Bureaucratic Networks and Government Spending: A Network Analysis of Nuclear Cooperation in Latin America

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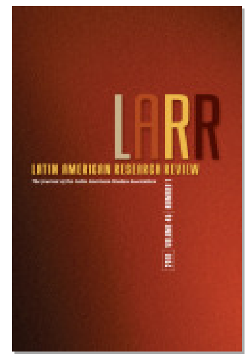

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BUREAUCRATIC NETWORKS AND GOVERNMENT SPENDING

A Network Analysis of Nuclear Cooperation in Latin America

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Abstract: What do technology-driven bureaucratic sectors do when their budgets are cut? In Latin America, this type of state institution has come to expect budget reductions, given recurrent economic crises, lack of coherent science policy, and more recently, state rationalization policies. On the basis of in-depth interviews I conducted with nuclear specialists of the region and drawing from network theories, I argue that bureaucratic institutions with expertise in nuclear science and technology respond strategically to decreased government spending by becoming more active in transnational policy networks. I test this argument using social network and maximum likelihood techniques to study collaborative research projects in nuclear science and technology among twenty Latin American countries over a period of twenty years (1984–2004). Study findings confirm expectations and carry implications for how science policies are adopted in Latin American states under chronic budget deficits.

What do technical bureaucratic agencies do when their budgets are cut? In Latin America, this type of state institution has come to expect budget reductions, given recurrent economic crises, lack of coherent science policy, and more recently, state rationalization policies. Technology-driven bureaucratic sectors have been affected particularly by declining public investment in research and development (R&D); declining salaries for expert personnel; and smaller budgets for education, training, and research projects (Velho 2005). Explaining how these technical agencies deal with the unstable financial capacity of the state is key to understanding how science policies are developed in Latin America.

In this study, I analyze the evolution of a Latin American network of state institutions that exchange scientific knowledge and work on joint R&D projects in the broad field of nuclear science and technology. I argue that this transnational network, formed by reciprocal and horizontal in-

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teractions among specialists and the institutions within which they work, evolves as a result of the ups and downs of state spending in Latin America. On the basis of in-depth interviews with nuclear experts, I assert that technical agencies connect transnationally because their bureaucrats—motivated by declining government financing—seek to share the costs of research and to pool existing resources with their peers in the region. Because in Latin America these sectors have persistent low financial capacity and the private economy offers limited if any employment alternatives (Schwartzman 1994; Solingen 1994), I expect state agencies to collaborate with like institutions in other countries thus forging transnational ties.[1] This study builds on, and contributes to, a rich literature on bureaucratic politics that emphasizes how technology-driven sectors require bureaucrats with specific technical expertise to implement policy (Carpenter 2001; Evans 1995; Mete 2002; Sikkink 1991; Weber 1958) and are embedded in policy networks through which skilled bureaucrats push their agenda, preserve their knowledge, and keep abreast of new technological developments (Carpenter 2001; Heclo 1978; Sabatier and Jenkins Smith 1999).

In this article, I use social network and maximum likelihood techniques to analyze seventy-six cross-national R&D projects in nuclear science over a period of twenty years (1984–2004) carried out by twenty Latin American countries.[2] These transnational projects apply nuclear science and technology to biotechnology, agriculture, industry, health, nuclear safety, and energy. All seventy-six projects were coordinated by the Regional Cooperative Arrangement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL), a Latin American network—created in 1984— that links domestic atomic institutions to the International Atomic Energy Agency (IAEA) (for a list of nuclear domestic institutions, see appendix 1). In addition, I gathered data by conducting a series of in-depth interviews with state officials from the national atomic agencies in Argentina and Brazil, and with Latin American officials from IAEA in Vienna.

1. In a 2005 overview of science and technology institutions in Latin America and the Caribbean (LAC), the author of the report states: "In Latin America and Caribbean countries the public sector is still responsible for over 70% of R&D funding and performance. . . . The research community, for example, struggles for more public research funds and to keep control over how resources are allocated. There is no denying that, as the public sector is the primary sponsor of R&D in LAC, any reduction in government spending has a strong negative effect. Most LAC countries have suffered such effects as the increase in private-sector expenditure on R&D in the region (from 20% in 1990 to 36% in 2000) did not compensate for the decrease in public R&D funding" (Velho 2005, 103–105).

2. These are all the countries that participate in the ARCAL network: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela.

Using a two-stage design, first I estimate different measures of network centrality and density to quantify the evolution of the nuclear network in Latin America and to locate the position of each country within the network.[3] Second, using as dependent variable the location of each country within the network and a battery of independent variables, I test the relationship between government spending and network participation with the expectation that the decline of the former will increase the later. Study results support this hypothesis. This research uncovers somewhat of a paradox that should be of interest for students of resource-starved Latin American countries: how bureaucrats and institutions forge science policy and regional cooperation not from abundance but from a scarcity of resources. This article also contributes to a growing literature studying the development of transgovernmental networks. In recent years, transnational networks have received considerable attention from scholars trying to understand international collaboration on international regimes, epistemic communities, human rights, environmental policies, transgovernmental relations, and social movements (Adler and Haas 1992; Haas 1992; Keck and Sikkink 1998; Keohane and Nye 1989; Rohrschneider and Dalton 2002; Slaughter 2004; Tarrow 2005). My research provides a precise method for analyzing such networks, using social network analysis to measure the evolution and structure of transnational collaboration.

This article proceeds as follows. In the following section, I discuss the theoretical basis of my argument. I then present a brief history of the network of Latin American nuclear bureaucrats. I then measure the structure of nuclear collaboration using the statistical toolbox of social network analysis, and I present cross-sectional time-series regressions explaining changes in the centrality of twenty Latin American countries in the ARCAL nuclear network. I conclude by discussing the implications of this study for future research on science policy networks.

WHY DO BUREAUCRATIC INSTITUTIONS FORGE TRANSNATIONAL NETWORKS?

