using Krackplot. David Krackhardt, Jim Blythe, and Cathleen McGrath, *Krackplot Version 3.0* (Columbia: Analytic Technologies, 1995).
[18] These results were obtained using the Borgatti et al. *UCINET IV* statistical software.
[19] Reprocessing and enrichment activities are higher danger commodities and are included under the categories of plutonium and highly enriched uranium. Enrichment equipment and plants are provided as their own commodity to represent the trade of the facilities and components for the enrichment of uranium. However, there is no category for reprocessing equipment and plants. This is due to a problem in the reporting of the data. Reprocessing equipment and plants were always lumped with enrichment equipment and plants. Thus, reprocessing could not be extracted separately. Often enrichment equipment and plants were reported separately and so, analysis could be performed on the category.
[20] Summary of information obtained from Center for Nonproliferation Studies, *Nuclear Abstracts Database* (Monterey, CA: Monterey Institute of International Studies), on-line subscriber access at <http://cns.miis.edu>.
[21] Map generated using Krackhardt et al., *Krackplot*.
[22] Ibid.
[23] Ibid.
[24] Plutonium was classified as a higher danger commodity; however, the maps reveal that it partly resembles a Spider Web configuration. Indeed, there are many actors in the networks with many interconnections. But this is an artifact of data limitations because the plutonium category included the trade of spent fuel and radwaste, which made the analysis of plutonium impossible to segregate. These less dangerous sub-commodities are the reason for this otherwise higher danger commodity to behave in a manner of a lower danger commodity. Specific SNA results for plutonium can be found in Table 1.
[25] Carlton E. Thorne, ed., *A Guide to Nuclear Export Controls 1999-2000* (Burke, VA: Proliferation Data Services, 1999), p. 8.
[26] Kathleen Bailey and Robert Rudney, eds., *Proliferation and Export Controls* (Lanham, MD: University Press of America, 1993).
[27] Randall Forsberg et al., *Nonproliferation Primer* (Cambridge, MA: MIT Press, 1995), pp. 105-107.