Sectoral and Regional Interdependency of Japanese Firms under the Influence of Information Security Risks

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Abstract

Although there are some studies on inter-sectoral information security interdependency, the lack of regional interdependency analysis is one of their limitations. In this empirical study, we used an inter-regional input-output table in order to analyze both sectoral and regional interdependencies under the influence of information technology and information security of Japanese firms. Our analysis showed that the economic scale of a region has a great influence on the characteristics of the interdependency. Furthermore, we found that the demand-side sectors can be classified into five classes based on the characteristics. Among them, the groups with high self-dependency get more benefits from simultaneous understanding of regional characteristics; for the sectors in these classes, investment advice obtained from sectoral characteristics only is very limited, whereas they can obtain much more from regional characteristics. Since these classes include a majority of the sectors, we can recognize the importance of regional interdependency analysis. In the above basic study, what we see is the situation before The Great East Japan Earthquake on March 11, 2011.

As an extended study, we estimated reductions in interdependency resulting from investment-dependent economic damages in order to study how security investment can change the impact of the earthquake. Our main finding in regional perspective is that the interdependency characteristics of the most damaged region (Tohoku) and of the economically largest region (Kanto) are impacted most significantly.

Both in the basic study and in the extended study, we can see that considering not only sectoral but also regional characteristics is an effective approach to the task of empirically deriving implications related to the interdependency. There are many possibilities of more extended studies based on our methodology.

Keywords: Interdependency, Backward dependency, Empirical analysis, Supply chain, Input-output table, The Great East Japan Earthquake.

1 Introduction

1.1 Interdependency

Interdependency of information security is one of the main concerns in security economics. Empirical studies on interdependency of information security require two main groups of knowledge: one is from the viewpoint of economic transactions, and the other is from the viewpoint of security efforts or investments.

Regarding the interdependency of economic activities, information technology (IT) becomes one of the role players in supply chains[1]. IT brings interdependency into many industrial sectors such as *automotive*[2], *computer*[3], *financial services*[4]–[6], and *retail and logistics*[7]–[9].

In the area of security economics, the interdependency is very important particularly in the context of externalities[10]. Kunreuther and Heal applied Nash equilibrium to assess the interdependent security[11]. The impacts of network security vulnerabilities and supply chain integration on firms' incentives to their investments in information security were studied by Tridib, et al.[12]. They showed that the degree of network vulnerability or the degree of supply chain integration has relations to security investments. Hausken provided a framework in which two interdependent firms will be impacted both by security investment and by attacks if their interdependency increases[13]. Ogut et al. showed that the interdependency reduces firms' incentives to their investments in security technologies as well as to insurance coverage[14]. Tanaka studies economic interdependency between sectors under the influence of the IT systems of the sectors[20]; he assumed that a malfunctioning IT system in a firm will affect not only the activities of the firm but also those of its business partners. He then introduced the concept of ISBL (information security backward linkage) and analyzed interdependencies between firms in different sectors. Although he empirically assessed the influence of business locations on information security efforts[21], he did not analyzed regional interdependencies in his ISBL study.

1.2 Our Contributions

In this paper, we analyze the interdependency of information security in both sectoral and regional perspectives by using Japanese official datasets. Showing how regional perspective is helpful in systematic analyses of interdependency is our main contribution. In other words, this paper broadens the concept of the measurement methodology of interdependency by considering both sectoral and regional interdependencies of information security.

After the above analysis, The Great East Japan Earthquake occurred on March 11, 2011. This unfortunately reduced the empirical significance of each particular interdependency characteristic observed. However, rather than being disappointed in the empirical analysis, we proceed to extended analyses on how IT investment and security investment can change the impacts of earthquakes in terms of interdependency reduction. Thus we suggest a wide variety of possibilities regarding extended studies based on the proposed methodology. This suggestion and some empirical findings in the earthquake analyses is our second contribution.

