Systems Analysis by Graph-theoretic Techniques: Assessment of Institutional Linkages in the Agricultural Innovation System of Azerbaijan

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Abstract

This paper develops a quantitative, graph-theoretic method for analysing systems of institutions. With an application to the agricultural innovation system of Azerbaijan, the method is illustrated in detail. An assessment of existing institutional linkages in the system suggests that efforts should be placed on the development of intermediary institutions to facilitate quick and effective flow of knowledge between the public and the private components of the system. Furthermore, significant accomplishments are yet to come in policy-making, research and education, and credit institutions.

Key words: Graph theory, systems approach, agricultural innovation system, Azerbaijan.
JEL classification: Q2, C8

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1. Introduction[1]

With the recent advancement of efficient computing algorithms and of computational capacity of computers, some of the concepts and techniques in graph theory have found wide applications in economics, political science, sociology, and psychology (Cormen, Leiserson, and Rivest, 1990; Shrum, 1997; Biggs and Matsaert, 1999; Richardson, 1999; OECD, 1997, 1999; Scott, 2000). It has also become widely recognized that these techniques serve as useful tools for analysis of not only engineering but also economic systems (Leontief, 1951; Manescu, 1980; Murota, 1987; Hudson, 1992).

Early attempts applying the systems approach to economics remained at the conceptual level, as it was not only problematic to express agents' behaviour mathematically but also difficult to measure it quantitatively. During the recent years, however, representation of systems as square matrices made it possible to bridge the gap between conceptual descriptions of systems and their quantitative characterizations. And the bridge was occupied with practitioners applying graph theoretical concepts, techniques, and results. Freeman (1997, 2000), for example, demonstrated the application of social network analysis to the analysis of hierarchical properties in organizational structures. Employing some of the concepts of graph theory, OECD (1997b, 1999) studied patterns common in innovation systems of the selected OECD countries. The list can be extended at will.

The present study seeks to develop a graph-theoretic method for quantitative assessment of institutional linkages[2] and institutional hierarchies in a system. The method adopts a framework in which the linkages do not assume *ad hoc* mathematical functional forms, reducing the complications likely to be faced in the integration of detailed physical, environmental, and institutional constraints into the system at hand. The method is especially useful to evaluate surveys consisting of questions with scaled answers. Qualitative information in these answers, expressed in scales as none, weak, medium, and strong, is translated into 0 for a nonexistent, 0.3 for a weak, 0.6 for a medium, and 1 for a strong relation. These values are then placed in the off-diagonal cells of the square matrix, each row of which represents an individual component in the system. This completes the representation of the system as a square matrix.[3] Finally, the method is applied the agricultural innovation system of Azerbaijan to examine interactions between the key components, to identify the dominant and subordinate components, to show how to develop effective agricultural policies, and to discuss ways to improve the effectiveness and efficiency of the system. To accomplish all, we use data from the survey results of Temel, Janssen, and Karimov (2001).

Quantification of interactions between institutions in an innovation system means a lot to the economic development community. It first means that dynamics of knowledge generation, diffusion, and application and hence of economic development, can be in part studied from an institutional perspective in order to provide modellers with information on the institutional parameters. Discovering the dominant and subordinate institutions, for example, is one such

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[1] We like to extend our thanks to a large number of people: Thanks to interviewees for sharing their views on the developments in the agricultural sector in Azerbaijan, to Prof. Jalal Aliyev, Dr. Mamadzadeh Nabiyev, Dr. Asad Musayev, Mr. Irsad Aliyev, Dr. Eldar Kosayev, Mr. Ahmedov Vugar, Dr. Akberov Zeynal, and Dr. Mahmudov Rafail for their insights into the workings of the system, and to Dr. Larry Zuidema for his contribution to the preparation of the Questionnaires and to the final reporting. Finally, many thanks go to seminar participants at ISNAR for their very useful comments on the earlier version of the report. While acknowledging contributions from a wide variety of participants, we are responsible for the content of the study.

[2] The terms, *linkages, interactions, and relations* are interchangeably used throughout the study.

[3] Rescaling this square matrix in such a way to obtain a stochastic matrix, each row of which adds up to one, allows us to characterize the system by using its mathematical properties (Debreu and Herstein, 1953).

information that can be incorporated into the overall objective function of the system. Modelling would further benefit greatly from information on the direction of influence between the two institutions in the system. Such information would facilitate the representation of institutional interactions in mathematical formats. Knowledge of the sequencing of institutional interactions would especially be valuable for constructing game theoretic models, as equilibria in these models are often conditional to a specific sequencing of institutional decisions.

What qualifies systems analysis to be the unique framework for examining innovation systems is the observation that science is necessary but not sufficient for the generation, diffusion, and application of new technologies and that learning takes place everywhere in society (EC, 2000). Although this is a powerful framework to understand the workings of innovation systems conceptually, such frameworks are not enough for policy makers to design and implement feasible science and technology policies consistent with overall economic goals. They need quantitative methods to compare alternative policies and predict consequences of their decisions and/or actions. With systems analysis by graph theoretic techniques, they should at least be in the position of identifying the existing cause-effect structures and detecting leverage points and mismatches in the system, and of developing alternative scenarios or mechanisms to release the constraints on innovative performance of the system.

Countries in transition seem to be most suitable for applying our methodology, as they are currently busy with building new knowledge systems and decision makers are in serious need of such tools to understand the workings of innovation systems. Our method would therefore be beneficial to technocrats of these countries to experiment with various policy reforms and understand their impact under laboratory conditions.

Following the Introduction, Section 2 describes our graph theoretical method. Section 3 shows how to make the method operational, with an application to the AIS of Azerbaijan. Section 4 discusses how to use the method to derive lessons for the improvement of the AIS. Finally, Section 5 concludes the study.

2. A graph theoretical method

The graph theoretical method that we seek to develop combines two fields of research: systems analysis in engineering and graph theory in discrete mathematics. The reason is that graph theory offers useful techniques and concepts that can be used in assessing properties of a system quantitatively. We define system as a set of agents or institutions organized around a common goal. A system has several characteristics. First, it must have a goal determining the type of institutions or agents to be included in the system. It should capture only those interactions related to the predetermined goal. Second, all of the interactions in the system should be expressed in a common unit of measure. Third, influence of an agent on itself and others must be bounded.

Several graph theoretical concepts are borrowed from discrete mathematics, and modified in such a way to reflect the specificities of the system under investigation. To start with, we set the goal of the system to be examined, make a list of agents likely to operate in the system, define linkage mechanisms that serve the goal, and translate qualitative data collected by a survey into quantitative scales. Here are some useful concepts.

Concept I: An interaction matrix. Matrix representation of systems allows us to study their underlying properties, such as controllability, solvability, and decomposability (Murota, 1987; Hudson, 1992). Therefore, we first explain how to create a matrix-form system.