The central argument of this article—that bureaucratic technical agencies seek to compensate the loss of state funding by forging ties with like institutions in other countries—is based on two key assumptions. First, bureaucrats in technology-intensive sectors are embedded in policy networks, where knowledge is the most important resource exchanged. As technological change accelerates, skilled bureaucrats increasingly rely on their ties with professional peers to keep abreast of developments in their

3. In this research, I focus primarily on two measures: centrality measures, which indicate the number of ties of the actors in the network, and multidimensional scaling measures, which estimate the relative location of these actors in n-dimensional spaces.

disciplines. Iterated exchanges with colleagues in their field create policy knowledge networks that become part of the bureaucrats' professional capital (Carpenter 2001; Heclo 1978; Sabatier and Jenkins Smith 1999; Schneider, Scholz, Lubell, Mindruta, and Edwardsen 2003). Bureaucratic networks, thus, are "networks [that] evolve across administrative and political boundaries and provide a potential alternative to more formalized, hierarchical coordination mechanisms" (Schneider et al. 2003, 143).

The second assumption has to do with the relative financial capacity of the state, the private sector, and universities, the three principal arenas in which science policy is forged (Schwartzman 1994; Solingen 1994). In Latin American countries where the private sector is small, and (mostly public) universities have few resources, the state is virtually the sole employer in technology-intensive areas (Velho 2005). Highly skilled and trained bureaucrats do not expect to find employment or alternative sources of funding outside the state.[4]

What are the precise mechanisms by which technologically driven state sectors compensate for the loss of funding through international networks? Building on previous studies that explain the networking strategies of state agencies as bureaucrats' attempts to build professional reputations (Carpenter 2001; Crowe 2007), to consolidate shared professional norms (Hawkins and Jacoby 2006), and to improve policy implementation (Evans 1995; Sikkink 1991), I highlight the link between transnational networking and budget reductions. Recently, Hawkins and Jacoby (2006) have argued that bureaucrats can use networking strategically to boost their political autonomy. In a similar vein, I argue here that skilled bureaucrats can use networking as a political strategy to compensate for budget reductions.

Specifically, when governments decrease spending, those sectors with higher salaries and investment costs face statewide hiring and spending freezes. In such circumstances, starting new R&D projects in government research agencies becomes extremely difficult and ongoing projects are revised, canceled, or downgraded (Velho 2005). Commercial agreements with suppliers, in particular international ones, are also interrupted,[5] and the lack of key supplies often results in the total shutdown of proj-

4. Most developing countries share this problem. As the former chair of the Pakistani Atomic Energy Commission put it, "While there is an increasing emphasis on privatization and deregulation, the energy program in the third world is still very much under the public sector and the nuclear can thus get the long term commitments it requires subject of course to the availability of the resources with the public sector" (Ishfaq Ahmad 2004 at http://www.iaea.org).

5. Domestic suppliers in developing countries are often state-owned, thus the government can intervene in order to guarantee the supply. However, governments are usually unable to wrestle supplies from foreign providers.

ects if there are no domestic alternatives to the imported equipment or technology.[6] Furthermore, reductions in anticipated spending levels frequently result in the cancellation of entire programs because default on contractual obligations in any aspect of the agreement also results in the loss of technology transferred pursuant to that agreement. When budgets are cut, research projects and programs are undermined and considerable scientific capital is lost (Dickson 2003).[7] This should be particularly pervasive in Latin America, where the adoption of structural adjustment programs since the 1980s has deeply affected government spending—and consequently, bureaucrats' financial capacity to implement policy (Huber and Solt 2004; Walton 2004; Wayland 2004).

To make up for lost research and to maintain existing programs, nuclear bureaucrats seek collaboration with peers in other developing countries by pooling scarce existing resources and sharing the costs of research. The Argentine coordinator of ARCAL explains how bureaucrats in domestic institutions with nuclear expertise promote their own research agendas in the region: "Each country has certain national priorities within its own (nuclear) institutions and the project ideas come from there. . . . [W]e present these ideas, just like the other countries and if there is a consensus, that is, if there is a minimum of four countries that have presented similar projects in the area, they get together and move forward."[8]

These bureaucrats generate low-budget projects that they can commit to (and afford) in nuclear science and technology.[9] As a Brazilian nuclear bu-

6. In particular for the more advanced countries in the region, such as Argentina, Brazil, and Mexico, bilateral treaties with advanced nuclear countries were instrumental in developing their nuclear programs. However, these comprehensive agreements (with both commercial and technology transfer aspects) are no longer affordable. This affects the possibility of cooperation between North and South. One nuclear bureaucrat explains: "Once the commercial aspect of the treaty is over, cooperation stops [. . .] that happened to us with Germany. Cooperation with Germany was very intense but once the [commercial] relationship was over they were done. The same thing happened with Canada [. . .] The French were brutally honest with us. They said clearly that they had little interest in cooperation by itself [. . .] rather they look at it through the dollar or Euro sign." (Roberto Ornstein, Director of International Cooperation of the Argentine National Atomic Energy Commission, Buenos Aires, Argentina, July 28, 2006. Personal interview with the author.)

7. Also see the Second Pugwash Workshop Report on Economic and Social Inequities in Latin America (September 1–12, 2004, Bariloche, Argentina) at http://www.pugwash.org/reports/ees/argentina2004/report.htm

8. César Tate, ARCAL liaison for Argentina, Buenos Aires, July 15, 2006. Personal interview with the author.

9. The problem of commitment is particularly acute in impoverished bureaucracies. For example, Argentina has a standing invitation to participate in cooperative (noncommercial) research projects with the European Atomic Energy Community (EURATOM). However, this has proved unfeasible because of insufficient resources. "We could participate if we had the means. You have to be responsible for your own expenses and you have to have available personnel to work full time on this. . . . [T]here is a very important opportunity

reaucrat explains: "To develop cooperation projects, there are many things that you might not need a lot of money to do. Nowadays with telecommunications there is exchange of information. Even more so given that people know each other, they can converse and exchange information."[10]

This type of horizontal cooperation replaces (expensive) bilateral commercial agreements. An Argentine nuclear bureaucrat states: "As time went by, the budget situation became tighter and we had to resort to multilateral cooperation as a way to continue having presence in, and collaborate with, the countries of Latin America, through programs like ARCAL or other regional projects . . . in a way, they have replaced the source of financing."[11]