In the rest of this paper, we will summarize more related works in Section 2. Our basic analysis methodologies will be described in Section 3. Then the paper will go on to a basic empirical study on Information Security Backward Dependency (ISBD) among Japanese firms by using data introduced in Section 4, and an extended study on the impacts of big earthquakes in Section 5. After showing and discussing the results in Section 6, we will give conclusions in Section 7.

2 Related Literatures

Let us start from Inoperability Input-output Model (IIM). IIM is a Leontief-based infrastructure input-output model introduced by Haimes and Jiang[15] in 2001. In particular, IIM can be used to quantify and address the risks from the intra- and inter-connectedness of infrastructures[16].

Inoperability in IIM is defined as "the inability of the system to perform its intended natural or engineered functions"[17]. It can be referred to as the level of the system's dysfunction. The main objective of their model is to assess the impact of interdependencies between infrastructures on the system. The use of IIM in [17] focused on the *industry–by–industry* viewpoint, and interdependencies between locations were not considered. Haimes et al. also introduced "Dynamic IIM" in order to test interdependency with temporal dynamic behaviors of industry recoveries after damages. In another work[18], they used high-attitude electromagnetic pulse (HEMP) attack scenarios on some industries to evaluate their model. The HEMP is an intense electromagnetic blast induced from high-elevation nuclear explosions which can damage electronic and electrical systems.

The IIM framework can be used to integrate analyses of systems from a hierarchical viewpoint where economic interdependency and physical interdependency are considered[16]. Here a hierarchical pyramid is used to show how economic and physical systems interact. Likewise, IIM can be used in the analysis of interdependencies under the influence of information security where several interactions may be considered. In fact, the framework for linking hierarchies of cyber security metrics is used to show consequent risks in the case of a cyber attack in an industrial sector such as Oil and Gas[19].

There are two main limitations of the existing works based on IIM. First, IIM does not distinguish differences between demand-driven perspective and supply-driven perspective. Another limitation is the lack of data regarding the level of IT dependency and information-security measures.

3 Methodology

Let us use a two-step approach to introduce our analysis methodology. The first step is about the analysis of cross-sectoral/regional interdependency as a basic economic analysis; we can conduct a sensitivity analysis by supposing a complete damage in a particular part of the input-output table. The second step is about the analysis of the interdependency under the influences of IT and information security (IS); we can conduct a similar but different analysis by supposing that the damage depends on the level of IT dependency and the level of IS efforts.

3.1 Structural Interdependency

From an economic viewpoint, structural interdependency can be assessed in two perspectives: demand-driven perspective and supply-driven perspective. In demand-driven perspective, the assessment is done from the purchaser's viewpoint. On the other hand, in supply-driven perspective, the assessment is done from the producer's viewpoint.

The assessment methodology from demand-driven and supply-driven perspectives was initially proposed by Dietzenbacher and van der Linder in 1997[22]. Their method was used to measure the inter-industry linkages in a multi-sectoral framework. They analyzed the value of absolute *Backward Linkages* (BL) which reflects sectors' dependency on its *inputs* that they produced within the production processes. Another analyzed value is the absolute *Forward Linkages* (FL), which, by contrast, reflects sectors' dependency on its *outputs* that were sold by a particular industry to other production sectors as well as to itself.

In our work, we aim to find interdependency from demand-driven perspective. Hence, we focus on BL. As another important feature of our work, we extend the basic definitions in the Dietzenbacher and van der Linder's work so that we can handle both sectoral and regional interdependencies.