Suppose, for example, that the system under investigation is an innovation system consisting of institutions organized around the goal to develop, diffuse, and apply new or improved technologies. For illustrative purposes, consider a system of 5 components[4]: Policy (**P**), Research and education (**R**), Extension and information (**I**), Farm organization (**F**), and External assistance (**X**). Interactions between these components are described following the clock-wise convention, and the components are placed in the diagonal and their binary (one-to-one or one-edge) interactions in the off diagonal cells of matrix-form system **S**:

$$\mathbf{S} = \begin{bmatrix} \mathrm{P} & PR & PI & PF & PX \\ RP & \mathrm{R} & RI & RF & RX \\ IP & IR & \mathrm{I} & IF & IX \\ FP & FR & FI & \mathrm{F} & FX \\ XP & XR & XI & XF & \mathrm{X} \end{bmatrix}.$$

The term PR placed in the first row-second column of **S** denotes that Component **P** interacts with Component **R**, and that **P** is the source of this interaction; likewise, the term RP placed in the second row–first column of **S** denotes that **R** interacts with **P**, and that **R** is the source of this interaction. Binary interactions of these kinds shown in **S** represent one-edge paths as they take place between two components only and contain no intermediate component(s). For notational simplicity we would sometimes refer to the interaction PR by **P→R** (or RP by **R→P**).

Concept 2: A coded interaction matrix. A value 1 (0) in **S**[c] implies that the corresponding interaction in matrix **S** above exists (does not exist) and is important (unimportant) for the investigation. Applying this rule, we define the system by **S**[c] in which coding is arbitrary,

$$\mathbf{S}[\mathrm{c}] = \begin{bmatrix} \mathrm{P} & 1 & 1 & 0 & 1 \\ 0 & \mathrm{R} & 1 & 1 & 0 \\ 1 & 0 & \mathrm{I} & 1 & 1 \\ 0 & 1 & 0 & \mathrm{F} & 0 \\ 0 & 0 & 0 & 1 & \mathrm{X} \end{bmatrix}.$$

According to the codes in **S**[c], **P** influences **R**, **I**, and **X**. Similarly, **R** influences **I** and **F**; **I** influences **P**, **F**, and **X**; **F** influences **R** only; and finally, **X** influences **F** only. Note that the interaction denoted by PR exists but not the other way around. This is manifested by 1 in the first row–second column of **S**[c] and by 0 in the second row-first column of **S**[c]. Likewise, **F** does not influence **X**, while **X** influences **F**. This is manifested by 0 in the fourth row-fifth column and by 1 in the fifth row-fourth column of **S**[c]. What this coding convention implies is that interactions in **S**[c] are directional and not necessarily symmetric. Below, we show the system **S**[c] in a different format that can be used for visual detection of patterns, where black (white) cells indicate the existing (absent) relations.

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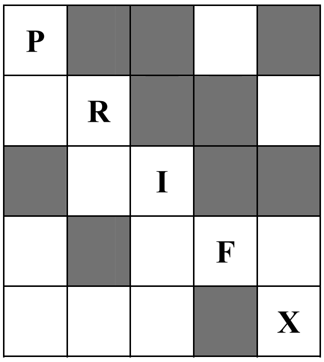
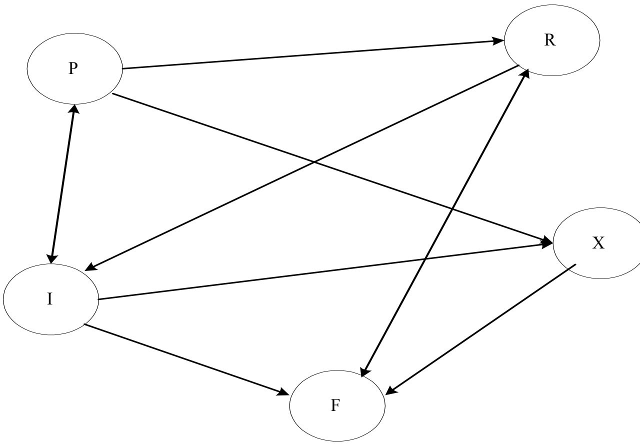
[4] Throughout the paper the terms "actors", "agents", "institutions", and "components" are all used to refer to sectors in a system.

Visual format of **S**[c]



P	■	■		■
	R	■	■	
■		**I**	■	■
	■		**F**	
			■	**X**

A third format to represent **S**[c] is to define it as a *digraph* (i.e., *directed graph*). The digraph consists of five actors (or vertices) (**P**, **R**, **I**, **F**, **X**) and assumes an implicit function that translates the interactions into real values: 1 or 0. Although it is difficult to immediately recognize patterns in the following diagram, this format has its own advantages.



Social relations are difficult but not impossible to quantify. Surveys with scaled questions can be used to quantify such relations. One way to accomplish it is to ask questions that can easily be scaled as weak, medium, and strong or formal, informal, and mixed, etc. A number between 0 and 1 can be arbitrarily assigned to each element of a scale. For example, a degree of interaction between the two institutions can be perceived as weak or strong depending on the amount of information flow between them. If an interaction is perceived as weak, a value of 0.3 can be assigned to it, 0.6 if medium, and 1 if strong. Such coding of interactions is commonly used in studies of psychology and sociology. Once scaled, the system of interactions between actors can then be represented visually and quantitatively.

<u>Concept 3: Qualitative coding.</u> Qualitative information on the nature of binary interactions in **S**[c] can be incorporated into the analysis by attributing (+) or (-) signs to an interaction between the two components. For illustrative purposes, let us suppose that this qualitative coding rule results in

$$\mathbf{S}[\mathrm{q}] = \begin{bmatrix} \mathrm{P} & 1 & -1 & 0 & 1 \\ 0 & \mathrm{R} & 1 & 1 & 0 \\ 1 & 0 & \mathrm{I} & 1 & -1 \\ 0 & -1 & 0 & \mathrm{F} & 0 \\ 0 & 0 & 0 & 1 & \mathrm{X} \end{bmatrix}.$$

A value 1 assigned to the cell RF in **S**[q] indicates that **R** influences **F** positively. On the contrary, a value -1 in the cell FR indicates that **F** influences **R** negatively. Negative influence usually occurs between competing actors that share the same objective and operate under the same resource constraints.

<u>Concept 4: Binary versus pathways of interactions.</u> **P→R** is a binary (one-edge) interaction but **P→I→F→R** is a pathway (three-edge) of interactions between **P** and **R**. In **S**[c] the former interaction represents a direct contact between **P** and **R**, while the latter implies three intermediary contacts in between **P** and **R**: **P** influences **I**, which then influences **F**, which then influences **R**. The choice between one-edge and three-edge interactions depends on values assigned to each edge in **S**. For illustrative purposes, let us suppose we have

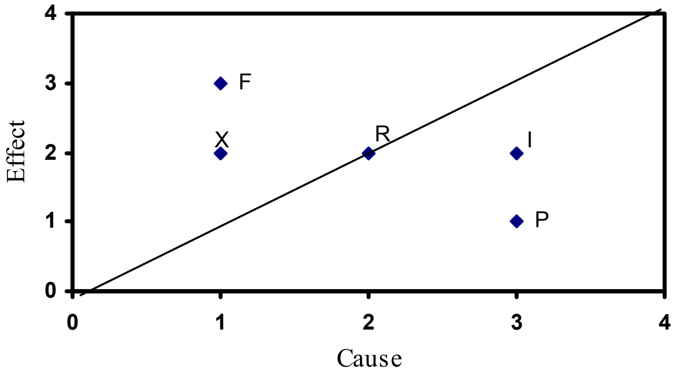
$$\mathbf{S}[\mathrm{v}] = \begin{bmatrix} \mathrm{P} & 3 & 1 & 0 & 1 \\ 0 & \mathrm{R} & 1 & 2 & 0 \\ 2 & 0 & \mathrm{I} & 3 & 4 \\ 0 & 5 & 0 & \mathrm{F} & 0 \\ 0 & 0 & 0 & 1 & \mathrm{X} \end{bmatrix}.$$

Implicit in the coding of **S**[v] is the assumption that each actor has an objective function and a set of constraints, and that a common decision made by an actor influences others' performance. We further assume that these cross-actor influences (i.e., binary influences) can be quantifiable by an implicit function. Suppose that the system at hand has the influence structure in **S**[v]. The binary relation **P→R** in **S**[v] has a value 3, which indicates the level of **P**'s influence on **R**. If the relation between **P** and **R** follows a pathway, for example, **P→I→F→R**, then the level of interaction would take on a value 9, which is the sum of values assigned to each edge: that is, 1 is assigned to **P→I**, 3 to **I→F**, and 5 to **F→R**. If the objective is to maximize (minimize) the influence, then the pathway **P→I→F→R** (the binary relation **P→R**) will be the optimal choice.