The Chilean liaison of ARCAL describes the makeup of the network, explaining that "the actors, in reality, are the small nuclear communities which developed around the national atomic agencies."[12] These central organizations are typically charged with planning and budgeting tasks to further research in their policy field. Thus, bureaucrats in these state organizations use networking with like organizations as a political strategy to compensate for budget reductions. Networking among developing countries is greatly aided by international organizations (IOs) that can assume, at least in part, the costs of coordination and serve as a forum for professionals to meet and discuss similar concerns.[13] In other words, IOs facilitate the conditions under which bureaucratic transnational networks develop (Slaughter 2004). In particular, IOs that advance technical cooperation, such as the IAEA, will likely be more effective than political IOs in generating these conditions across all or most countries in a region.[14] However, international organizations cannot force member states to develop ties with one another, as a key attribute of a network (that clearly separates it from hierarchical social constructs, like IOs) is its voluntary

in terms of technology but limited resources prevent us from taking advantage of this." (Roberto Ornstein, director of international cooperation of the Argentine National Atomic Energy Commission, Buenos Aires, Argentina, July 28, 2006. Personal interview with the author.)

10. Laercio Vinhas, director of international cooperation of the Brazilian National Commission of Nuclear Energy, Rio de Janeiro, Brazil, July 19, 2006. Personal interview with the author.

11. Roberto Ornstein, July 28, 2006, personal interview with the author.

12. María Cecilia Urbina Paredes, Chilean program manager of ARCAL. Vienna, June 2007. Personal interview with the author.

13. In the nuclear field, where sensitive technology (with both peaceful and nonpeaceful uses) can limit international exchanges, the role of IAEA in international cooperation is key in certifying its nonstrategic nature. In the case of Latin America, as in other developing regions of the world, all countries have formally committed to nuclear nonproliferation.

14. I expect this to be the case because the political consensus required for countries to engage in technical cooperation (through IO-sponsored cross-national R&D projects) is much less demanding than for political cooperation.

nature. Therefore, IOs do not create transnational networks. Rather, "horizontal information networks bring together [bureaucratic actors] to exchange information and to collect and distill best practices. This information exchange can also take place through technical assistance and training programs provided by one country's official to another" (Slaughter 2004, 19). Indeed, for the case at hand, from the first initiative, design, and implementation phase, these research projects are carried out by the countries within ARCAL, not IAEA.[15]

In the final section of this article, I test the hypothesis that as government spending decreases, state institutions increase their participation in the Latin American nuclear network. If bureaucrats (embedded in state agencies) activate ties with their peers in neighboring countries more when their funding dissipates, then we should see a negative relation between government spending and a country's participation in the network. I also test for two alternative explanations: (1) networking is driven by the democratization process initiated in the region in the early 1980s, and (2) networking is driven by economic liberalization reforms adopted in Latin America to varying degrees in the late 1980s and throughout the 1990s.

Students of Latin American regional politics have pointed to the internal demands of democratizing regimes as a primary cause of regional cooperation (Solingen 1998; Sotomayor 2004). One of these demands is the need of the new civilian leadership to establish a favorable balance of power vis-à-vis the military (Alcañiz 2000; Carasales 1997; Sotomayor 2004). This leads to interstate cooperation because regional agreements can help reinforce the demilitarization of the state and "cope with the uncertainties posed by democratization" (Sotomayor 2004, 32). A second, somewhat-related factor is the series of economic reforms adopted and implemented in the region during the 1980s and 1990s. The expectation here is that by opening up their economies, Latin American countries increase their economic interdependence with neighbors, which in turn leads to increased cooperation in other policy areas. Although Hurrell (1998, 538), for example, has critiqued this liberal expectation, he nevertheless explains cooperation in the Southern Cone as "the best case which can plausibly be taken to illustrate these liberal arguments" and "that economic liberalization . . . promotes peace." Hurrell builds on Solingen (1998, 63), who posits a direct link between domestic coalitions that favor economic liberalization and regional cooperation, whereby "higher and extensive levels of cooperation can be expected where internationalist coalitions prevail throughout a given region."

15. María Zednik, former Peruvian section head of ARCAL, Vienna, June 2007. Personal interview with the author.

Given these theoretical expectations, I test the effects of democracy and economic liberalization to determine whether the two factors increase state centrality in the Latin American nuclear network. The dependent, independent, and control variables of this study are described in greater detail in the final section and in appendix 2.

THE DEVELOPMENT OF A NETWORK OF NUCLEAR SCIENCE AND TECHNOLOGY IN LATIN AMERICA

Nuclear science in Latin America offers an excellent opportunity to study the evolution of bureaucratic behavior in science policy. Among the twenty countries in this study, there are examples of high-end nuclear expertise, such as Argentina and Brazil, which are major exporters of nuclear technology in the developing world, together with Mexico, a producer of nuclear energy; cases of low-end expertise, such as Haiti and the Dominican Republic; and intermediate cases, with niche specialization, such as Cuba (nuclear medicine), Peru (mining applications), and Uruguay (agricultural applications). Fifteen of the twenty countries in this study have national nuclear programs; of the remaining five, one has a nuclear subdivision under the Ministry of Energy, and the other four have general national agencies for technical cooperation (see appendix 1 for the liaison institutions for all twenty countries participating in the network). As these state institutions coordinate all nuclear research in the country, in the following analyses—for the purpose of clarity—I use central agencies interchangeably with their respective countries.

I expect countries that possess larger nuclear programs with institutional autonomy to be "most likely cases," given that these programs will have greater discretion to network transnationally. Correspondingly, countries with smaller and less autonomous institutions should be "least likely cases," as they will have less discretion to network outside the national bureaucracy. The countries of interest here also offer most and least likely cases with regards to the two key alternative explanations of this study, liberalization and democratization. That is, countries with open economies should participate more actively in the nuclear network because they have fewer trade barriers to exchanging resources with other countries. Similarly, countries that have experienced political liberalization should be most likely cases, as democratization typically entails the demilitarization of the state, which should facilitate transnational cooperation.[16] Conversely, where the military is in control of the state, we

16. The political takeover by the new civilian leadership triggers the demilitarization of the state. This process, however, remains distinct from democratization given that its scope varies among democracies.

should expect security considerations to hinder transnational networking in the nuclear field; thus, authoritarian regimes should be least likely cases.[17]

Nuclear development in Latin America began in Argentina, Brazil, and Mexico in the 1950s as part of a developmental strategy to industrialize and secure independent sources of energy. In the 1950s, all three countries created centralized government agencies to advance nuclear science and became members of IAEA. By the late 1970s, the Argentine and Brazilian programs mastered virtually all stages of the nuclear energy cycle (i.e., uranium mining, conversion and enrichment, fuel fabrication, and spent fuel reprocessing) (Adler 1988). Mexico, the third country in the region that generates nuclear energy, began experimenting in nuclear physics and purchased the first particle accelerator in Latin America (Ramos Lara 2006). In the late 1970s, Mexico started the construction of an atomic power plant that became operational more than a decade later.

