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9 February 2013

Online at https://mpra.ub.uni-muenchen.de/44303/
MPRA Paper No. 44303, posted 09 Feb 2013 09:48 UTC

Targeting Information Policy for Improved System Performance

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Working Paper No. 13-02

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Abstract

This paper introduces a method for characterising the structure of a multi-sector information system and illustrates its application in formulating testable hypotheses and targeting information policy for improved system performance. This characterisation is accomplished by identifying information gaps and cause-effect information pathways in the system concerned. An experimental workshop and a questionnaire are designed to gather data for the application of the method. The method allows one to analyze system information structure and performance implied by qualitative expert knowledge.

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Keywords: information systems, system formation and performance, institutional and information flow analysis, structure-conduct-performance approach

JEL Codes: D02, D23, D81, D83, D85, O17, P2

1 Introduction

This paper introduces a method for characterising the structure of a multi-sector information system and illustrates its application in formulating testable hypotheses and targeting information policy for improved system performance. This characterisation identifies information gaps and cause-effect information pathways in the system concerned,[1] drawing on graph-theoretic concepts and principles of systems analysis. An experimental workshop[2] and a questionnaire are designed to gather data for the application of the method. The method allows one to analyze systems's information structures and performance implied by qualitative expert knowledge.

The method starts with a mathematical description of a dynamic information system consisting of a set of non-linear difference equations. Then, this system is presented in a matrix format. Next, with an experimental workshop, critical binary causal relations (or information flow) and pathways of relations are identified. Finally, these critical relations and pathways are substituted into the implied information system to derive the reduced form of the implied system that is used to identify testable hypotheses. Expert knowldge gathered through the workshop represents the key input used in the analysis. The method developed allows to disentangle the unobserved from the observed information flow using data gathered by a questionnaire.

The idea here is not new. Econometrics provides a wide range of techniques, including logit, probit, and discriminant analysis, for estimating the probability distribution implied by qualitative expert knowledge. What is new here is the way a complex, dynamic model is treated in a workshop setup to obtain its reduced form implied by expert knowledge, and the way hypotheses are developed to test the underlying characteristics of the system concerned. With this method, a bridge is established to close the gap between theoretical models (linear as well as a subset of non-linear models) and their characterisation in a social setup, such as workshops or expert panels often adopted as the means of information collection for policy design and research.

The chapter is organised in five sections. Following the introduction, Section 2 presents a mathematical description of an arbitrary information system with its structural properties at the component and system levels. Section 3 extends the method for targeting information policy. Section 4 illustrates the application of the method within a workshop set-up and shows how to derive testable hypotheses based on expert knowledge gathered by a questionnaire. Finally, Section 5 concludes the chapter.

2 A structure for an information system

An information system S_K is defined as a collection of K components of n organisations that jointly and/or individually generate, disseminate, or use information to accomplish a common goal G.

$$S_K = \left\{ \{C^i, G^i, G\}_{i=1}^{K} \mid \cap C^i = 0, \cap G^i = G, n = \textstyle\sum_{i=1}^{K} n_i \right\}. \tag{1}$$

This definition postulates three conditions. First, n_i organisations within component i, denoted by C^i, are assumed to have a common goal G^i in the generation or dissemination or use of the information concerned.[3] Secondly, components are mutually exclusive, meaning that an organization cannot be a member of more than one component during the same time period. This is implied by $\cap C^i = 0$. Thirdly, individual components support the system goal, which is implied by $\cap G^i = G$.

S_K is assumed to operate at two levels. At the component level, each component aims to realize its goal by considering its isolated, one-to-one (binary) interactions with other components in the system. Hence, each component gives priority to the improvement of its own environment $e^i(.)$, while abstracting itself from the needs of the entire system. At the system level, however, a benevolent body governs the entire network of binary interactions across K components to realize the system goal; hence, it gives priority the improvement of the system environment $e(.)$ in which individual components operate. The distinction between the component and system environments arises from the fact that a component does not invest in areas that are likely to lead to substantial positive externalities for others because S_K does not assume any property rights system. On the contrary, the benevelont body is expected to invest in areas where positive externalities are likely to arise.

The case of ICT is one such example to show the distinction between the two environments. Consider, for example, the investment in ICT infrastructure: human, capital and institutional. A component will naturally be interested in the investment aimed to enhance staff capacity, acquire new information technologies and design rules for binary information exchange within the component as well as with other components with which it has relations. However, the benevelont body will be interested in creating an enabling environment aimed to facilitate individual components to operate more effectively. Organizing information exchange communities, investing in the economy-wide ICT infrastructure and establishing policy and institution making public bodies are some of the elements of such environment.

To this end, we conjecture that there are two implicit information management functions: one operating at the component level $m^i(.)$ and another at the system level $m(.)$. The term ***information management*** refers to the management of three information activities: information production, dissemination and use.[4] Following Steven Wolfe, David Zilberman, Steven Wu and David Just [6], information refers to a highly context-sensitive resource, the meaning and value of which depend on the competencies of the organisations interacting.

2.1 Component-level information management

Given $(\alpha_t^i, G^i, I_{t-1})$, a representative organization in component i characterized by $\{e^i(.), m^i(.)\}$ chooses (L_t^i, D_t^i):

$$I_t^i = \alpha_t^i m^i(e^i(L_t^i, D_t^i) \mid G^i, I_{t-1}) \tag{2}$$

$$where\, I_{t-1} \equiv (I_{t-1}^1, I_{t-1}^2, ..., I_{t-1}^K).$$

$m^i(.)$ denotes component i's information management function. Equation 2 specifies that, given component i's goal G^i and the system information stock I_{t-1} at time t, component i organizes its information activities by investing in the development of its learning L_t^i and dissemination D_t^i capacities. The parameter $\alpha_t^i = \alpha^i(L_t, D_t)$ represents component i's capacity to internalize changes taking place at the system level (L_t, D_t). Only the ratios of the α_t^i's matter, so without loss of generality we can normalize $\alpha_t^1 = 1$.