<u>Concept 5: A cause-effect structure.</u> What is the underlying cause-effect structure implied by **S**[v]? In other words, which agents in the system **S**[v] are *sources* of influences and which ones are *sinks*? To answer this question, we need to define the terms Cause (C) and Effect (E). Cause of an agent is defined as the sum of influences in the respective row of **S**[v], and Effect of others on that agent is defined as the sum of influences in the respective column of **S**[v]. **S**[v] implies the following cause-effect (or source-sink) coordinates (**C, E**): (5, 2) for **P**, (3, 8) for **R**, (9, 2) for **I**, (5, 6) for **F**, and (1, 5) for **X**.

Not surprisingly, in social sciences, causes and effects are difficult to measure mathematically, making it difficult to establish the system **S**[v]. But, we can relatively easily construct the system S[c] as it only includes binary information. The (**C, E**)-coordinates of S[c] are (3, 1) for **P**, (2, 2) for **R**, (3,2) for **I**, (1, 3) for **F**, and (1, 2) for **X**. Figure 1 shows the underlying cause-effect structure, where **P** is the key source, while **F** is the key sink in the system.

Figure 1. The cause-effect structure of **S**[c]



Following the same procedure, one can also establish a scaled cause-effect structure to reflect a more realistic picture of interactions prevailing in the system.

Concept 6: Density of the cause-effect structure. The density, *d*, of the cause–effect structure is calculated as $d=b/[n(n-1)]$ with $1\geq d \geq 0$, where *b* denotes the total number of existing binary interactions, and *n* is the number of dimension in **S**[c]. Given this definition, the density of **S**[c] is 0.5 where b=10 and n=5. Fully identified structures will have d=1, implying that all agents are connected to each other.

Concept 7: A cluster. A cluster is a subset of actors that have close cause-effect coordinates. The cause-effect diagram is a useful tool for detecting clusters in the system. This concept, useful especially in a system with a large number of actors, helps us identify subsystems and examine their characteristics.

3. An application

3.1. Definitions: National innovation systems and agricultural innovation systems

The literature introduces various definitions of national innovation system. Freeman (1987), for example, defines it as a network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies. Nelson (1993) describes it as a set of institutions whose interactions determine the innovative performance of productive units. Metcalfe (1995) and Smith et al. (1996) consider it as set of distinct institutions that jointly and individually contribute to the development, diffusion, and application of new technologies. While the above definitions are quite similar at face value, there are some differences in meaning, emphasis, and use of the concept. The key difference is that some view the concept as a simple aggregation of institutions, while others point at the synergies that originate from their joint operation. Our point of departure is the view that the innovation system is not a simple aggregation of organizations but it is a group of agents who operate like an *invisible orchestra*, each member of which plays pieces of a one-big melody with an invisible harmony among them. This orchestra would be characterized by coherence, harmony, and synergy: Coherence brings different pieces under the same melody; harmony creates a tune that keeps the members around the same spirit; and synergy ties them more strongly around the common goal. Adapting the above definitions into our context, we propose the following definition, which will be referred to throughout this study:

An agricultural innovation system (AIS) is a set of agents (i.e., farm organizations, input supply-processing-marketing enterprises, research and education institutions, credit institutions, extension and information units, private consultancy firms, international development agencies, and the government) that jointly and/or individually contribute to the development, diffusion, and use of new technologies, and that directly and/or indirectly influence the process of technological change.

3.2. Data

Data are obtained from the Agricultural Innovation Questionnaire (AIQ) carried out in Azerbaijan (see Temel, Janssen, and Karimov, 2001). The AIQ covers a total of 9 components including policy, research, education, credit, extension and information, inputs-outputs-processing-marketing, farm organization, consultancy, and external assistance. It was used to interview a total of 63 persons: 7 policy makers, 12 directors of agricultural research institutes, 5 professors and graduate students, 1 director from credit institutions, 4 extension and information specialists, 8 directors from private input supply, processing, and marketing enterprises, 10 farmers from large and small farm organizations, 11 directors of private consultancy firms, and 5 project managers from international development agencies.

The AIQ is organized into 5 sections. Section 1 provides information on organizational profiles, including internal and external factors that influence organizational performance. Section 2 characterizes innovation activities, presenting information on types and goals of the activities, sources of knowledge about innovations, funding mechanisms, and factors that constrain the activities. Section 3 describes linkages that organizations develop during the innovation process, with special emphasis on strength of linkages, linkage mechanisms used, and constraining factors. Section 4 characterizes the most recent innovation developed or diffused or used by the respondent's organization. Section 5 intends to describe the science and technology policy in place. The current study utilizes information in Section 3 only as this is the section where the nature of linkages between the 9 components is explored.

3.3. Description of the components of the AIS

Policy Component (**P**) comprises 5 key units operating under the responsibility of the Cabinet of Ministers. These units are the State Committee for Science and Technology (SCST), the Ministry of Agriculture (MoA), the Ministry of Education (MoE), the Ministry of Finance (MoF), and the Ministry of Economy (MoEc). In addition, each unit has several operational committees and commissions performing specific tasks to support the formulation of agricultural policy in general, and agricultural research policy in particular. Presently, the SCST is at a standstill due to the absence of science and technology priorities at the national level and the lack of qualified human resources at the organizational level. The MoA and MoE are also undergoing major reorganizations concerning the coordination of agricultural research and education institutes and the management of information dissemination activities.

Research Component (**R**) consists of a total of 26 research institutes, 15 of which are under the Agrarian Science Center (ASC) of the MoA and 11 operate under several committees and the Academy of Sciences. Of these 11 institutes, 6 belong to the Academy of Sciences, 3 to the Committee for Water Economy, one to the Committee for State Land, and one to the "Azerforest" industrial amalgamation. In late 1996, the Agency for Support to the Development of Private Agricultural Sector (ASDPAS) was established to manage projects initiated by donors and international development agencies, being responsible towards the State Commission for Assistance to Agricultural Private Farm Sector Development. In early 2000, the Agricultural Research Board (ARB) was created to coordinate the Competitive Grants System and Knowledge System Reform components of ADCP.

Education Component (**E**) comprises 42 universities (25 public, 17 private) and 77 colleges (73 public, 4 private), all of which are under the partial supervision of MoE. Soon, the MoE is expected to assume full responsibility for all educational institutions, including 21 agricultural colleges and one Agricultural Academy that used to be under the control of the MoA (ARKTN, 2000). The Agricultural Academy should, according to its mandate, engage in both teaching and research (mostly theoretical). The colleges, on the other hand, should engage in both teaching and applied research. The MoA will still be expected to supervise post-graduate education through the Head Dept. Scientific Research, Education, and Personnel Training (HDSREPT). Every year, a total of 8-10 post-graduate students are accepted to the 15 research institutes of the ASC. Moreover, there are several agriculture-related faculties in Azerbaijan State University and other engineering and technical universities. Newly established in 2001 is the Agricultural Education Department in the MoE. This Department is responsible for administrative coordination and curriculum preparation of the agricultural education institutions.