3.1.1 Observed Values

In [22], the input-output table is used to show relationships between industrial sectors both in demand-driven perspective and in supply-driven perspective. We extend their definitions by considering additional indices to indicate different regions. In other words, we consider an *inter-regional input-output table* $Z = (z_{q,i,r,j})$ where each intersection $z_{q,i,r,j}$ is the economic transaction of goods and services purchased by demand-side companies of sector j in region r from supply-side companies of sector i in region q. Each transaction is valued at producers' prices. The combination of a region and a sector is called a *group*. When we talk about firms in a particular sector in a particular region on the demand side, we call the corresponding group as a *demand-side group*. Likewise, we define a *supply-side group*. In terms of the matrix structure, the four indices are used as follows:

$$Z = \begin{pmatrix}
z_{1,1,1,1} & z_{1,1,1,2} & \cdots & z_{1,1,1,n} & z_{1,1,2,1} & z_{1,1,2,2} & \cdots & z_{1,1,2,n} & \cdots & z_{1,1,d,1} & z_{1,1,d,2} & \cdots & z_{1,1,d,n} \\
z_{1,2,1,1} & z_{1,2,1,2} & \cdots & z_{1,2,1,n} & z_{1,2,2,1} & z_{1,2,2,2} & \cdots & z_{1,2,2,n} & \cdots & z_{1,2,d,1} & z_{1,2,d,2} & \cdots & z_{1,2,d,n} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \cdots & \vdots & \vdots & \ddots & \vdots \\
z_{1,n,1,1} & z_{1,n,1,2} & \cdots & z_{1,n,1,n} & z_{1,n,2,1} & z_{1,n,2,2} & \cdots & z_{1,n,2,n} & \cdots & z_{1,n,d,1} & z_{1,n,d,2} & \cdots & z_{1,n,d,n} \\
z_{2,1,1,1} & z_{2,1,1,2} & \cdots & z_{2,1,1,n} & z_{2,1,2,1} & z_{2,1,2,2} & \cdots & z_{2,1,2,n} & \cdots & z_{2,1,d,1} & z_{2,1,d,2} & \cdots & z_{2,1,d,n} \\
z_{2,2,1,1} & z_{2,2,1,2} & \cdots & z_{2,2,1,n} & z_{2,2,2,1} & z_{2,2,2,2} & \cdots & z_{2,2,2,n} & \cdots & z_{2,2,d,1} & z_{2,2,d,2} & \cdots & z_{2,2,d,n} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \cdots & \vdots & \vdots & \ddots & \vdots \\
z_{2,n,1,1} & z_{2,n,1,2} & \cdots & z_{2,n,1,n} & z_{2,n,2,1} & z_{2,n,2,2} & \cdots & z_{2,n,2,n} & \cdots & z_{2,n,d,1} & z_{2,n,d,2} & \cdots & z_{2,n,d,n} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
z_{d,1,1,1} & z_{d,1,1,2} & \cdots & z_{d,1,1,n} & z_{d,1,2,1} & z_{d,1,2,2} & \cdots & z_{d,1,2,n} & \cdots & z_{d,1,d,1} & z_{d,1,d,2} & \cdots & z_{d,1,d,n} \\
z_{d,2,1,1} & z_{d,2,1,2} & \cdots & z_{d,2,1,n} & z_{d,2,2,1} & z_{d,2,2,2} & \cdots & z_{d,2,2,n} & \cdots & z_{d,2,d,1} & z_{d,2,d,2} & \cdots & z_{d,2,d,n} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \cdots & \vdots & \vdots & \ddots & \vdots \\
z_{d,n,1,1} & z_{d,n,1,2} & \cdots & z_{d,n,1,n} & z_{d,n,2,1} & z_{d,n,2,2} & \cdots & z_{d,n,2,n} & \cdots & z_{d,n,d,1} & z_{d,n,d,2} & \cdots & z_{d,n,d,n}
\end{pmatrix}$$

where we denote the number of regions by d and the number of sectors by n.

In addition to Z, the following values are directly observed from [23]:

Final demand: Final demand is denoted by matrix $F = (f_{q,i,r})$. From F, we obtain the following two vectors:

Regional final demand: $f^* = \left(f^*_{q,i}\right)$ where $f^*_{q,i} = f_{q,i,q}$.