Using equation 2, we map the component-based information flow as:

$S_K^C \equiv S_K((L_t^1, D_t^1), ..., S_K(L_t^K, D_t^K)) =$

$$\begin{bmatrix} I_{t-1}^1 I_t^1 & I_{t-1}^1 I_t^2 & . & . & I_{t-1}^1 I_t^K \\ I_{t-1}^2 I_t^1 & I_{t-1}^2 I_t^2 & . & . & I_{t-1}^2 I_t^K \\ . & . & . & . & . \\ . & . & . & . & . \\ I_{t-1}^K I_t^1 & I_{t-1}^K I_t^2 & . & . & I_{t-1}^K I_t^K \end{bmatrix}. \tag{3}$$

It should be noted that each column of this square matrix is associated with one component. For example, the 1^{st} column corresponds to component 1; and the 2^{nd} column, component 2. The diagonal cells $I_{t-1}^i I_t^i$ for all i and t show information loops. The off-diagonal cells $\left\{I_{t-1}^i I_t^j, i = j = 1, ..., K \, and \, i \neq j\right\}$

indicate binary information flow between two components. For example, $I_{t-1}^2 I_t^1$ indicates that information available in C^2 at $t-1$ flows into C^1at time t. It can also be interpreted that C^2's information stock at time $t-1$ can be used to exert ***influence*** on the information production activity of C^1 at time t. Information flow might be through formal mechanisms, such as information sharing committees, joint publications, and joint sta training, or through informal interactions of organisations. In this model, we assume that the flow is purposefully organised by the two components interacting by using formal mechanisms.

To fully measure the ***net*** information flow in S_K^C, a total of $(2K^2 - K)$ parameters should be determined. Take, for example, the net information flow via the off-diagonal cell $(I_{t-1}^2 I_t^1)$. This requires the determination of two parameters: C^2's dissemination and linkage development capacity D_{t-1}^2 as well as C^1's learning capacity L_t^1, which then results in $[2K(K-1)]$ parameters to be known. Further, K parameters need to be determined for α_t^i. As a result, with the determination of $[2K(K-1)+K] = (2K^2 - K)$ parameters, S_K will be fully identified.

2.2 System-level information management

A ***benevolent*** body characterized by $\{e(.), m(.)\}$ is assumed to purposefully organise all the components around the system goal. Given (β_t, G, I_{t-1}), this body applies a governance rule $m(.)$ to manage the system-level information flow:

$$I_t = \beta_t m(e(L_t, D_t) \mid G, I_{t-1}). \tag{4}$$

Note that equation 4 is expressed in vector notation. In its undertakings, the benevolent body aims to create an enabling environment for improved learning and information dissemination to take place. β_t is exogenous to the benevolent body's actions, reflecting its adjustment capacity against shocks. Only the ratios of the β_t's matter, so without loss of generality we can normalize $\beta_t^1 = 1$.

Using equation 4, we map the system-based information flow as:

$$S_K^S \equiv S_K(L_t, D_t) = \begin{bmatrix} I_{t-1}^1 I_t^1 & I_{t-1}^1 I_t^2 & . & . & I_{t-1}^1 I_t^K \\ I_{t-1}^2 I_t^1 & I_{t-1}^2 I_t^2 & . & . & I_{t-1}^2 I_t^K \\ . & . & . & . & . \\ . & . & . & . & . \\ I_{t-1}^K I_t^1 & I_{t-1}^K I_t^2 & . & . & I_{t-1}^K I_t^K \end{bmatrix}. \tag{5}$$

S_K^S captures one new property that components cannot support individually. This is the property that the system is greater than the sum of its components. That is, the economy-wide information stock under S_K^S is greater than the sum of the component-level information stocks under S_K^C. This is attributed to the fact that in S_K^C, binary information flow is determined by common interests of the two components concerned, while the flow in S_K^S is determined by the benevolent body's effort to tune all the binary linkages in the system into the system goal G. The system information management function $m(e(L_t, D_t) \mid G, I_{t-1})$ does not affect the internal affairs of components, but promotes the growth of necessary binary linkages in the entire system.

3 Targeting information policy

To design effective information policy interventions for the improvement of system performance - in terms of generation, fludity and use of information, one needs to have a clear understanding of the nature of ***observed*** information flow in the system. In reality, the observed flow S_K comprises two types of ***entangled*** binary relations $\{S_K^C, S_K^S\}$. Equation 3 maps Type I relations that individual components establish by using their own resources, while equation 5 maps Type II relations that are either fully or partially established through the employment of system resources. The task is to disentangle these relations, identify the weak spots at the component as well as system levels, and design policy interventions.

Type I and Type II relations can be disentagled by analyzing the key factors that shape the component and system environments. **Tables 1-2** provide a list of such factors. Information on the extent to which these factors have been realized can be used to derive a weight for disentangling S_K^C from S_K (or S_K^S from S_K). The strength of individual factors is assessed by using a scale from 1 through 5: 1=weak, 2=below-average, 3=average, 4=above-average and 5=strong. The level 1 (level 5) represents the minimum (maximum) strength, and over 8 factors listed, the minimu (maximum) total score would be 8 (40). Having defined the minimum (maximum) total scores, we calculate the following weights for every organization j in the system and then take the component level average:

$$\bar{l}_i = \sum_{j=1}^{n_i} \left[\frac{actual\, total\, score\, for\, L^j - min\, total\, score\, for\, L^j}{max\, total\, score\, for\, L^j - min\, total\, score\, for\, L^j} \right] / n_i$$

$$\bar{d}_i = \sum_{j=1}^{n_i} \left[\frac{actual\, total\, score\, for\, D^j - min\, total\, score\, for\, D^j}{max\, total\, score\, for\, D^j - min\, total\, score\, for\, D^j} \right] / n_i.$$