Other countries in the region lagged behind. Although most Latin American states joined IAEA a few years after its creation in 1957, the development of nuclear science has not resulted in comprehensive, energy-generating programs across the region. Rather, several countries have focused on specific areas and applications of nuclear technology, and their efforts have been greatly assisted by IAEA and the more advanced nuclear programs of Latin America. In particular, Argentina and Brazil, the only two Latin American members of the international Nuclear Suppliers Group, have exported technology and know-how to many neighbors.[18] For example, Argentina designed and built a research reactor for Peru in the 1980s and a radioisotopes generator for Cuba in the 1990s (Buch 1998; Radicella 1998); Brazil sold reactor supplies and uranium concentrate to Argentina in the 1980s (Solingen 1996). Moreover, the two countries have contributed to the advancement of nuclear science in the region through numerous noncommercial activities, such as personnel training, symposia, workshops, and so on (Carasales and Ornstein 1998; Schwartzman 1994; Solingen 1996). As the indebted countries of Latin America constantly face budget crises, nonprofit cooperation has often been the most reliable source of scientific knowledge for the region.

The IAEA has been a critical source of technical assistance for developing countries engaged in nuclear science. But the organization favors members' self-initiative and nonmaterial assistance. For example, ARCAL

17. Most likely and least likely cases help determine the fit of a theory as well as how much can be inferred from it (George and Bennett 2005).

18. On the nuclear rollback of Argentina and Brazil, initiated in the mid-1980s after decades of rivalry in nuclear development, see Alcañiz 2000; Carasales 1997; Hurrell 1998; Solingen 1998; and Sotomayor 2004.

was an initiative proposed to the IAEA by the countries of the Andean Group (AG) and later endorsed by the Southern Cone states.[19]

The ARCAL group was first organized in 1984, just two years after the 1982 foreign debt crisis and at the beginning of the wave of democratization that was to sweep Latin America throughout the decade. After 1984, the remaining Latin American countries, including the Central American states; Mexico; and the Caribbean states of Cuba, the Dominican Republic, and Jamaica joined the agreement. The central mission of ARCAL was to promote horizontal cooperation, to pool regional resources, and to transfer know-how and technology from the more advanced to the least advanced countries. As briefly explained earlier, under this program, nuclear bureaucrats from some or all of the twenty member states propose, approve, and carry out joint projects in nuclear science and technology.

These joint projects may be classified as four types: (1) cross-national training of nuclear personnel as well as the establishment of new and the maintenance of existing laboratories; (2) standardizing nuclear techniques in the region; (3) creating regional systems, such as the 1995 Regional Network of Nuclear Agricultural Techniques; and (4) organizing and managing nuclear knowledge through translations, reports, manuals, bibliographies, and so on.[20] The IAEA's financial contribution to these projects is modest; over the period of time studied in this article, the agency contributed approximately $26 million to ARCAL (an average of $1.3 million per year for all twenty members).[21] Members of ARCAL match these disbursed funds but mostly through in-kind contributions; that is, little money is disbursed directly.[22] The leading states in nuclear development in the region (Argentina, Brazil, and Mexico) are the ones that contribute the most funds, goods, and services.[23]

From 1984 to 2005, ARCAL was an agreement through which only domestic nuclear institutions were linked.[24] During this period of time,

19. The Andean Group is made up of Bolivia, Colombia, Ecuador, Peru, and Venezuela. Argentina, Brazil, Chile, Paraguay, and Uruguay are known as the Southern Cone states. See http://arcal.cnea.gov.ar/quees/como.asp. Accessed August 15 2007.

20. Productos e Impactos de los Proyectos ARCAL durante 20 Años de Vida (1984–2004). http://arcal.cnea.gov.ar/ Accessed August 15, 2007.

21. "Extrabudgetary contributions" from outside donors have amounted to approximately $4 million from 1983 to 2004. In "The ARCAL Programme: Over Two Decades of Cooperation in Science and Technology." http://arcal.cnea.gov.ar/. Accessed August 15, 2007

22. "The ARCAL Programme: Over Two Decades of Cooperation in Science and Technology." http://arcal.cnea.gov.ar/. Accessed August 15, 2007.

23. To date, Argentina and Brazil have contributed close to US$2.5 million each, and Mexico approximately $1 million. http://arcal.cnea.gov.ar/paises/paises.asp. Accessed August 15, 2007.

24. For a complete list of participating state institutions, see http://arcal.cnea.gov.ar/instituciones/institu.asp. Accessed August 15, 2007.

ARCAL grew to include most Latin American states and significantly increased the number of projects being developed in the region. From 1984 through 1988, Latin American nuclear scientists carried out eleven projects; from 1989 through 1994, an additional nine projects. During a third period (1995–1999) there were twenty-eight projects executed, and finally, from 2000 to the present, ARCAL has twenty-eight active projects.[25] In part because of the rise in the number of projects, ARCAL was formally instituted in 2005 as an intergovernmental agreement.[26] However, as a Brazilian bureaucrat states: "Nothing changed when ARCAL became an intergovernmental agreement. Even in ARCAL's Representation Organ [ORA], where technically an ambassador should lead the Brazilian delegation, I never saw an ambassador. The president of the National Commission of Nuclear Energy [CNEN] always presides, together with the ARCAL liaison."[27]

In the following two sections, I test my argument and some hypotheses by applying social network analysis to the data on regional collaboration under the ARCAL program.