Accumulated final demand: $\hat{f} = \left(\hat{f}_{q,i}\right)$ where $\hat{f}_{q,i} = \sum_{r=1}^{d} f_{q,i,r}$.

Import: Import is denoted by vector $m = (m_{r,j})$ where each element represents the absolute value of the import by each demand-side group. Normalization of the import vector m by the regional final demand gives the *import coefficient* matrix $B = (b_{q,i,r,j})$ where

$$b_{q,i,r,j} = \begin{cases} m_{q,i}/f^*_{q,i} & \text{if } r = q \text{ and } j = i \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

Export: Export is denoted by vector $e = (e_{q,i})$ where each element represents the value of the export by each supply-side group.

Value added: Value added is denoted by vector $c = (c_{r,j})$ where each element represents the value or tax added to the purchase by each demand-side group. From Z and c, we compute the gross output vector $g = (g_{r,j})$ where

$$g_{r,j} = \sum_{q=1}^{d} \sum_{i=1}^{n} z_{q,i,r,j} + c_{r,j} \tag{2}$$

represents the gross output to each demand-side group. Normalization of Z by the gross output gives the *input coefficient* which is denoted by matrix $A = (a_{q,i,r,j})$ where

$$a_{q,i,r,j} = z_{q,i,r,j}/g_{r,j}. \tag{3}$$

In order to extract the input coefficients inside each region, we define a matrix $A^* = \left(a^*_{q,i,r,j}\right)$ by

$$a^*_{q,i,r,j} = \begin{cases} a_{q,i,r,j} & \text{if } q = r \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

3.1.2 Backward Dependency

If all the deliveries to a demand-side group $(\overline{r}, \overline{j})$ are reduced to be zero by a disastrous event, the output from the group will be reduced. We compute such output reductions in order to study absolute backward linkages. The output reductions are given by $h - \overline{h}\left(\overline{r}, \overline{j}\right)$ where

$$h = \{I - [A - BA^*]\}^{-1} \left(\hat{f} - Bf^* + e\right), \tag{5}$$

$$\overline{h}\left(\overline{r}, \overline{j}\right) = \left\{I - \left[\overline{A}\left(\overline{r}, \overline{j}\right) - B\overline{A}^*\left(\overline{r}, \overline{j}\right)\right]\right\}^{-1} \left(\hat{f} - Bf^* + e\right), \tag{6}$$

and I is the identity matrix of the corresponding size. The matrices $\overline{A}\left(\overline{r}, \overline{j}\right) = \left(\overline{a}\left(\overline{r}, \overline{j}\right)_{q,i,r,j}\right)$ and $\overline{A}^*\left(\overline{r}, \overline{j}\right) = \left(\overline{a}^*\left(\overline{r}, \overline{j}\right)_{q,i,r,j}\right)$ are calculated from A and A^* as follows:

$$\overline{a}(\overline{r}, \overline{j})_{q,i,r,j} = \begin{cases} 0 & \text{if } r = \overline{r} \text{ and } j = \overline{j} \\ a_{q,i,r,j} & \text{otherwise} \end{cases} \tag{7}$$

and

$$\overline{a}^*(\overline{r},\overline{j})_{q,i,r,j} = \begin{cases} 0 & \text{if } r = \overline{r} \text{ and } j = \overline{j} \\ a^*_{q,i,r,j} & \text{otherwise.} \end{cases} \tag{8}$$

Let vector $u(\overline{r},\overline{j}) = \left(u(\overline{r},\overline{j})_{q,i}\right)$ denote the backward dependency (BD) of a demand-side group $(\overline{r},\overline{j})$ on the supply-side groups. We can obtain $u(\overline{r},\overline{j})$ in terms of percentage by

$$u(\overline{r},\overline{j})_{q,i} = 100\frac{h_{q,i} - \overline{h}(\overline{r},\overline{j})_{q,i}}{g_{\overline{r},\overline{j}}}. \tag{9}$$