Credit Component (**C**) is the weakest component. Extensive efforts are made to restructure and reorganize it. By the end of 1999, the banking system comprised 70 banks, down from 180 in 1995. Four state-owned banks dominated the system, basically extending loans to public enterprises. For the last two years, no credit was provided to the agricultural sector. The 66 private banks also remained in a precarious state (Owen et al. 2000; ARKTN, 2000). At present, preparations are underway to merge the Agro-Industry and Security banks to create a Universal Bank. Most recently, the government of Azerbaijan has established an oil fund to help mobilize resources to rural sector in general, and to the agricultural sector in particular.

Extension and Information Component (**I**) comprises various subcomponents. The Information and Consulting Services Center (ICSC) was established in 2000 within the framework of the ADCP. Its task is to coordinate information and extension services specified in the ADCP, and its main activities are carried out at its regional branches. These branches provide extension services to people with land but without farming skills and to those without knowledge of how to prepare business plans or apply for credits or loans. Another activity of the Center, again through its branches, is to disseminate research results of projects implemented within the context of the competitive grants program. The Information Dissemination Unit (IDU) of the MoA was established in 1998 to coordinate agricultural knowledge flow at the national level. The IDU supports the introduction of new techniques or methods for information gathering about the current status of farming activities, provides extension services to farmers, and disseminates information about the new techniques available. Private enterprises also provide services in the information and extension sector. They are promoted indirectly by the ADCP and the FPP activities. Several water user associations, agro-business firms, and agro-consulting centers have emerged around the pilot study areas of the ADCP and the FPP.

Private Enterprise Component (**M**) includes private input and supply, processing, and marketing firms. Typically, a firm engages in all kinds of activities: input supply, processing, and marketing. The increasing number of such firms should bring specialization in the near future. As many as 20 input supply firms currently operates in the market. Some of them have grown out of the pre-independence co-operatives, while others have been newly established. With a total of 1759 agricultural processing enterprises, which are presently under the subordination of the Ministry of State Property for Privatization, the processing sector is waiting for further initiatives to accelerate the privatisation, consolidating, and reforming processes. Currently, of 1759 enterprises, 1121 are involved with food processing (114 in grapes, 40 in canneries, 33 in meat and dairy, 19 in cotton, and 14 in tea), 540 with weaving, and 98 with leather processing. There are also a total of 42 food-canning factories to be privatized. The food industry currently accounts for 12.9 percent of total labor force. A relatively speedy privatization has taken place in the cotton sector. At the moment, all 19 cotton-processing plants are in private hands. Meat and milk products were and still are important in the diet of the Azeri people. Forty percent of total household food expenses are for the purchase of milk and dairy products, 26 percent for meat and meat products. For such a vital sector, recent developments are not as significant, although the market for dairy products shows some progress.[5]

Private Farm Component (**F**) includes 6 types of farms: household farms, farmers' holdings, collective enterprises, leased enterprises, production cooperatives, and small enterprises. Large farms could play a considerable role in the diffusion of new technologies as they undertake production, processing, and marketing activities simultaneously. They benefit from their structural suitability to the irrigation infrastructure and relatively easy access to other farm inputs on the one hand, and their close connections with experimental stations of research institutes on the other. Small farms, on the other hand, literally lack everything, but most important of all, they lack land large enough to think about farming for markets. They also lack the knowledge and skills required for market oriented farm production. Under these circumstances, they can only grow crops and livestock for own consumption.

Private Consultancy Component (**D**) emerged in 1998, with the law allowing for private consultancy firms. Since then, around 35 consultancy firms were founded. Many of them employ academicians, researchers, and post-graduate students. Their activities grow through opportunities offered by donors and international development agencies, and the areas of focus include agricultural, ecological, and agro-business issues. In many cases these firms are spin-off entities growing around the "Information and Consulting Services" component of the ADCP. This component seeks to help farmers find appropriate sources of credits and prepare business plans. The consultancy firms aim to provide all kinds of services to farmers, ranging from preparing business plans to problem diagnosis.

External Assistance Component (**X**) is the stick place on a slippery surface. This component includes a variety of international development agencies, donors, and NGOs, and has been the key entry point for new or improved knowledge, processes, and practices. Joint project-based activities are the means for exposing national entities to international standards. These activities usually involve private consultancy firms, as they have relatively better human and physical resources and have flexible organizational structures. Public entities, however, have been slow in adapting to international standards due to organizational rigidities, continuing organizational changes, and lack of qualified human resources.

In the paragraphs above we have described the key responsibilities and activities of organizations in each component of the AIS. In addition, in Chart 1 below, we provide a visual classification of these organizations that is based on 6 functions: general policy-making (F1), policy formulation, co-ordination, supervision and assessment (F2), financing R&D (F3), R&D performance (F4), technology application (F5), and technology applying (F6).[6] This chart is an extremely useful tool to quickly identify those organizations that perform similar role while belonging to different components. For example, the fourth layer

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[5] The reader is referred to ARKTN (2000) for a more detailed information.

[6] Chart 1 is adopted from OECD (1999b).

shows that experiment stations of the ASC, NGOs, private agro-consulting firms, Information and Consulting Services Center, and Competitive Grants System are all involved in R&D financing and technology dissemination activities. But, experiment stations and Competitive Grants System belong to **R**, Information Services Center to **I**, and NGOs to **EA**, Therefore, one should logically expect linkages between these three components performing similar tasks.

In the previous paragraph we implicitly use two functionals.[7] The first maps the 6 organizational functions onto organizational types and the second maps organizational types onto the 9 components of the AIS. Analysis of each layer in Chart 1 should, therefore, shed light onto the currently existing linkages between the components or linkages likely to emerge in the future.

3.4. Description of interactions between the components

Using the information drawn from Section 3 of the AIQ, we prepared Table 1 (henceforth Interaction Matrix) that indicates a structure for linkages between the 9 components. This structure is characterized by information on (i) three types of linkages as formal *(f)*, informal *(i)*, and mixed *(m)*, (ii) four levels of linkage strength as strong *(s)*, medium *(m)*, weak *(w)*, and none *(n)* (see Form 9 in Section 3 of the AIQ), and (iii) five groups of linkage mechanisms (see List 3 in Section 3 of the AIQ). This information is placed on the off-diagonal cells of the matrix **S** below, and interactions between the components follow clockwise rotation shown by a thick arrow in the interaction matrix. The first row of the matrix presents the information obtained from organizations of **P**. It shows the mechanisms and the ways by which these organizations influence the rest of the system. Likewise, the information on the second row indicates how **R** influences the rest of the system. Information placed in the columns of the matrix indicates by which mechanisms others in the system influence **P**. Thick arrows on the matrix show the direction of influence. The diagonal cells include individual components. The notation *(fw)* stands for a formal-weak relation, *(fm)* formal-medium, *(fs)* formal-strong, *(iw)* informal-weak, *(im)* informal-medium, *(is)* informal-strong, *(mw)* mixed-weak, *(mm)* mixed-medium, and *(ms)* mixed-strong. Zeros that appear in some of the off-diagonal cells imply either that interaction does not exist between relevant components or that it exists at a negligible level, or that it exists but investigator was not able to identify it.