A NETWORK ANALYSIS OF SCIENTIFIC COLLABORATION IN LATIN AMERICA

I begin by providing some key descriptive statistics of participation in the ARCAL. This first analysis reveals two things: (1) the existence of a regional network formed by cross-national collaboration of bureaucratic agencies in the field of nuclear science and technology and (2) the level of country participation in the network varies over time. Such variation will be the object of analysis in the penultimate section.

To analyze the network of collaboration among nuclear agencies in Latin America, I first compiled a data set consisting of all projects implemented by ARCAL participant countries between 1984 and 2004. A total of seventy-six collaborative projects were analyzed with information on cosponsorship, type of project, year of initiation of the project, and its duration. The cosponsorship data was then transformed into a symmetric $R \times C$ (row by column) affiliation matrix that describes the number of projects in which countries (reported by pairs) have collaborated together since 1984. This affiliation matrix was used to measure the structure of the Latin American nuclear network.

25. In "Productos e impactos de los proyectos ARCAL durante 20 años de vida" (1984–2004). Also see http://arc.cnea.gov.ar/proyectos/proyec.asp.

26. See INFCIRC/686 at http://arc.cnea.gov.ar.

27. Laercio Vinhas, director of international cooperation of the Brazilian National Commission of Nuclear Energy, Rio de Janeiro, Brazil, July 19, 2006. Personal interview with the author.

Table 1 provides the affiliation matrix with summary information on project collaboration between 1984 and 2004. The top-diagonal row in table 1 describes the total number of projects in which each country participated. As shown, Brazil participated in sixty-nine projects, followed by Argentina (sixty-eight), Chile (sixty-three), Mexico (sixty-one), and Cuba (sixty). Unexpectedly, Chile, the third most active country, does not have a nuclear energy program, as Argentina, Brazil, and Mexico do. However, the country has invested in nuclear research since the 1950s, mostly through university programs. After the coup d'état against socialist president Salvador Allende, the Pinochet dictatorship (1973–1990) gave the military a stronger stake in nuclear development by strengthening the Military Center for Nuclear Studies (CENE) and signing cooperative nuclear treaties with the military governments of Argentina (1976) and Brazil (1980).[28] Finally, Cuba, a country that by its size and geographical location should be closer to smaller states such as the Dominican Republic (with participation in only twenty projects), owes its place with the regional leaders to the many years of Soviet subsidy and to Fidel Castro's investment in advanced health care. Indeed, under Castro's leadership, Cuba has carved its niche as one of the high-tech medical centers of Latin America, including nuclear medicine.

A first measure of the level of activity of nuclear collaboration is to analyze the density of the network; that is, the average number of ties between each pair of countries. The density of the nuclear network, therefore, estimates the average number of times each pair of countries participated together in an ARCAL project. Using the ARCAL project data, the average density of the network in the 1984–1988 period was 3.11. It increased to 3.14 in the 1989–1994 period, to 9.25 in the 1995–1999 period, and declined to 7.67 in the 2000–2004 period.[29] The density of the network, however, provides little information about the relative position of each country's nuclear sector within the network. This information is critical if we want to understand why different national groups of nuclear bureaucrats become more or less active in the nuclear network.

To analyze the relative position of Latin American states within the collaborative nuclear network, I provide three centrality measures in table 2.[30] Centrality measures describe how active participants are in a net-

28. http://reportajes.canal13.cl/reportajes/html/ReportajesDelSiglo/Reportajes/1999/263079.html.

29. Density values were computed with UCINET. The time periods are established by ARCAL.

30. Degree centrality measures the number of nodes that are adjacent to an actor n_i. The standardized measure proposed by Wasserman and Faust (1994, 179) is $C_D(n_i) = [d(n_i)/(g - 1)]$, where $d(n_i)$ describes the number of nodes that are adjacent to n_i and g describes the group size.

Table 1 Nuclear Collaboration among Latin American Countries, Number of Projects in which They Have Participated between 1984 and 2004

(Affiliation Matrix, ARCAL)

	Argen-tina	Bo-livia	Brazil	Chile	Colom-bia	Costa Rica	Cuba	Domini-can R	Ecua-dor	El Salva-dor	Guate-mala	Haiti	Jamaica	Mexico	Nicaragua
1 Argentina	68														
2 Bolivia	34	37													
3 Brazil	66	36	69												
4 Chile	62	33	61	63											
5 Colombia	38	28	39	37	40										
6 Costa Rica	44	29	43	40	29	49									
7 Cuba	55	30	55	52	32	40	60								
8 Dominican R	17	12	15	16	12	16	19	20							
9 Ecuador	39	29	38	38	31	30	31	10	39						
10 El Salvador	15	16	17	13	8	15	17	9	11	18					
11 Guatemala	38	28	39	37	26	37	34	13	28	14	44				
12 Haiti	4	3	4	4	3	3	4	4	3	2	3	4			
13 Jamaica	4	4	4	4	4	3	4	2	4	1	3	2	4		
14 Mexico	59	29	58	56	33	41	52	17	34	15	34	4	4	61	
15 Nicaragua	16	14	17	14	12	18	18	9	9	10	14	3	2	17	20
16 Panama	23	17	23	22	16	24	26	11	17	10	22	3	2	23	14
17 Paraguay	32	25	33	30	27	27	25	11	26	12	27	4	2	26	12
18 Peru	50	32	52	48	34	35	45	15	33	17	31	3	2	47	18
19 Uruguay	49	24	48	44	29	34	46	18	27	14	28	4	2	47	15
20 Venezuela	37	21	36	34	23	28	37	12	24	13	24	3	2	37	16

Note: Estimated with data from ARCAL (2004).

Table 2 Nuclear Network Centrality for Participating Countries, 1984–2004

	Centrality (Degree)	Centrality (Num Degree)	Centrality (Share)
Brazil	684	54.545	0.078
Argentina	682	54.386	0.077
Chile	645	51.435	0.073
Mexico	633	50.478	0.072
Cuba	622	49.601	0.071
Peru	588	46.89	0.067
Uruguay	548	43.7	0.062
Costa Rica	536	42.743	0.061
Guatemala	480	38.278	0.054
Ecuador	462	36.842	0.052
Colombia	461	36.762	0.052
Venezuela	457	36.443	0.052
Bolivia	444	35.407	0.05
Paraguay	411	32.775	0.047
Panama	328	26.156	0.037
Nicaragua	248	19.777	0.028
D. Republic	238	18.979	0.027
El Salvador	229	18.262	0.026
Haiti	63	5.024	0.007
Jamaica	55	4.386	0.006

Note: Estimated using UCINET 6.1.

work by counting the number of ties between actors. As Wasserman and Faust (1994, 178) describe, "The simplest definition of actor centrality is that central actors must be the most active in the sense that they have the most ties to other actors in the network or graph." By measuring actors' different share and degree of involvement in the network, we are able to understand group structure and identify the most active or central players, which in turn informs us of the prominence of different actors.