3.2 Interdependency under the Influence of Information Security

In [20], the ISBD vector of a demand-side group $(\overline{r},\overline{j})$ is defined as the BD vector computed by replacing Eqn. (7) and Eqn. (8) with

$$\overline{a}(\overline{r},\overline{j})_{q,i,r,j} = \begin{cases} (1 - s_i s_j)a_{q,i,r,j} & \text{if } r = \overline{r} \text{ and } j = \overline{j} \\ a_{q,i,r,j} & \text{otherwise} \end{cases} \tag{10}$$

and

$$\overline{a}^*(\overline{r},\overline{j})_{q,i,r,j} = \begin{cases} (1 - s_i s_j)a^*_{q,i,r,j} & \text{if } r = \overline{r} \text{ and } j = \overline{j} \\ a^*_{q,i,r,j} & \text{otherwise} \end{cases} \tag{11}$$

where s_i represents the security risk level of sector i. The values of security risk levels are obtained from additional datasets[24], [25].

4 Data for Sectoral and Regional Interdependency

4.1 Inter-Regional Input-Output table for 2005[23]

In this paper, we mainly use the dataset of 12 sectors. The dataset of 53 sectors is used for further analyses on some sectors. The list of the sectors is shown in Table 8[1].

In this dataset, Japan is divided into nine regions: Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Okinawa. These regions are indexed by A, B, C, $\cdots$, and I, respectively. Regarding the economic scale, Kanto(C), Kinki(E), and Chubu(D) are top three regions with high production values. On the other hand, Okinawa(I), Shikoku(G), and Hokkaido(A) are bottom three regions with low production values.

In sectoral perspective, top three sectors with high production values are Services(12), Commerce&logistic(09), and Manufacturing-machinery(05), whereas Mining(02), Agriculture(01), and Utilities(08) are bottom three sectors with low production values.

Table 6 and Table 7 show Japanese production values in regional and sectoral (12 sectors) perspectives, respectively.

[1]The tables and the figures regarding fundamental data are shown in Appendix.

4.2 The 2006 Survey of Information Technology[24]

We use the average number of information security (IS) measures deployed by the firms in each sector as a proxy of the level of IS in each sector. The IS measures are classified into four categories shown in Table 9.

We compute *IS multiplier* (denoted by m_i) which represents the normalized level of IS measures. This variable is defined by

$$m_i = \mathrm{M}^*/\mathrm{M}_i \tag{12}$$

where M^* is the average number of deployed IS measures in all the sectors and M_i is the average number of deployed IS measures in sector i.

4.3 Japan Industrial Productivity Database 2008[25]

We use data of *IT Capital Stock* and *non-IT Capital Stock* in order to estimate *the level of IT dependency* of each sector. Let t_i denote the level of IT dependency of sector i. We estimate the level of IT dependency by

$$t_i = \mathrm{IT}_i/(\mathrm{IT}_i + \mathrm{nIT}_i) \tag{13}$$

where IT_i denotes the IT capital stock of sector i and nIT_i denotes the non-IT capital stock of sector i.

We then use

$$s_i = t_i m_i \tag{14}$$

as a proxy for the security risk level of sector i.

Figure 1 shows the security risk levels for 12 sectors. The levels of IT dependency, the levels of IS measure, and the IS multipliers computed from our dataset are shown in Fig. 2 and in Fig. 3.

5 Extended Analysis on the Impact of the Earthquake

At 14:46 p.m. on March 11, 2011, The Great East Japan Earthquake hit Tohoku region with magnitude 9.0. This massive earthquake also triggered tremendous and powerful Tsunami waves which left dreadful damages. The cabinet office, Government of Japan, defined seven prefectures as disaster areas regarding this earthquake[26]. Among them, three most significantly damaged prefectures are in Tohoku region. The Cabinet office defined the following two cases of damages.

Case 1: refers to the damage directly by the earthquake, and

Case 2: refers to the damage by the earthquake and the consequent Tsunami.