The same calculations are also performed to determine $\underline{l}(i)$ abd $\underline{d}(i)$ for the system variables D and L, respectively. Normalizing $\left(\bar{d}_i, \underline{d}(i)\right)$ and $\left(\bar{l}_j, \underline{l}(j)\right)$ yields:

$$(d_i, l_j) \equiv \left(\frac{\bar{d}_i}{\bar{d}_i + \underline{d}(i)}, \frac{\bar{l}_j}{\bar{l}_j + \underline{l}(j)} \right) \; \forall_{i,j=1,2,\ldots,K}.$$

Use a geometric mean of d_i and l_i, we construct a matrix of indices W_K to measure the fluidity of information between two components:

$$w_{ij} = (d_i^{0.5} l_j^{0.5}) \, \forall_{ij} \Longrightarrow W_K = \begin{bmatrix} w_{11} & w_{12} & . & . & w_{1K} \\ w_{21} & w_{22} & . & . & w_{2K} \\ . & . & . & . & . \\ . & . & . & . & . \\ w_{K1} & w_{K2} & . & . & w_{KK} \end{bmatrix}.$$

Applying the Hadamard product (also known as the entry-wise product) yields:

$$S_K^C = W_K \circ S_K =$$

$$\begin{bmatrix} w_{11} & w_{12} & . & . & w_{1K} \\ w_{21} & w_{22} & . & . & w_{2K} \\ . & . & . & . & . \\ . & . & . & . & . \\ w_{K1} & w_{K2} & . & . & w_{KK} \end{bmatrix} \circ \begin{bmatrix} I_{t-1}^1 I_t^1 & I_{t-1}^1 I_t^2 & . & . & I_{t-1}^1 I_t^K \\ I_{t-1}^2 I_t^1 & I_{t-1}^2 I_t^2 & . & . & I_{t-1}^2 I_t^K \\ . & . & . & . & . \\ . & . & . & . & . \\ I_{t-1}^K I_t^1 & I_{t-1}^K I_t^2 & . & . & I_{t-1}^K I_t^K \end{bmatrix}$$

$$= \begin{bmatrix} w_{11}(I_{t-1}^1 I_t^1) & w_{12}(I_{t-1}^1 I_t^2) & . & . & w_{1K}(I_{t-1}^1 I_t^K) \\ w_{21}(I_{t-1}^2 I_t^1) & w_{22}(I_{t-1}^2 I_t^2) & . & . & w_{2K}(I_{t-1}^2 I_t^K) \\ . & . & . & . & . \\ . & . & . & . & . \\ w_{K1}(I_{t-1}^K I_t^1) & w_{K2}(I_{t-1}^K I_t^2) & . & . & w_{KK}(I_{t-1}^K I_t^K) \end{bmatrix}.$$

The disentangling of S_K^C provides three advantages in the design of policy interventions. First, the relations with poor information flow can be projected, and this would allow policy makers to take measures to release the constraints on these relations before decisions are implemented. Second, the effective information flow can be projected with the identification of dominant and sub-ordinate components in the system. Specific policies/programs and institutions can target the dominant sources (i.e., components) and subordinate users of critical information. Third, the estimated matrix together with the underlying institutional structure can provide us with information on the type of the system: flexible versus rigid. A system is said to be flexible (rigid) if the organizational capacities are highly developed (undeveloped) and institutions such as property rights and enforcement rules are in place (at embryonic stage).

4 An experiment

4.1 Characterizing S_K

An experimental workshop is used to show how to establish S_K and identify the critical information gaps and pathways it contains. The implied structure of S_K is further analysed to develop testable hypotheses. Suppose that the workshop gathers representatives of $n = 15$ organisations, which are divided into $K = 5$ components (or subsets), with $n_i = 3$ organisations each. Fifteen representatives are organised in three working groups (WG), each of which includes one representative from each component. These groups separately discusse areas that warrant better understanding and where information flow is constrained in relation to a system goal. One such goal is to enhance agricultural productivity through an effective flow of biotechnological information. Every WG prepares a map of information flow (or of causal relations): S_5^{WG1}, S_5^{WG2} and S_5^{WG3}, which are consolidated as $S_5 = S_5^{WG1} + S_5^{WG2} + S_5^{WG3}$.

A multi-voting scheme is adopted to rank the preferences of 15 representatives over binary information flow or causal relations placed in the off-diagonal cells of S_5. Each representative is given three votes: a ***strong*** vote worth three points, a ***mediocre*** vote worth two points, and a ***weak*** vote worth one point. Suppose that the voting yields three hypothetical systems: $S_{5,strong}$ for ***strong*** votes, $S_{5,mediocre}$ for ***mediocre*** votes, and $S_{5,weak}$ for ***weak*** votes.