As expected, the data confirms the crucial position of Argentina and Brazil in the network. The two countries have the most advanced programs in Latin America, and they have assisted in past decades other South and Central American programs, including programs in Chile, Guatemala, Peru, and Uruguay.[31] Chile once more occupies a central position, in part because of its privileged ties to Argentina and Brazil. Peru also has close ties to Argentine nuclear scientists, as Argentina supplied that country

31. Carasales and Ornstein 1998; Laercio Vinhas, director of international cooperation, National Commission of Atomic Energy of Brazil, Rio de Janeiro, Brazil, July 19, 2006, personal interview with the author; and Renato Radicella, former ARCAL liaison for Argentina, Buenos Aires, Argentina, July 31, 2006, personal interview with the author.

with its first research reactor of 10 megawatts and trained its personnel in the late 1970s (Carasales and Ornstein 1998). Uruguay, nestled geographically between Argentina and Brazil, has a small program. However, the country has worked closely with its two neighbors and has participated actively in ARCAL, especially in all projects dealing with nuclear applications in agriculture.

To better visualize the relationship among central nuclear agencies in Latin America, I provide a nondirectional network graph with nodes describing each institutional actor by country and jittered ties summarizing their proximity.[32] Not unexpectedly, Argentina, Brazil, and Mexico are at the center of the network. Chile, Colombia, Cuba, Peru, and Uruguay—countries with intermediate development of nuclear science and technology—are closely located to the network's core. Along the edge of the network are the less advanced states of the region; all of Central America, the poorest South American countries, and two Caribbean states. Guatemala appears surprisingly connected to the core, as can be observed by the density of its ties. This country experienced almost forty years of civil war from the 1950s to the late 1990s. Yet in 1985, Guatemala was the first country of Central America and the Caribbean to join ARCAL. Why is the country so active in the network? In the early 1980s, a small but proactive group of Guatemalan scientists sought to develop nuclear technology with the help of the more advanced countries of the region.[33] By 1986, Guatemala had also signed cooperation agreements with Chile and Argentina. During the period 1980–1997, twenty-nine Guatemalan scientists were trained in the Argentine nuclear program (Carasales and Ornstein 1998).

Although the descriptive results in table 1 and figure 1 provide valuable information about the structure of nuclear network collaboration in Latin America, they say little about its evolution. To show how the network evolves, I analyze the variance in centrality share by country for four different time periods: 1984–1988, 1989–1994, 1995–1999, and 2000–2004, and estimate centrality measures for each one. The four time periods correspond with the first four phases or cycles of ARCAL (IAEA, Information Circular/686, 21 November 2006) and reflect major political and economic events in the region—in chronological order, the foreign debt crisis and the early regime transitions in South America, the second wave of democratization of Latin America (Chile and Central America), wide-

32. The network was plotted using the SNA package in R 2.6, with a matrix of probabilities drawn from table 1 and distances estimated via multidimensional scaling (MDS). The MDS option takes as input a matrix of similarities and finds a "set of points in k-dimensional space such that the Euclidean distances among these points corresponds as closely as possible to the input proximities" (Borgatti, Everett, and Freeman 2002, 81).

33. Renato Radicella, former ARCAL liaison for Argentina, Buenos Aires, Argentina, July 31, 2006, personal interview with the author.

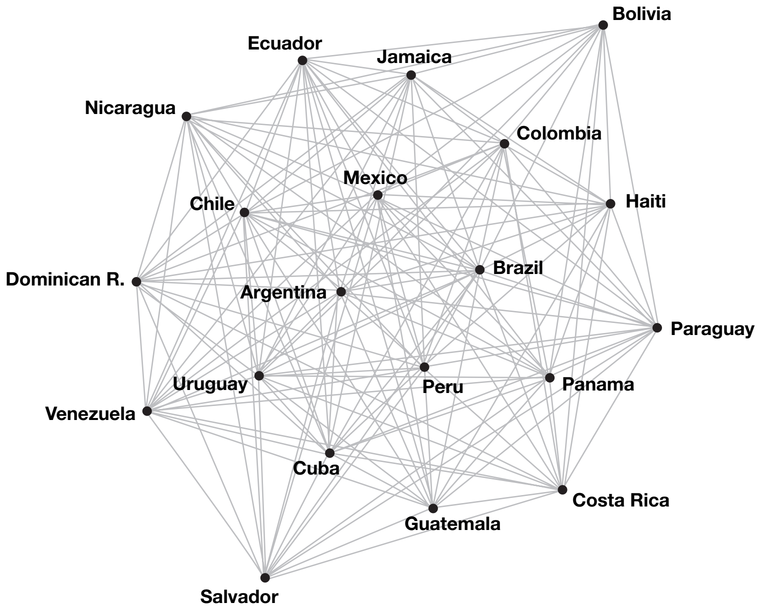

Figure 1 The Nuclear Collaboration Network, 1984–2004 (Multidimensional Scaling Estimates)

Note: Network plot using multidimensional scaling with probabilities drawn from the affiliation matrix.

spread administrative reforms in Latin America, and the institutional and economic crises that affected Latin America in recent years. Figure 2 presents the variation in centrality share over twenty years. Although the top nuclear powers in the region are consistently positioned at the center of the regional nuclear network, the centrality share values for most other countries vary considerably over the twenty-year period examined. In the next section, I test a series of hypotheses to explain the variation in the position of Latin American states in a regional nuclear network.