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[7] $m{:}F \Rightarrow O$ defines a correspondence relation between organizational functions $F=\{f_1,\ldots,f_6\}$ and subsets of organizations $O_j \subset O$ where $O=\{o_1,\ldots,o_n\}$. $h{:}O_j \rightarrow C$ defines a functional relation between subsets of organizations and components $C=\{c_1,\ldots,c_9\}$.

$$\mathbf{S}^{8} = \begin{bmatrix} \mathrm{P} & fw & fw & fw & mw & 0 & 0 & 0 & fm^{1} \\ fw & \mathrm{R} & fw & 0 & mw & mm & im & im^{1} & fw^{1} \\ fw & fw & \mathrm{E} & 0 & 0 & 0 & iw & im & fw^{1} \\ fw & 0 & 0 & \mathrm{C} & 0 & 0 & 0 & 0 & fw \\ fm^{1} & fm^{1} & 0 & 0 & \mathrm{I} & 0 & fm^{1} & fm^{1} & fw^{1} \\ fm & im & 0 & 0 & 0 & \mathrm{M} & mm^{1} & 0 & mw^{1} \\ im^{1} & im^{1} & iw^{1} & 0 & 0 & mw^{1} & \mathrm{F} & 0 & 0 \\ im^{1} & im^{1} & mm^{1} & 0 & fm^{1} & iw & mm^{1} & \mathrm{D} & fm^{1} \\ fm^{1} & fw & 0 & 0 & fs^{1} & mw & fm^{1} & fm^{1} & \mathrm{X} \end{bmatrix}$$

The matrix **S** has several distinct features. First, it shows that the AIS is not fully identified. Of a total of 72 relations, only 45 are identified. The AIS has a density of 0.63 (= 45/72) and the component **C** is fully isolated from the rest of the system. Second, it shows that the AIS is fairly flexible. Of 45 relations, 25 are formal (13 weak, 11 medium, 1 strong), 11 informal (3 weak, 8 medium, 0 strong), 9 mixed (5 weak, 4 medium, 0 strong). Third, all relations are formal and weak (*fw*) between the public components (**P**, **R**, **E**, **C**), while relations are mixed and mostly medium between the private components (**I**, **M**, **F**, **D**). This suggests a much stronger connection between the private components than that between the public sector components. Fourth, not surprisingly, informal relations are common between the public and the private components, reflected especially by the dominantly informal relations between (**R**, **E**) and (**I**, **M**, **F**, **D**). Equivalently important in this respect is the willingness of (**M**, **F**, **D**) to develop contacts with **P**, which is implied by (*fm, im, im*) in the first column and *(0, 0, 0)* in the first row. Lastly, the component **X** has one way or another developed relations with all the components in the system. Among these relations, the strongest ones are with **I**, **F**, **D**, and **P**.

3.5. Quantification of the interactions

Below, we construct the matrix **S**[Scaled] by expressing linkage strengths in **S** in terms of codes (i.e., a number between 0 and 1). The coding rule followed assigns a value of 0.3 to a weak, 0.6 to a medium, and 1 to a strong relation.[9] Figure 2 shows the cause-effect structure associated with the matrix **S**[Scaled]. According to this structure, the component **D** dominates over the AIS (i.e., *source* of influence) as it has more effect on the rest of the components than others' effect on it. Interestingly, however, the component **R** is highly interactive[10] with the rest of the AIS, and is followed by **X**, **I**, and **F**. Furthermore, the component **P** is found to be subordinate (i.e., *sink* of influence) since it is influenced by others more than it influences them. Lastly, the component **C** has very low interaction with the rest of the AIS.

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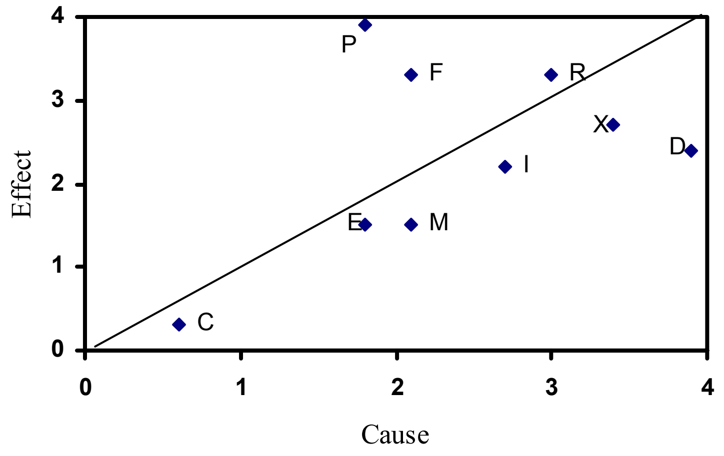
[8] The links with a superscript 1 in **S** represent those established through specific linkage mechanisms. These are the links to which a value 1 is assigned to create **S**[Mechanism].

[9] The coding rule considers linkage strengths only because the AIQ does not have information on the effectiveness and efficiency of linkage types. Without such information one can hardly express linkage types in terms of codes.

[10] Points on the 45-degree line in the Cause-Effect diagrams represent the case in which cause is equal to effect.

$$\mathbf{S}[\text{Scaled}] = \begin{bmatrix} \text{P} & 0.3 & 0.3 & 0.3 & 0.3 & 0 & 0 & 0 & 0.6 \\ 0.3 & \text{R} & 0.3 & 0 & 0.3 & 0.6 & 0.6 & 0.6 & 0.3 \\ 0.3 & 0.3 & \text{E} & 0 & 0 & 0 & 0.3 & 0.6 & 0.3 \\ 0.3 & 0 & 0 & \text{C} & 0 & 0 & 0 & 0 & 0.3 \\ 0.6 & 0.6 & 0 & 0 & \text{I} & 0 & 0.6 & 0.6 & 0.3 \\ 0.6 & 0.6 & 0 & 0 & 0 & \text{M} & 0.6 & 0 & 0.3 \\ 0.6 & 0.6 & 0.3 & 0 & 0 & 0.3 & \text{F} & 0 & 0 \\ 0.6 & 0.6 & 0.6 & 0 & 0.6 & 0.3 & 0.6 & \text{D} & 0.6 \\ 0.6 & 0.3 & 0 & 0 & 1 & 0.3 & 0.6 & 0.6 & \text{X} \end{bmatrix}$$

Figure 2. The cause-effect structure of **S**[Scaled]



Presented below is a visual representation of the information in **S**[Scaled], where white cells represent nonexistent linkages, grey cells weak linkages, black cells medium linkages, and heavily dark cells strong linkages.[11] The visual tool would help us detect areas to be strengthened for facilitating an effective and efficient flow of knowledge, while the cause-effect structure would indicate the components that can serve as the source and the ultimate target of this knowledge.