$S_{5,strong}$ indicates the causal relations that received strong votes only, putting first things first. For instance, the causal relation $I_{t-1}^1 I_t^4$ placed in the 1^{st} row - 4^{th} column of $S_{5,strong}$ received four strong votes that amount to 12 points. Placed in the 3^{rd} row - 2^{nd} column, the relation $I_{t-1}^3 I_t^2$ received five strong votes that amount to 15 points. With 15 points, $I_{t-1}^3 I_t^2$ stands out as the top priority causal relation to be investigated, followed by $I^1_{t-1}I^4_t$ and $I^5_{t-1}I^4_t$ with 12 points each.

$$S_{5,strong} = \begin{bmatrix} I^1_{t-1}I^1_t & 3 & 3 & 12 & 3 \\ 9 & I^2_{t-1}I^2_t & . & . & . \\ . & 15 & I^3_{t-1}I^3_t & . & . \\ 3 & 6 & . & I^4_{t-1}I^4_t & . \\ 3 & . & . & 12 & I^5_{t-1}I^5_t \end{bmatrix}.$$

$S_{5,mediocre}$ indicates the causal relations that received only mediocre votes. With six points in the 1^{st} row - 5^{th} column of $S_{5,mediocre}$, the binary relation $I^1_{t-1}I^5_t$ is the strongest, followed by the relations $I^1_{t-1}I^2_t$, $I^2_{t-1}I^1_t$, $I^3_{t-1}I^2_t$, and $I^4_{t-1}I^1_t$ with four points each.

$$S_{5,mediocre} = \begin{bmatrix} I^1_{t-1}I^1_t & 4 & 2 & 2 & 6 \\ 4 & I^2_{t-1}I^2_t & . & . & . \\ . & 4 & I^3_{t-1}I^3_t & 2 & . \\ 4 & . & . & I^4_{t-1}I^4_t & 2 \\ 3 & . & . & 2 & I^5_{t-1}I^5_t \end{bmatrix}.$$

$S_{5,weak}$ indicates the causal relations that received weak votes only. With four points, the relation $I^2_{t-1}I^1_t$ is the strongest, followed by $I^1_{t-1}I^5_t$ and $I^4_{t-1}I^3_t$ with three points each.

$$S_{5,weak} = \begin{bmatrix} I^1_{t-1}I^1_t & 2 & 1 & . & 3 \\ 4 & I^2_{t-1}I^2_t & . & . & . \\ . & . & I^3_{t-1}I^3_t & . & . \\ . & . & 3 & I^4_{t-1}I^4_t & 1 \\ 2 & . & . & 1 & I^5_{t-1}I^5_t \end{bmatrix}.$$

Finally, $S_{5,total}$ indicates the aggregate votes calculated as $(S_{5,strong} + S_{5,mediocre} + S_{5,weak})$. With 19 points, the relation $I^3_{t-1}I^2_t$ stands out as the top priority relation, followed by $I^2_{t-1}I^1_t$ with 17 points, $I_{t-1}^5 I_t^4$ with 15 points, $I_{t-1}^1 I_t^4$ with 14 points, and $I_{t-1}^1 I_t^5$ with 12 points.[5]

$$S_{5,total} = \begin{bmatrix} I_{t-1}^1 I_t^1 & 9 & 6 & 14 & 12 \\ 17 & I_{t-1}^2 I_t^2 & . & . & . \\ . & 19 & I_{t-1}^3 I_t^3 & 2 & . \\ 7 & 6 & 3 & I_{t-1}^4 I_t^4 & 3 \\ 5 & . & . & 15 & I_{t-1}^5 I_t^5 \end{bmatrix}.$$

The $cause - effect$ structure: Cause (c) of a component is defined as the sum of the points in the corresponding row; and Effect (e), as the sum of the points in the corresponding column (**Table 3**). Listing the (c, e) coordinates in **Table 3**, **Figures 1-4** show the underlying structures of $S_{5,strong}$, $S_{5,mediocre}$, $S_{5,weak}$, and $S_{5,total}$, respectively.[6] These figures have three critical regions. Region 1 is the locus of the 45-degree line, where $c = e$. A component on this line is said to be highly interactive with the rest of the system if its coordinate falls in the north-east corner of the figure; and minimally interactive if its coordinate is close by the $(0, 0)$ coordinate. Region 2 is the area below the 45-degree line, where $c > e$. A component with a very high c and a very low e, denoted by $c >> e$, suggests that it strongly dominates the others in the system. Region 3 is the area above the 45-degree line, where $c < e$. A component with a very low c and a very high e, denoted by $c << e$, suggests that it is strongly subordinate.

The $(c - e)$ structure of $S_{5,total}$ shown in **Figure 1** reveals that:

1. I_t^1 is the most dominant component in the system, with $c = 41$ points, followed by I_t^3 with 21 points.

2. I_t^5 is relatively speaking the most interactive component.

3. I_t^2 and I_t^4 are both subordinate components.

The observation (1) and the three key relations $I_{t-1}^1 I_t^4$, $I_{t-1}^1 I_t^5$ and $I_{t-1}^3 I_t^2$ in $S_{5,total}$ all together suggest that research needs to be done to uncover the mechanisms through which I_t^1 influences both I_t^4 and I_t^5, and I_t^3 influences I_t^2. Furthermore, the observation (2) and the key relation $I_{t-1}^5 I_t^4$ in $S_{5,total}$ together suggest that research needs to be done to uncover the mechanisms through which I_t^5 influences I_t^4. Finally, the observation (3) reveals that I_t^1 is also influenced strongly by the rest of the system points to the need for further research as to how I_t^2 influences I_t^1. These three suggestions imply the following reduced form that reveals the identified critical relations only.

$$S_{5,total} = \begin{bmatrix} I^1_{t-1}I^1_t & . & . & 14 & 12 \\ 17 & I^2_{t-1}I^2_t & . & . & . \\ . & 19 & I^3_{t-1}I^3_t & . & . \\ . & . & . & I^4_{t-1}I^4_t & . \\ . & . & . & 15 & I^5_{t-1}I^5_t \end{bmatrix}..$$