Shinozaki et al. estimated the damage on ICT-related private capital stock due to the Great East Japan Earthquake[27]. Their result shows that the damage is around 2.5-4.4 trillion yen in total.

We study the impact of the Great East Japan Earthquake by using the methodology in Section 3 with a modification based on the following two additional datasets:

1. **Special cabinet meeting material on monthly economic report due to the earthquake**[26]
   This report is provided few weeks after the earthquake by the government. We obtain the overall damage on capital stock, D^{all}, from this dataset.

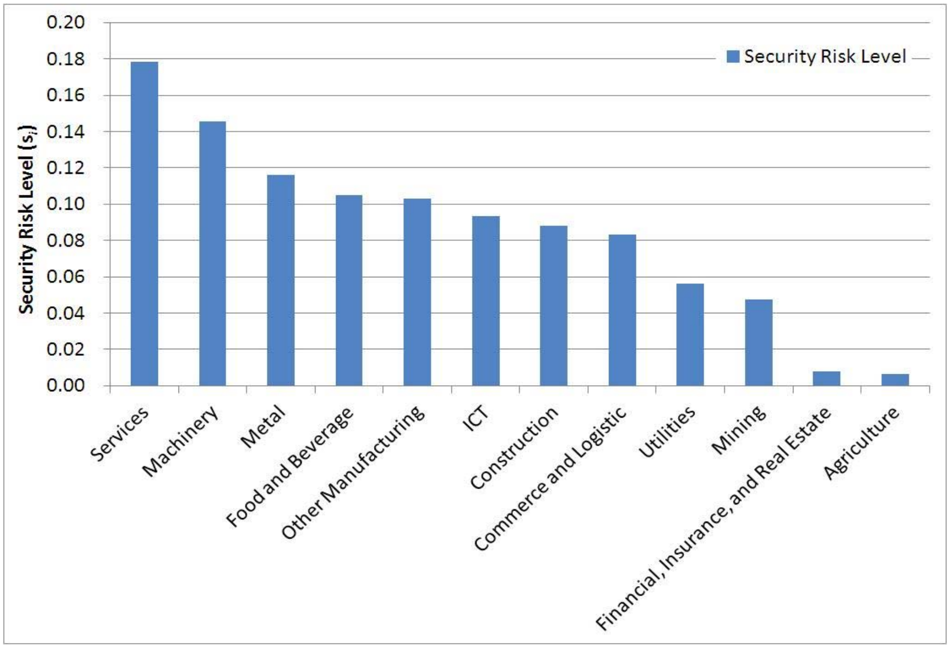

Figure 1: Security risk level for 12 industrial sectors.

2. **Gross Capital Stock by Industry** [28]
   We use the values of gross capital stock of year 2009, which is the newest at the time we estimated the impact of the earthquake. We obtain the nationwide capital stock, C_n, from this dataset.

Now let us describe the extended analysis. First, in the analysis regarding the structural interdependency, we use

$$\overline{z}_{q,i,r,j} = \begin{cases} (1 - R_r) z_{q,i,r,j} & \text{if } r = \text{Tohoku} \\ z_{q,i,r,j} & \text{otherwise} \end{cases} \tag{15}$$

instead of $z_{q,i,r,j}$. R^r is a "regional ratio of damage" of region r defined by

$$R_r = D^{all} / C_r \tag{16}$$

where C_r represents the capital stock of region r estimated by

$$C_r = \frac{P_r}{P_{total}} \cdot C_n. \tag{17}$$

P_r is the production value of region r, and P_{total} is the total production value of all regions. P_r and P_{total} are observed from the inter-regional input-output table[23].