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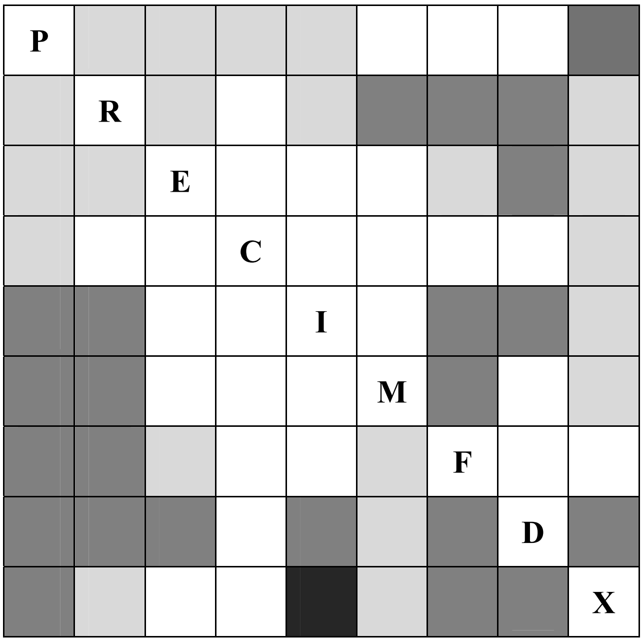
[11] It is straightforward to develop computer algorithms to generate cause-effect structures and visual representations automatically. Such automation will be very helpful especially in the context of large systems.

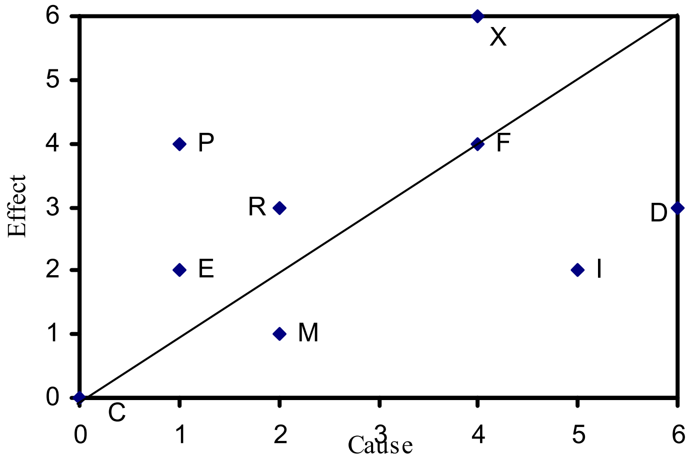
A visual representation of **S**[Scaled]



S[Mechanism] shows only those linkages established through specific linkage mechanisms in List 3 of the AIQ in Temel, Janssen, Karimov (2001). The density of **S**[Scaled] sharply declines from 0.63 to 0.35 in **S**[Mechanism]. Furthermore, polarization tends to emerge between the private and public sectors. The components (**D**, **X**, **I**, **F**) move upward, while others move downward. The component **D** remains to be the dominant one, which is followed by **I**. The component **X** is most interactive, which is followed by **F**. On the other hand, **P** remains to be the most subordinate component (Figure 3). A visual examination of the AIS shows that **D** and **X** often perform by using linkage mechanisms. This can in part be attributed to the fact that their activities are strictly determined by written agreements.

$$\mathbf{S}[\mathrm{Mechanism}] = \begin{bmatrix} \mathrm{P} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & \mathrm{R} & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & \mathrm{E} & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & \mathrm{C} & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & \mathrm{I} & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & \mathrm{M} & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & \mathrm{F} & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 & 1 & \mathrm{D} & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & \mathrm{X} \end{bmatrix}$$

Figure 3. The cause-effect structure of **S**[Mechanism]



A visual representation of **S**[Mechanism]

P								■
	R						■	■
		E						■
			C					
■	■			**I**		■	■	■
					M	■		■
■	■	■			■	**F**		
■	■	■		■		■	**D**	■
■				■		■	■	**X**

4. Discussion: when and how to use our method

Decision makers can use the Interaction Matrix to assess the impact of alternative decisions as it encompasses all of the possible pathways in a system under investigation. Consider, for example, the pathway **P→C→I→F→R→P**. This is a *feedback* pathway in which initial change takes place in **P** and its influence is carried back to **P** through the pathway **C→I→F→R**. To simplify the matters, suppose that **P** introduces a rural development fund for farmers to have access to new technologies (**P→C**). Executing actual transfer of funds, agricultural banks would disseminate information on procedures for loan or credit applications (**C→I**). Extension agents, information dissemination workers, private consultants, etc. will all be busy with passing this information onto farmers (**I→F**). The outcome of this process would be either by farmers' organization or by experts in regional information centers or by field researchers passed to regional extension units of research institutes (**F→R**). Finally, success or failure of the initiative could be reported in a policy dialogue (**R→P**). Once this cycle of interactions is completed, the government would be able to assess the effectiveness of its initiative. Under the current circumstances, this feedback pathway cannot be operational in Azerbaijan because necessary credit institutions are still absent.

Decision makers can use the Interaction Matrix to identify the optimal pathway to the realization of specific goals. Suppose, for example, that the goal is to diffuse a new variety of crops among farmers in a specific location. Clearly, farmers **F** would be the end users of this new variety but agents who pursue this goal might be diverse. For the sake of argument, let us suppose that **X** introduces the new variety. One simple strategy to identify the optimal pathway is to list all of the possible pathways starting with **X** and ending with **F**. In the context of the AIS of Azerbaijan, this experiment would result in the following pathways: {**X→F**}, {**X→D→F**}, {**X→M→F**}, {**X→I→F**}, {**X→R→F**}, {**X→D→M→F**}, {**X→D→I→F**}, {**X→D→R→F**}, {**X→I→D→F**}, {**X→I→R→F**}, {**X→R→M→F**}, {**X→M→R→F**}, {**X→R→I→F**}, {**X→R→D→F**}, {**X→R→I→D→F**}, {**X→R→D→I→F**}, {**X→R→D→M→F**}, {**X→R→I→D→M→F**}, {**X→M→R→I→D→F**}, assuming that the new variety meets official quality standards. Although possible paths are various, only few will be qualified when additional constraints are introduced. Let us suppose that farmers face budgetary difficulties and are risk averse. This reduces the set of possible pathways to {**X→M→F**}, {**X→R→F**}, {**X→R→M→F**}, {**X→M→R→F**}, {**X→R→I→F**}, {**X→R→D→F**}, {**X→R→I→D→F**}, {**X→R→D→I→F**}, {**X→R→D→M→F**}, {**X→R→I→D→M→F**}, and {**X→M→R→I→D→F**}. The rationale behind it is that either profit maximizing input-output supply firms, represented by **M**, or social welfare-maximizing public institutes, represented by **R**, would take the risk by providing farmers with information, inputs, and technical support. For the sake of argument, let us suppose that the private value outweighs the social value of adopting the new variety, and this would further reduce the feasible paths to {**X→M→F**}, {**X→M→R→F**}, and {**X→M→R→I→D→F**}. The optimal choice, which is the shortest path and would support the development of market institutions, is {**X→M→F**} as **M** would provide farmers with extension services.

The Interaction Matrix can be used to identify constraints of the system. For instance, the public and private components of the AIS interact at a low tone. This reflects the fact that the system requires intermediary institutions such as marketing associations, farmers' organizations, trade and commerce organizations, etc. to bring together the diffuse elements of the system. Specifically, links between the components (**I**, **M**, **F**, **P**, **R**) could be strengthened through policy dialogues where the intermediary institutions could pass information from (**I**, **M**, **F**) to (**P**, **R**).