The reduced form underlines the key feature of the system at hand. I^3_t is the only truly exogenous component, while I^4_t is the only truly endogenous component. One implication of this feature is that pathways of interest in the reduced $S_{5,total}$ would always start with I^3_t and end at I^4_t, resulting in the following $3-edged$ and $4-edged$ pathways, respectively:

$$I^3_{t-1}I^2_t,\ I^2_{t-1}I^1_t,\ I^1_{t-1}I^4_t$$

$$I^3_{t-1}I^2_t,\ I^2_{t-1}I^1_t,\ I^1_{t-1}I^5_t,\ I^5_{t-1}I^4_t.$$

The $(c-e)$-structure of $S_{5,strong}$ shown in **Figure 2** is interpreted similarly. It shows an almost identical structure to that in **Figure 1**, except that the components are more polarised. Furthermore, the reduced form of $S_{5,strong}$ has two exogenous components, I^3_t and I^5_t, while I^4_t still remains to be the only endogenous component. Therefore, the pathways of interest would include $I^3_{t-1}I^2_t$, $I^2_{t-1}I^1_t$, $I^1_{t-1}I^4_t$ and $I^5_{t-1}I^4_t$. (The interpretation of $S_{5,mediocre}$ and $S_{5,weak}$ is left to the reader.)

$$S_{5,strong} = \begin{bmatrix} I^1_{t-1}I^1_t & . & . & 12 & . \\ 9 & I^2_{t-1}I^2_t & . & . & . \\ . & 15 & I^3_{t-1}I^3_t & . & . \\ . & . & . & I^4_{t-1}I^4_t & . \\ . & . & . & 12 & I^5_{t-1}I^5_t \end{bmatrix}.$$

All in all, the analysis suggests that pathways including $I^3_{t-1}I^2_t$, $I^2_{t-1}I^1_t$, $I^1_{t-1}I^4_t$ (**Figure 5**) and $I^3_{t-1}I^2_t$, $I^2_{t-1}I^1_t$, $I^1_{t-1}I^5_t$, $I^5_{t-1}I^4_t$ (**Figure 6**) warrant better understanding.

The ***connectedness*** of S_K, denoted by Z, is calculated as $\frac{R}{K(K-1)}$ with $1 \geq Z \geq 0$, where R is the total number of ***identified*** causal relations; K, the number of dimensions of S_K; and $[K(K-1)]$, the total number of causal (binary) relations in S_K. Thus, $Z_{total} = \frac{13}{20}$, where $R = 13$ and $K = 5$.

Other measures of connectedness include: $Z_{strong} = \frac{10}{20}$, $Z_{mediocre} = \frac{10}{20}$ and $Z_{weak} = \frac{8}{20}$. A system is said to be fully identified if $Z = 1$, which implies that all of the components in the system are connected to each other.

A cluster is a subset of components concentrated around a certain (c, e)-coordinate. The analysis shows that there are two clusters: (I_t^2, I_t^4) and (I_t^3, I_t^5). The component I_t^1 represents an island as it stands alone separated from the rest of the system.

4.2 Disentangling S_K^C and S_K^S from S_K

For illustrative purposes, we set arbitrary values for $(d_1, l_1) = (0.7, 0.5)$, $(d_2, l_2) = (0.5, 0.5)$, $(d_3, l_3) = (0.4, 0.6)$, $(d_4, l_4) = (0.8, 0.5)$, $(d_5, l_5) = (0.3, 0.8)$. Using $S_{5,total}$, we calculate the following disentagled information system:

$$S^C_{5,total} = W_5 \circ S_{5,total}$$

$$= \begin{bmatrix} 0.59 & 0.59 & 0.65 & 0.59 & 0.75 \\ 0.50 & 0.50 & 0.55 & 0.50 & 0.63 \\ 0.45 & 0.45 & 0.49 & 0.45 & 0.57 \\ 0.63 & 0.63 & 0.69 & 0.63 & 0.80 \\ 0.39 & 0.39 & 0.42 & 0.39 & 0.49 \end{bmatrix} \circ \begin{bmatrix} 0 & 9 & 6 & 14 & 12 \\ 17 & 0 & 0 & 0 & 0 \\ 0 & 19 & 0 & 2 & 0 \\ 7 & 6 & 3 & 0 & 3 \\ 5 & 0 & 0 & 15 & 0 \end{bmatrix}$$

$$S^C_{5,total} = \begin{bmatrix} I^1_{t-1}I^1_t & 5 & 4 & 8 & 9 \\ 9 & I^2_{t-1}I^2_t & 0 & 0 & 0 \\ 0 & 9 & I^3_{t-1}I^3_t & 1 & 0 \\ 4 & 4 & 2 & I^4_{t-1}I^4_t & 2 \\ 2 & 0 & 0 & 6 & I^5_{t-1}I^5_t \end{bmatrix}.$$

Table 4 lists the implied (c, e)-coordinates of $S^C_{5,total}$ and $S^S_{5,total}$. These coordinates imply that the influence on the information flow of changes in the system and component environments is comparable. The design of policy intervention is conditional on the specific system and component goals.

4.3 Hypothesis development

The findings can be analysed with three concepts: information gaps, ***cause-effect*** information pathways, and potential testable hypotheses. The multi-voting scheme carried out resulted in the identification of five critical gaps that warrant better understanding (see the reduced forms of $S_{5,total}$ and $S_{5,strong}$). These gaps are: the effects of I_t^3 on I_t^2; the effects of I_t^2 on I_t^1; the effects of I_t^1 on I_t^4; the effects of I_t^1 on I_t^5; and the effects of I_t^5 on I_t^4. Each one of these gaps represents a hypothesis that deserves to be tested empirically.

The gaps further imply that the system under investigation has a total of two cause-effect information pathways, $I_{t-1}^3 I_t^2$, $I_{t-1}^2 I_t^1$, $I_{t-1}^1 I_t^4$ and $I_{t-1}^3 I_t^2$, $I_{t-1}^2 I_t^1$, $I_{t-1}^1 I_t^5$ $I_{t-1}^5 I_t^4$, to be examined (**Figures 5** and **6**). The first pathway should read as follows. The organisations in C^3 make their time $t-1$ information stock available to those organizations in component 2, while those in component 2 make their $t-1$ information stock to those in component 1 and so on. Interpreted likewise, the second pathway additionally indicates the need for information on the effects of I_{t-1}^1 on I_t^5 and those of I_{t-1}^5 on I_t^4. The sequence of interactions in these pathways is crucial and remains to be tested empirically.