NETWORK EVOLUTION: VARIABLES, DATA ANALYSIS, AND RESULTS

Why do bureaucratic institutions become more or less active in transnational networks over time? In this section, I explain the evolution of the nuclear network in Latin America between 1984 and 2004. To explain changes in the level of participation of countries, I run multivariate regression models using centrality share as the dependent variable, estimated in the previous section. The centrality share scores for each country were estimated for each of the four periods displayed in figure 2, using the ARCAL nuclear collaboration data and the agreement matrices described

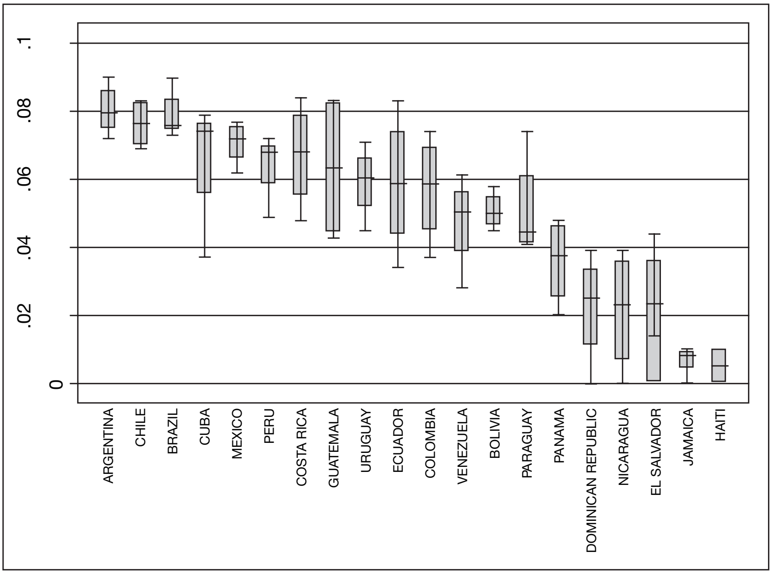

Figure 2 Centrality Share by Each Latin American Country in Four Periods, 1984–1988, 1989–1994, 1995–1999, and 2000–2004

Note: Estimated from Ucinet 6.1 results

in the previous section. Given the theoretical expectations discussed previously, the central hypothesis tested here is as follows:

H_1: As government spending decreases, nuclear bureaucratic agencies will increase their participation in the regional network.

I expect to see a negative relation between these two variables, whereas when a government reduces its expenditure, state institutions from that country increase their participation in the regional network. To test this hypothesis, I collected country- and period-level covariates, including measures of government spending, democratic status of the country, private investment, and other relevant controls.

The most important independent variable, government spending as a share of gross domestic product (GDP), tests for the negative association with participation in nuclear networks. A second variable of interest tests for the democratic status of each country. In the past twenty-five years, Latin America has seen not only an important retrenchment of the state but also a wave of democratization. It could be argued that democratization increases transparency in security policy and, consequently, facilitates the expansion of collaborative networks in nuclear science and technology. To control for the possible effect of a country's democratic status on network participation, I use a dummy variable coded 1 if country *i* in period j was democratic and 0 otherwise.[34] I also test for the joint effect of government spending and democratic status of a country by interacting the two variables.

I introduce several controls for the level of development of a country, which is an important confounding factor: the investment share of GDP, the size of the country as measured by the log of its population, GDP per capita, and the average consumption share of GDP. The final control variable of the analysis is the level of trade exposure (openness). Here we would expect a positive relation between network centrality and trade openness, as more open economies tend to impose fewer restrictions on nuclear collaboration because they depend more on foreign investment and are better integrated into foreign markets (and thus more prone to transnational cooperation).[35]

Because I have sixteen different countries measured at four different time periods, I estimated two ordinary least squares models with panel-corrected errors.[36] This allows me to explain variation within and across countries and to obtain estimates of time dependency. Table 3 presents the results of the two models. In both, the government-spending variable has the expected direction and is statistically significant. As expected, an increase in government spending leads to a decline in a country's level of participation in the ARCAL nuclear network. Because both the centrality share variable and the government-spending variable have a [0, 1] range, the interpretation of the coefficients is relatively simple. In model 1, for example, a 1 percent increase in government spending results in a 1.76 percent decline in the centrality of a country in the nuclear network.

Contrary to expectations, neither the variable democracy nor its interaction with government spending is statistically significant. This result merits further research to determine whether the anticipated effects of regime type can be better captured by other measures of democracy.[37] Increasing private investment, by contrast, is associated with a more active involvement in nuclear networks. There could be two different explanations for this positive relationship. First, an increase in private-sector investment

34. This variable was retrieved from the Polity IV data set and is described in appendix 2.

35. I also ran a number of alternative specifications using institutional variables, such as years from democratization and degree of institutional stability. None of the alternative models yielded significant coefficients. The main variables of interests were robust to changes in the specification of the models.

36. As explained earlier, I followed ARCAL in splitting the data on nuclear collaboration in four different periods, which helps better explain the evolution of the network. Four of the smaller countries had no observations in some of the data subsets; thus, I dropped them from the multivariate regression.

37. Given, in particular, past discussion regarding the need for more substantive measures of democracy and democratization (Epstein, Bates, Goldstone, Kristensen, and O'Halloran 2006).

Table 3 Explaining Latin American Countries' Centrality Share in the Nuclear Network, Panel-Corrected Ordinary Least Squares Estimates

	Centrality (Share)	Centrality (Share)
Government Spending	−1.760*	−2.350*
	(1.035)	(1.238)
Democracy (Dummy)		−5.104
		(4.100)
Democracy (Dummy)*		1.772
Government Spending		(1.401)
Openness	−0.024	−0.028*
	(0.016)	(0.017)
Investment	2.310**	2.161**
	(0.964)	(1.007)
Consumption	−0.532	−0.626
	(2.535)	(2.724)
Population (LN)	0.268	0.172
	(0.407)	(0.436)
GDP (LN)	−1.046	−0.813
	(0.763)	(0.856)
Constant	14.618	16.148
	(15.002)	(16.938)
Wald	16.360***	17.180**
Sigma(u)	1.3991	1.555
Sigma(e)	1.2903	1.3108
Rho	0.5404	0.5846
R-sq Within	0.152	0.1671
R-sq Between	0.4184	0.4723
R-Sq Overall	0.3318	0.3715
N	64	64

*$p < .1$; **$p < .05$; ***$p < .01$

provides an alternative supply of resources, which reduces the degree of insularity of the nuclear sector by reducing its dependence on state resources. Second, more favorable investment climates tend to concentrate in a few of the network countries; in turn, bureaucrats from these states are more actively recruited into new collaborative efforts. If nuclear bureaucrats are strategically attempting to make up for lost state financing, then they should gravitate toward countries with a surplus of resources. This finding is intriguing and merits further investigation.