Analysis has shown two trends in the AIS of Azerbaijan. First, as seen from Figure 2, the private components are connected around activities initiated by the component **X**, which is the key *source* of new technologies. They concentrate on adapting the imported technologies to local conditions. The component **D** serves as channel of new technology from **X** to (**I, F, M**). The public components, however, operate weakly, as they are less flexible in taking initiatives or operating around externally determined goals. **P** and **F** are the most subordinate components. Moreover, the credit component **C** has very low interaction with the rest of the system, which is the area ignored totally, although it is the most vital one to glue the distinct elements of the system. Second, as seen from Figure 3, when it comes to the usage of linkage mechanisms in List 3 in Temel, Janssen, Karimov (2001) as tools of communication between the components, we observe that the components are strongly polarized as high usage by (**D**,

I, **F**, **X**) versus low-usage by (**R**, **P**, **E**, **M**). The mechanisms are most often used by **D** and **I**, which can be attributed to the fact that these two components are engaged in organized activities with specific plans and programs. Other side of the coin is that the working style of organizations in **X** also requires involving parties to operate with work plans and programs. Interestingly, however, the components **P**, **R**, **M**, and **E** do not utilize as many linkage mechanisms as expected, implying unorganised activities and weak management.

5. Conclusions

This study sought to develop a method for quantitative assessment of institutional interactions and illustrated its application to the AIS of Azerbaijan. Analysis suggests that the essential elements of the system are at an embryonic stage. Efforts should be placed on the formation of public policy, science and technology institutions and organizations, and on the development of links through intermediary organizations between the public and private components of the system. At present, the public component is under construction, lacking sectoral priorities, clear organizational mandates and objectives, qualified human resources, physical and financial resources, and motivation to initiate interactions with the private sector. The private component, however, is attracted to activities of international organizations. The public and private components are isolated and have limited basis for interaction.

What remains to be addressed is to develop methodological guidelines in order to evaluate empirically national institutional set-ups with the view of obtaining comparable results at the international levels. As argued by Capron and Cincera (2000), the present literature does not report any operational guidelines regarding the assessment of institutional linkages underpinning national innovation systems. Such guidelines could also be used as a benchmarking approach in the management of agricultural, science, and technology policies. An equivalently important issue, which has not received enough attention from the literature, is, as argued by (Nelson, 1993), the need for well articulated and verified analytical frameworks linking institutional arrangements to technological and economic performance.

Two weaknesses of our method remain to be topics of future research. First, quantitative representation of institutional interactions, like we attempted in this study, will be questionable especially when rare but influential interactions take place between the institutions. An interaction may only be infrequent but of crucial importance, whilst some, such as committee meetings, may occur frequently, but may be of low importance in impact. Second, the development of solid quantitative measures of policies (or strategies) and the testing of specific hypotheses still require a theoretical formulation of institutional objectives and constraints. This calls for a reformulation of the systems approach as a mathematical model.

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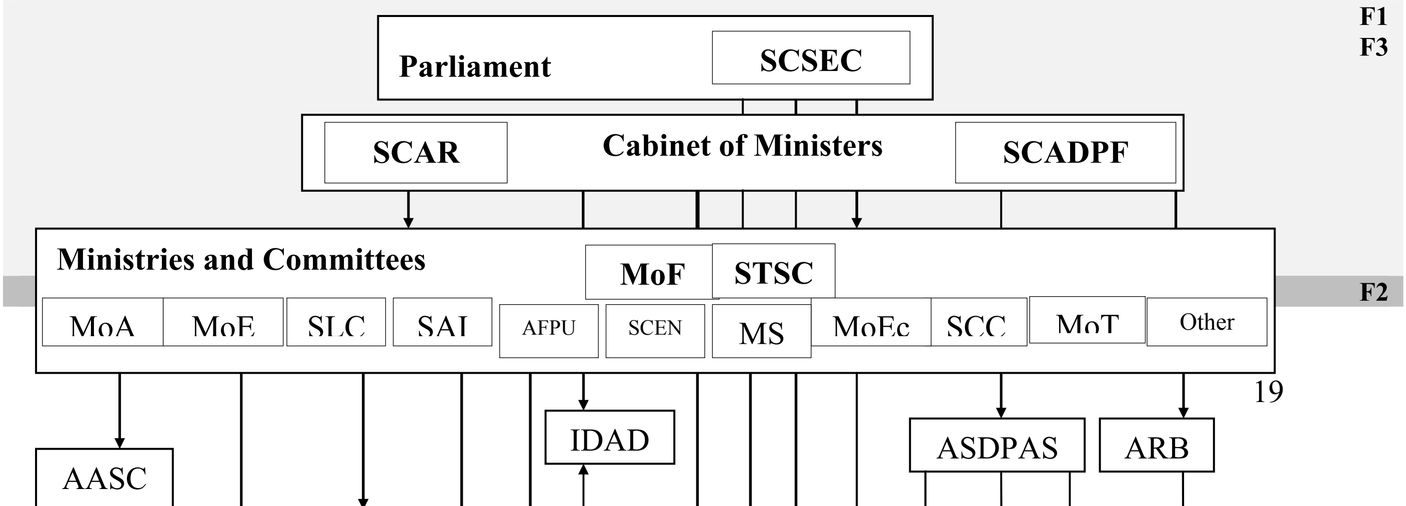
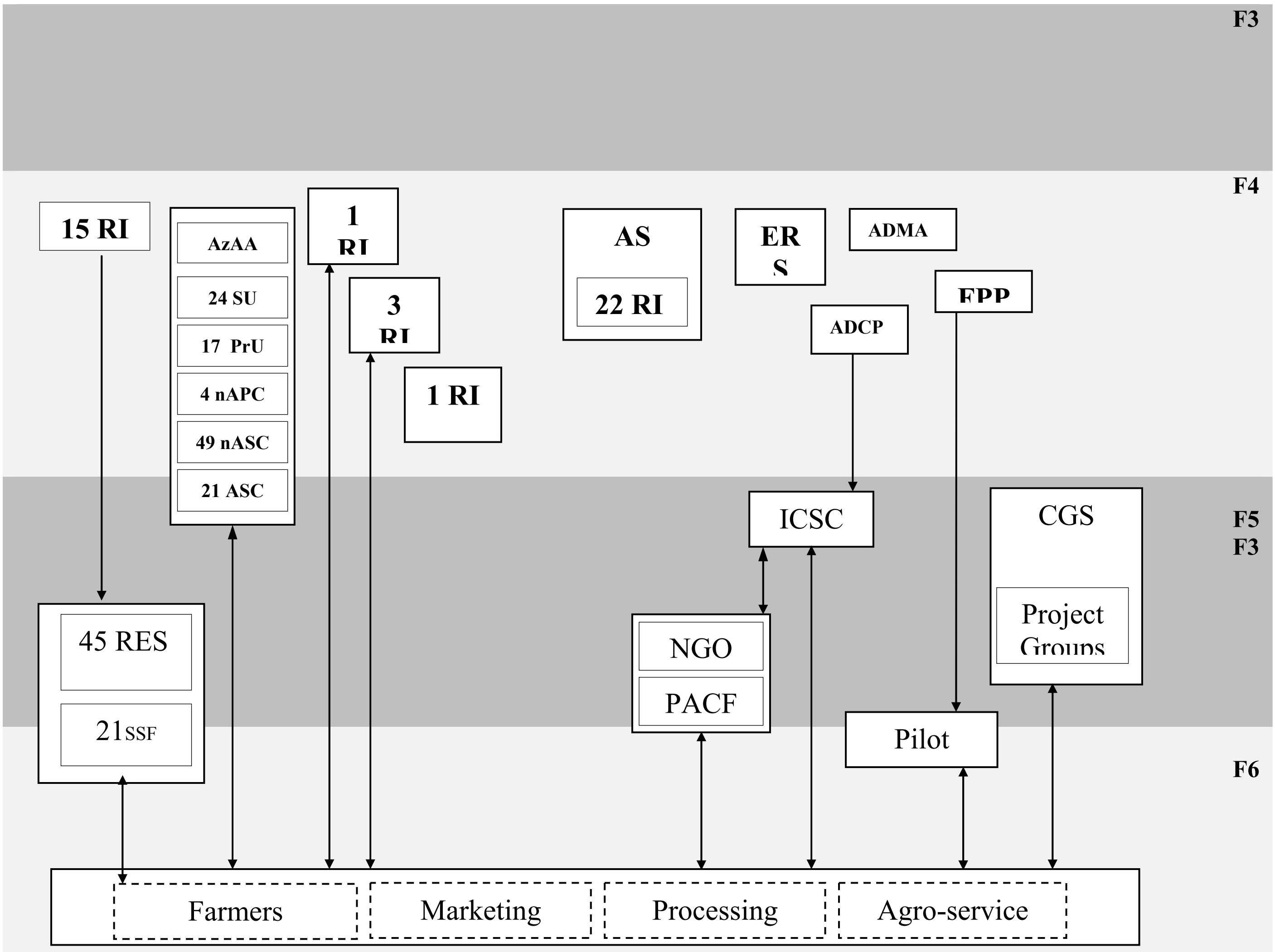
Chart 1. Agricultural Innovation System – Organizational Structure