The ***directed*** causal relations in **Figures 1-2** show that C^1 is the dominant source of information, which is followed by C^3 and C^5, and that C^2 and C^4 are the subordinate users of information. Each one of these observations represents an area to be investigated empirically. Regarding C^1 being the dominant source, one can formulate a hypothesis that organisations in this component significantly influence the information management in C^4 or C^2. Likewise, the influence on the information management in C^4 and C^2 of the second degree sources (C^3 or C^5) can also be tested.

The analysis indicates that some components have distinct testable characteristics. The first characteristic is that I_t^3 is exogenous. This immediately follows from the reduced forms of $S_{5,total}$ and $S_{5,strong}$, where the column associated with I_t^3 is empty. The second is that I_t^4 is endogenous. This follows from the reduced forms of $S_{5,total}$ and $S_{5,strong}$, where the row associated with I_t^4 is empty.

The multi-voting scheme was applied to classify binary relations into three groups: high, mediocre, and weak. The implied information structures are then mapped in **Figures 2-4**, respectively. A comparison of these structures points to two regularities to be investigated further. First, no matter which group is used, C^1 remains to be the most crucial source of information. Second, C^4 shows the highest variability on the spectrum: subordinate in **Figure 2**, interactive in

Figure 3 and dominant in **Figure 4**.

5 Concluding remarks

This paper introduces a method for characterising the structure of a multi-sector information system and illustrates its application in formulating testable hypotheses and targeting information policy for improved system performance. This characterisation is accomplished by identifying information gaps and cause-effect information pathways in the system concerned. An experimental workshop and a questionnaire are designed to gather data for the application of the method. The method allows one to analyze system information structure and performance implied by qualitative expert knowledge.

The method can also be applied in targeting information policy. What is observed is the entangled information flow patterns, which are partly developed by one-to-one component interactions and partly by system-wide efforts of a benevolent body. For targeting information policy, policy makers should have a clear mapping of the component-based flow patterns as well as a mapping of the system-based flow patterns. Such mappings can be used to identify the areas critical for the investment aimed to enhance the system performance.

The method has several weaknesses, however. The information circulating in the system must be standardised for measurement and comparability of the effects of pathways identified on the system goal (see Kenneth Arrow [1]). The organisations interact with each other during the process of the generation, exchange and use of information. This interaction can only be quantified if it is measured by a common unit. The method assumes that this task is undertaken by a benevolent decision making body whose only goal is to improve the system goal.[7]

For a complete identification of the system, formal and informal information should be distinguished. One way to do this, suggested by Steven Wolfe, David Zilberman, Steven Wu and David Just [6], is to classify information with respect to the medium of communication and intentions underlying the interactions. Information derived from texts, conferences, phone calls, etc., can be classified as formal, while conversations and social interactions among family, friends and business associates like colleagues, customers, suppliers and competitors, can be classified as informal information.

On the empirical account, the design and implementation of a real workshop is critical. The design should take into account such characteristics as type, qualification and number of participants.

The implementation should make sure that compositions of and discussions in working groups are tuned into the achievement of the system goal.

Notes

[1]The term ***gap*** is used to refer to an area that warrants better understanding; the term ***pathway***, a chain of interactions between organisations; and the term ***information pathway*** is used to mean that the content of the interaction concerned is information exchange.

[2]A multi-voting scheme is carried out in the workshop to identify the gaps, pathways and develop hypotheses.

[3]The terms Component i and C^i are interchangeably used throughout the chapter.

[4]Irini Theodorakoupoulou and Nicholas Kalaitzandonakes [5] introduces a similar model, except that our model of information management additionally considers the system characteristics, which are exogenous to individual organisations.

[5]See Kazuo Murota [4] for studying the features of systems.

[6]Thanks to Rick Davies for indicating the usefulness of such figures (personal communications). The reader is also referred to Linton Freeman [2] for visual graph-theoretic methods.

[7]The reader is also referred to the public economics literature for further reading on the value of public goods.

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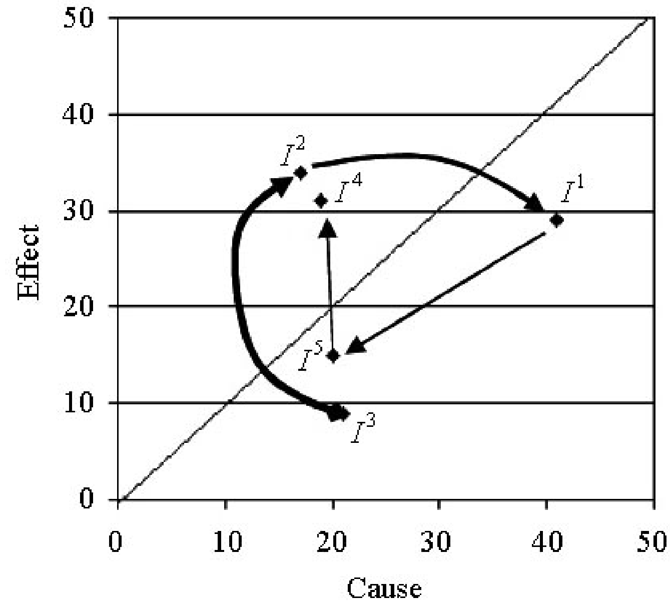