Second, in the analysis regarding ISBD, we estimate the damage on IT systems, D^{IT}, by

$$D^{IT} = D^{all} t_{\text{total}} \tag{18}$$

where t_{total} is the ratio of IT capital stock given by

$$t_{\text{total}} = \text{IT}_{\text{total}} / (\text{IT}_{\text{total}} + \text{nIT}_{\text{total}}) \tag{19}$$

where $\mathrm{IT}_{\mathrm{total}}$ denotes the total amount of IT capital stock, and $\mathrm{nIT}_{\mathrm{total}}$ denotes the total amount of non-IT capital stock.

To investigate the effects from investment in information security, we assume that the investment will reduce the damage from disasters such as earthquakes. In particular, we assume that a pre-disaster investment in information security can improve the amount of damage from the disaster by a certain *degree of improvement*, Deg. So we replace R_r in Eqn. (15) with

$$\tilde{R}_r = (1 - \mathrm{Deg})D^{IT}/C_r \tag{20}$$

in our analysis. We set the degree of improvement as 10% (therefore, Deg=0.1) as a first estimation, but the same methodology can be used for more detailed analysis with different degrees.

6 Results and Discussions

6.1 Sectoral and Regional Interdependency

First, we analyze the sectoral and regional interdependencies before the earthquake. The dataset with 53 industrial sectors is used to analyze more details of Agriculture(01) and Financial, insurance, and real estate(10) because these two sectors showed very low values of ISBD in the analysis based on the 12-sector dataset.

By using a heuristic threshold ISBD=0.01%[2], we say "dependent" if ISBD is larger than or equals to this threshold, and "not dependent" otherwise. We count the number of dependent pairs to see regional and sectoral interdependencies.

6.1.1 Sectoral Interdependency

The results regarding sectoral interdependency can be summarized by Table 1.

In Table 1, different symbols indicate different levels of interdependency as follows. For example, let us look at the sixth row of Table 1. The i-th element of this row shows the level of interdependency between the demand-side sector Manufacturing-Other(06) and the supply-side sector i. When we evaluate the interdependency level of this element, we compute the ISBD for each of the $9 \times 9 = 81$ pairs of (demand-side group in Sector 06, supply-side group in Sector i), and count the number of "dependent" pairs. The result of this counting is shown in the last row of Table 2. The largest element in this last row is the sixth row, and its value is 56. Then we compute the ratio of "the value of each element of this row" to this highest value. If the ratio is larger than or equals to 50%, we use the sign "∘∘" in the corresponding element in Table 1. Likewise, we use "∘" if the ratio is between 10% and 50%. We use "•" if the ratio is non-zero but less than 10%. Finally, we use "–" if the ratio is zero. Since $(0/56, 2/56, 0/56, 8/56, 0/56, 56/56, 2/56, 9/56, 28/56, 11/56, 10/56, 22/56) = (0, 0.036, 0, 0.143, 0, 1, 0.036, 0.161, 0.500, 0.196, 0.179, 0.393)$, the sixth row of Table 1 is

$$(-, \bullet, -, \circ, -, \circ\circ, \bullet, \circ, \circ\circ, \circ, \circ, \circ).$$

[2] In our raw result, the average mean value of ISBD is 0.00754%. By considering this mean value and the standard deviation, we set the threshold.

Table 1: Summary of sectoral interdependency of information security

Demand-side sector name (ID)	Sector ID of supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Agriculture(01)	–	–	–	–	–	–	–	–	–	–	–	–
Mining(02)	–	–	–	∘	–	∘∘	–	∘	∘∘	∘	•	∘∘
Manufacturing-Food &beverage(03)	∘	–	∘∘	∘	–	∘∘	–	∘	∘∘	∘	∘	∘∘
Manufacturing-Metal(04)	–	–	–	∘∘	–	∘∘	∘	∘	∘∘	∘	∘	∘
Manufacturing-Machinery(05)	–	–	–	∘∘	∘∘	∘∘	•	∘	∘∘	∘	∘	∘∘
Manufacturing-Other(06)	–	•	–	∘	–	∘∘	•	∘	∘∘	∘	∘	∘
Construction(07)	–	–	–	∘∘	∘	∘∘	–	∘	∘	∘	∘	∘
Utilities(08)	–	–	–	–	–	∘∘	∘	∘	∘∘	∘	∘	∘∘
Commerce&logistic(09)	–	–	–	–	∘	∘∘	•	∘	∘∘	∘	∘∘	∘∘
Financial, insurance, and real estate(10)	–	–	–	–	–	–	–	–	–	–	–	∘∘
ICT(11)	–	–	–	–	–	∘∘	•	∘	∘∘	∘	∘∘	∘∘
Services(12)	•	–	∘	∘	∘∘	∘∘	∘	∘	∘∘	∘	∘	∘∘