Functions in institutional matrix

F1: General Policy making

F2: Policy formulation, co-ordination, supervision and assessment

F3: Financing R&D

F4: R&D Performance

F5: Technology diffusion

F6: Technology applying

Policy Component (P) (Reorganization)	**Formal & weak**	**Formal & weak**	**Formal & weak**	**Mixed & weak**				**Formal & medium** Priority setting Programe devel. & review
Formal & weak	**Research Component (R) (Reorganization)**	**Formal & weak**		**Mixed & weak**	**Mixed & medium**	**Informal & medium**	**Informal & medium** Information sharing Problem diagnosis Technology diffusion Exchange of staff	**Formal & weak** Workshops/seminars Information sharing Personnel training
Formal & weak	**Formal & weak**	**Education Component (E) (Reorganization)**				**Informal & weak**	**Informal & medium**	**Formal & weak** Workshops/seminars Information sharing
Formal & weak			**Credit Component (C) (Reorganization)**					**Formal & weak**
Formal & medium Information sharing	**Formal & medium** Information sharing			**Extension and Information Component (I)**		**Formal & medium** Program developmnt Problem diagnosis Priority setting Tech diffusion/demon Training	**Formal & medium** Program developmnt Tech. diffusion Info&finance shraring Workshops Seminars	**Formal & weak** Tech. diffusion & demonstration Information sharing
Formal & medium	**Informal & medium**				**Private Enterprise Component (IPM)**	**Mixed & medium** Tech. demonstration Training		**Mixed & weak** Program developmnt Tech. developmnt Workshops
Informal & medium Information sharing	**Informal & medium** Information sharing Problem diagnosis Technology diffusion Exchange of staff	**Informal & weak** Information sharing			**Mixed & weak** Tech. demonstration Training	**Private Farm Component (F)**		
Informal & medium Information sharing	**Informal & medium** Information sharing Problem diagnosis Technology diffusion Exchange of staff	**Mixed & medium** Information sharing		**Formal & weak** Program development Sharing of info. & finance Workshops	**Informal & weak**	**Mixed & medium** Problem diagnosis Priority setting Technology diff. & demonstration	**Private Consultancy Component (CO)**	**Formal & weak** Program developmnt Tech. diffusion Info &finance sharing Workshops
Formal & medium Priority setting Program development Program review	**Formal & weak**			**Formal & strong** Priority setting Program development Technology development Technology diffusion and demonstration Information sharing	**Mixed & weak**	**Formal & medium** Problem diagnosis Program developmnt Tech. demonstration Information sharing Training	**Formal & medium** Program developmnt Tech. diffusion Info&finance sharing Workshops	**External Assistance Component (EA)**

Table 1. A Structure for the Agricultural Innovation System: Linkages and Linkage Mechanisms

Abbreviations and Acronyms

AASC	Azerbaijan Agrarian Science Center
ADB	Asia Development Bank
ADCP	Agricultural Development and Credit Project
ADPMA	Agricultural Development Project in Mountainous Areas
AFPU	"Azer-Forest" Production Unit
AIS	Agricultural Innovation System
ARB	Agricultural Research Board
AS	Academy of Sciences
ASDPAS	Agency for Support to the Development of Private Agricultural Sector
AzAA	Azerbaijan Agricultural Academy
CGS	Competitive Grants System
CIMMYT	International Center for Maize and Wheat
EAF	Euro-Asia Fund
ERS	Economic Reform Center
FAO	Food and Agriculture Organization
FPP	Farm Privatization Project
HDSREPT	Head Dept. Scientific Research, Education, and Personnel Training
IARC	International Agricultural Research Center
ICARDA	International Center for Agricultural Research in Dry Areas
ICSC	Information and Consulting Services Center
IDA	International Development Association
IDU	Information Dissemination Unit
IFAD	International Fund for Agricultural Development
GTZ	German Technical Support Society
MoA	Ministry of Agriculture
MoE	Ministry of Education
MoEc	Ministry of Economy
MoF	Ministry of Finance
MoT	Ministry of Taxes
MSP	Ministry of State Property
nAPC	Non-agricultural Private Colleges
nASC	Non-agricultural State Colleges
NARS	National Agricultural Research System
NGO	Non Governmental Organization
PACF	Private Agro-Consulting Firms
PrU	Private Universities
RES	Regional Experimental Stations
RI	Research Institutes
SAC	State Agricultural Colleges
SCEN	State Committee for Ecology and Nature Use
PCSEC	Permanent Commission for Science, Education an Culture
SCAR	State Commission for Agrarian Reforms
SCADPF	State Commission for Assistance to Development of Private Farms
SSF	State Seed Farms
SAIC	State Amelioration & Irrigation Committee
SLC	State Land Committee
SU	State Universities
SCST	State Committee on Science and Technology
SCC	State Customs Committee
TACIS	Technical Assistance Committee for Independence States
USAID	United States Agency for International Development
UNDP	United Nation Development Program
WB	World Bank

February 25, 2002

J.C. Bureau
Program Committee EAAE Congress
INRA-ESR, BP1, 78850 Thiverval-Grignon
France.

Dear Sirs/Madam:

I am writing to submit the following study titled ***Systems Analysis by Graph-theoretic Techniques: Assessment of Institutional Linkages in the Agricultural Innovation System of Azerbaijan*** for presentation in the EAAE meetings that will be held in Zaragoza, Spain, on 28-31 August 2002. Attached please find three (3) copies of the study. I should also note that the study should not be considered for poster session.

This study develops a quantitative, graph-theoretic method for analysing systems of institutions. With an application to the agricultural innovation system of Azerbaijan, the method is illustrated in detail. An assessment of existing institutional linkages in the system suggests that efforts should be placed on the development of intermediary institutions to facilitate quick and effective flow of knowledge between the public and the private components of the system. Furthermore, significant accomplishments are yet to come in policy-making, research and education, and credit institutions.

I am looking forward to hearing from you.

With best regards,

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