Figure 1: Map of directed (causal) relations in $S_{5,total}$

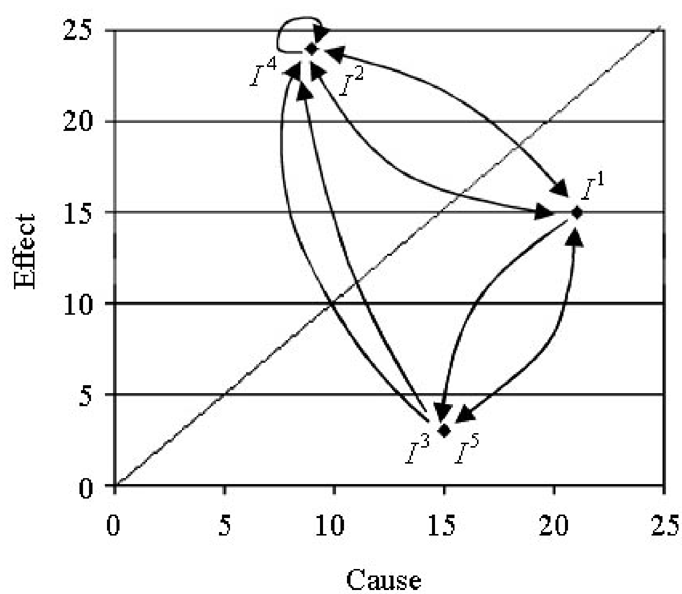

Figure 2: Map of directed (causal) relations in $S_{5,strong}$

Table 1: Factors that influence the component-level environment

	factors that shape organizational learning	environment of L^i 1	2	3	4	5
[1]	professional learning activities					
[2]	use of information exchange mechanisms: formal distribution plans, peer-to-peer relations, cross department teams					
[3]	organization characteristics: challenging status quo, experimenting with new methods, collaboration with others on learning projects					
[4]	support innovation and flow of new ideas					
[5]	implementation of new ideas or use of new learning mechanisms					
[6]	acquisition of info by: accident, intentional efforts, partnerships					
[7]	investment in learning resources: skilled labor, ICT, financial					
[8]	use of formal/informal rules and regulations in learning processes: public-private partnerships, community/network of organizations					
	actual total score ($40 \geq x \geq 8$)					

	factors that shape organizational information dissemination	environment of D^i 1	2	3	4	5
[1]	work culture: professional, cross-organizational sharing, collaboration					
[2]	understanding of relations with its environment: interrelationships b/w org and its environment, act with an understnding of the system					
[3]	information dissemination strategies: dissemination plans, innovative dissemination means and mechanism, professional networking					
[4]	exploring and learning information dissemination strategies					
[5]	info dissemination: scale, type (personal/formal), networking (formal, informal), peer-to-peer communication, demand-driven, use of dissemination means & mechanisms (reports, bulletin boards, meetings, briefings, cross-organizational teams, electronic communication networks)					
[6]	resource availability for dissemination: human and non-human resources (i.e., time, money and technology)					
[7]	role of computer &communication technologies on professional & org info dissemination, technology used by staff (www, e-mail)					
[8]	understanding and implementing policies, formal/informal institutions that affect dissemination of information					
	actual total score ($40 \geq x \geq 8$)					

Table 2: Factors that influence the system-level environment

	factors that shape organizational learning	environment of L 1	2	3	4	5
[1]	networking professional and organizational learning activities					
[2]	promoting cross-network collaboration on learning processes					
[3]	facilitating & supporting the flow of externality generating new ideas					
[4]	promoting the use of learning mechanisms within and across networks					
[5]	facilitating & regulating the use of formal/informal rules and laws governing public-private partnerships, communities/networks of organizations					
[6]	promoting the acquisition and use of new information through networks, partnerships and communities					
[7]	promoting the investment in learning resources: skilled labor, ICT, innovative funding schemes					
[8]	promoting tranparency, security and plurality in learning processes					
	actual total score ($40 \geq x \geq 8$)					

	factors that shape organizational information dissemination	environment of D 1	2	3	4	5
[1]	improving work environment in areas where cross-organizational information sharing offers large-scale externalities					
[2]	funding within and cross-network information exchange processes					
[3]	understanding and implementing policies (such as intellectual property rights), formal/informal institutions that affect information exchange and dissemination					
[4]	facilitating and funding large-scale information dissemination activities (expos, science and technology parks, etc.)					
[5]	developing secure electronic communication tools (i.e., world wide web, e-mail) and networks					
[6]	resource availability for public and public-private dissemination: human and non-human resources (i.e., time, money and technology)					
[7]	promoting tranparency, security and plurality in exchange and dissemination					
	actual total score ($35 \geq x \geq 7$)					

Table 3: Entangled cause-effect ($c - e$) coordinates

components	$S_{5,strong}$	$S_{5,mediocre}$	$S_{5,weak}$	$S_{5,total}$
I_t^1	(21, 15) +	(14, 8) +	(6, 6) =	(41, 29)
I_t^2	(9, 24) +	(4, 8) +	(4, 2) =	(17, 34)
I_t^3	(15, 3) +	(6, 2) +	(0, 4) =	(21, 9)
I_t^4	(9, 24) +	(6, 6) +	(4, 1) =	(19, 31)
I_t^5	(15, 3) +	(2, 8) +	(3, 4) =	(20, 15)

Table 4: Disentangled cause-effect ($c - e$) coordinates

components	$S^{C}_{5,total}$		$S^{S}_{5,total}$		$S_{5,total}$
I^1_t	(26,15)	+	(15,14)	=	(41, 29)
I^2_t	(9,18)	+	(8,16)	=	(17, 34)
I^3_t	(10,6)	+	(11,3)	=	(21, 9)
I^4_t	(12,15)	+	(7,16)	=	(19, 31)
I^5_t	(8,11)	+	(12,4)	=	(20, 15)