Interestingly enough, greater trade exposure has no effect on network participation in model 1 and is barely significant—and in the wrong direction—in model 2. This is surprising, as the level of openness of a country could be considered a factor that facilitates the flow of scientific resources across countries. Perhaps the explanation for the lack of statistical significance here is that the trade in nuclear science and technology (even with no strategic application) is more constrained by government regulations than other commodities. Moreover, the negative direction of the openness coefficient appears to confirm Hurrell's (1998) skepticism regarding the liberal assumption of linking economic liberalization to increased international cooperation.

Although the most developed economies are also the most active members of the network, the relationship between GDP and centrality share is not statistically significant. Indeed, the relationship displays an unexpected negative sign. Finally, the panel-corrected model shows that there is significant variation within and across countries. This indicates that the effect of government spending and private-sector investment is not just a function of the different country means but also affects how countries change their relative position in the network.

CONCLUSION

What do skilled bureaucratic agencies do when facing sharp reductions in their operating budgets? The central finding presented in this article is that, when government spending declines, the nuclear sector in Latin America compensates by increasing participation in knowledge networks to maintain the viability of their research programs. For bureaucratic agencies, such as the ones analyzed here, networking outside the bureaucracy means activating international ties with like institutions. This article builds on previous research on how state actors use networking strategically to increase bureaucratic autonomy (Carpenter 2001; Hawkins and Jacoby 2006; Crowe 2007). Different from past studies, however, I show that networking can be used as a mechanism to pool scarce resources and to compensate for budget reductions.

This type of networking allows Latin American countries to advance science policies even under chronic state deficits. Over the past twenty years, the ARCAL network has developed local know-how and institutional capacity, for example, by training more than five thousand scientists and technicians, setting up regional laboratories, and writing countless manuals, reports, and guides on applications and protocols in nuclear science and technology.[38] Although IAEA's sponsorship has been critical in terms of organizational and financial contributions, the network is sustained by the ties and exchanges in kind among local state institutions.[39]

Finally, as ARCAL covers a wide range of science policy areas—such as biotechnology, agriculture, food sciences, nuclear medicine, and radiation

38. In "Productos e impactos de los proyectos ARCAL durante 20 años de vida" (1984–2004).

39. Ibid.

safety—the theoretical and empirical results presented here should serve as a starting point to examine bureaucratic institutions in other policy settings. Similarly, the present study sheds some light on how international organizations facilitate transgovernmental networks by sharing some of the coordination costs and offering a forum where state officials can discuss similar concerns. Like the IAEA, other technical IOs (e.g., UNESCO, World Health Organization) also provide the conditions under which collaboration networks of skilled bureaucratic actors may develop (Finnemore 1993; Slaughter 2004).

APPENDIX 1: PRINCIPAL NUCLEAR INSTITUTIONS—LIAISONS OF ARCAL

Atomic Energy Commission of Costa Rica, Costa Rica
Bolivian Institute of Nuclear Science and Technology, Bolivia
Chilean Commission of Nuclear Energy, Chile
Division of International Technical Cooperation, Panama
Division of Nuclear Affairs, Venezuela
Ecuadorian Commission of Atomic Energy, Ecuador
General Division for External Cooperation, El Salvador
General Division of Nuclear Energy, Guatemala
Institute for Geoscience, Enviro-Mining, and Nuclear Research and Information, Colombia
Ministry of Foreign Affairs, Haiti
National Commission of Atomic Energy, Argentina
National Commission of Atomic Energy, Nicaragua
National Commission of Atomic Energy, Paraguay
National Commission for Nuclear Affairs, Dominican Republic
National Commission of Nuclear Energy, Brazil
National Division of Nuclear Technology, Uruguay
National Institute of Nuclear Investigations, Mexico
Nuclear Energy Agency, Cuba
Peruvian Institute of Nuclear Energy, Peru
Planning Institute of Jamaica, Jamaica

Source: http://arc.cnea.gov.ar/instituciones/institu.asp

APPENDIX 2: VARIABLES DESCRIPTION

Variable	Description
DV	
Centrality (share)	The standardized measure proposed by Wasserman and Faust (1994) is $C_D(n_i)=\frac{d(n_i)}{N-1}$ where $d(n_i)$ describes the number of nodes that are adjacent to n_i and N describes the population size.

Variable	Description
IVs	
Government Spending share of GDP	One of the component shares of GDP. The component shares of real GDP for 1996 are obtained directly from a multilateral Geary aggregation over all the countries. Shares will not add up to 100 because the denominator includes the net foreign balance. (Source: Penn World Table, http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)
Democracy-dummy	From the polity IV data set. Polity IV scores all countries using a range from –10 (fully institutionalized autocracy) to 10 (fully institutionalized democracy), based on measures of executive constraints, political competition, and quality of political participation. Coded 1 when country scores >6 on polity scale, 0 when <6.
Openness	Total trade as a percentage of GDP (Source: Penn World Table http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)
Consumption share of GDP	One of the component shares of GDP. The component shares of real GDP for 1996 are obtained directly from a multilateral Geary aggregation over all the countries. Shares will not add up to 100 because the denominator includes the net foreign balance. (Source: Penn World Table http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)
Investment share of GDP	One of the component shares of GDP. The component shares of real GDP for 1996 are obtained directly from a multilateral Geary aggregation over all the countries. Shares will not add up to 100 because the denominator includes the net foreign balance. (Source: Penn World Table http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)
Population	Population is from the World Bank World Development Indicators 2001, and UN Development Centre sources prior to 1960. (Source: Penn World Table, http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)
GDP per capita	Real GDP per capita and components for 1996 are obtained from an aggregation using price parities and domestic currency expenditures for consumption, investment and government of August 2001 vintage. For countries that were not in the 1996 benchmark study, the price parities are estimated using either a short-cut method or extrapolated from previous benchmarks. (Source: Penn World Table http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php)

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