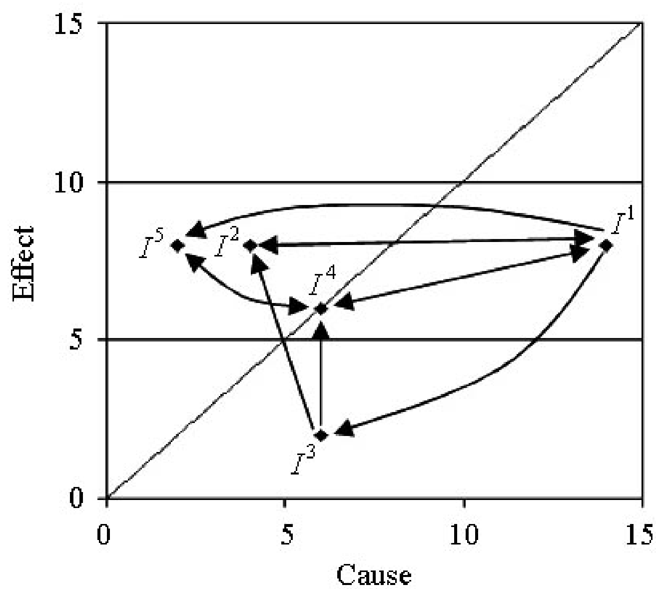

Figure 3: Map of directed (causal) relations in $S_{5,mediocre}$

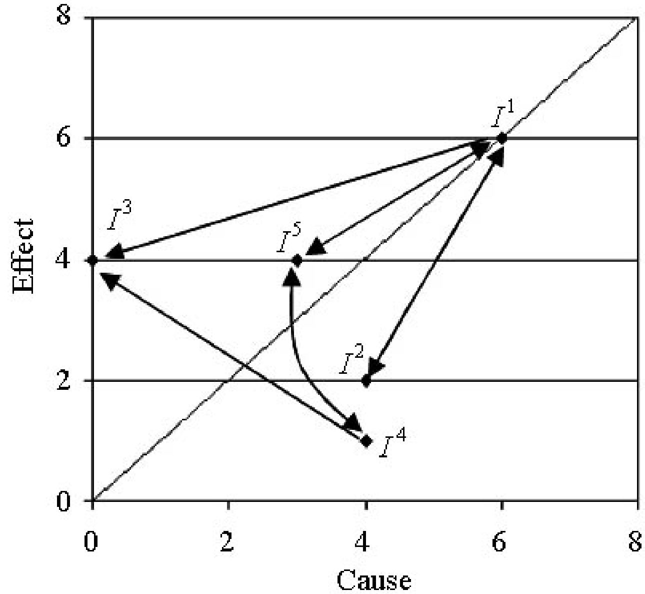

Figure 4: Map of directed (causal) relations in $S_{5,weak}$

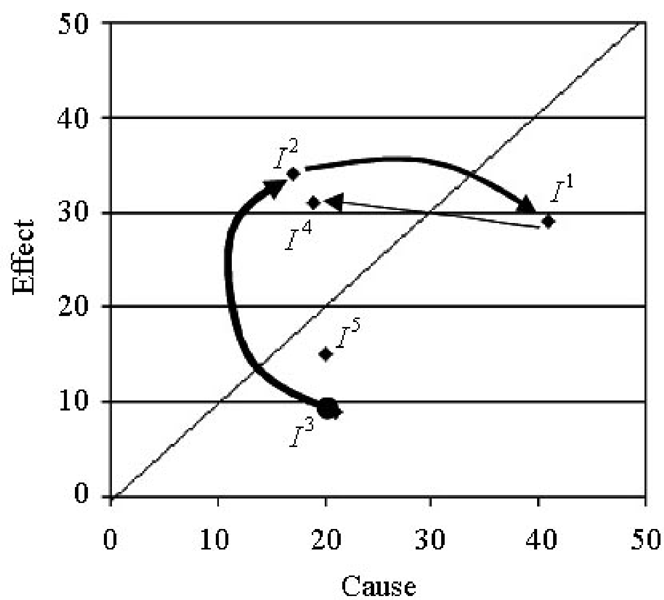

Figure 5: A 3-edged priority pathway $\{I^3 \rightarrow I^2 \rightarrow I^1 \rightarrow I^4\}$

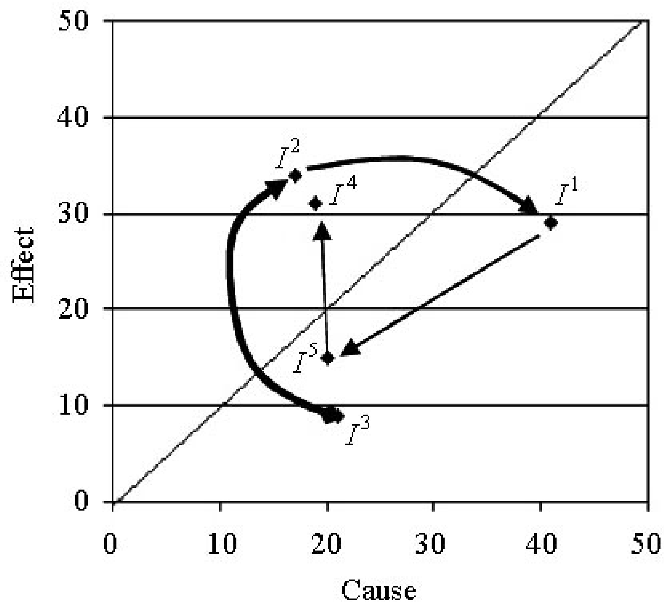

Figure 6: A 4-edged priority pathway $\{I^3 \to I^2 \to I^1 \to I^5 \to I^4\}$