Table 1 shows that supply-side sectors of Manufacturing-other(06), Commerce&logistic(09), and Services(12) are the sectors highly depended by demand-side sectors. We call these three sectors as *critical sectors* or *influential sectors*. Demand-side sectors have high opportunities to be affected by security incidents in the critical sectors. Likewise, Table 1 shows that demand-side sectors of Machinery(05) and Services(12) are the most *influenced sectors*.

By observing Table 1 in more detail, we can classify demand-side sectors into the following five classes.

Class 1: *Sectors which show high interdependency* ***when and only when*** *tested with the critical sectors.* Mining(02) and Utilities(08) belong to this group.

Class 2: *Sectors which show high interdependency when tested with its own sector and* ***all*** *of the critical sectors.* Manufacturing-Food&beverage(03), Manufacturing-Machinery(05), Commerce&logistic(09), ICT(11), and Services(12) belong to this group.

Table 2: Number of dependent pairs for demand-side sector of Manufacturing-Other (06)

Demand-side region name (ID)	Number of dependent pairs for each supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Hokkaido (A)	0	1	0	0	0	6	0	1	2	1	1	2
Tohoku (B)	0	0	0	1	0	6	0	1	3	2	1	2
Kanto (C)	0	0	0	1	0	7	1	1	2	1	1	2
Chubu (D)	0	0	0	3	0	6	0	1	3	2	2	3
Kinki (E)	0	0	0	1	0	7	1	1	3	1	2	2
Chugoku (F)	0	0	0	1	0	6	0	1	4	1	1	3
Shikoku (G)	0	0	0	0	0	6	0	1	5	1	1	3
Kyushu (H)	0	0	0	1	0	6	0	1	4	1	1	3
Okinawa (I)	0	1	0	0	0	6	0	1	2	1	0	2
Total	0	2	0	8	0	56	2	9	28	11	10	22

Class 3: *Sectors which show high interdependency when tested with its own sector and **not all but some** of the critical sectors.* Manufacturing-Metal(04) and Manufacturing-other(06) belong to this group.

Class 4: *Sectors which little interdependency when tested with supply-side sectors.* Although Financial, insurance, and real estate(10) belongs to this group, our detailed analysis by using the 53-sector dataset shows that the sub-sector of Financial and insurance(0400) shows characteristics similar to Group 3.

Class 5: *The rest of the demand-side sectors.* Agriculture(01) and Construction(07) belong to this group. These two sectors show no interdependency when tested with its own sector.

We can see that the demand-side sectors with high self-dependency (i.e. the sectors in Class 2 and Class 3) do not show high interdependency with non-critical sectors. Since investment advices regarding self-dependency and critical sectors are trivial, they need to learn from the analysis of regional interdependencies. Paying attention to the fact that majority of sectors belong to these two classes, we notice the importance of regional interdependency analysis.

6.1.2 Regional Interdependency

The results regarding regional interdependency can be summarized by Table 3 where different symbols indicate different levels of interdependency in the same way as in the sectoral interdependency. In Table 3, we can see the economic scale of a region has a great influence on the characteristics of the interdependency, and most of the results are intuitively easy to accept; for example, on the supply-side, Kanto (economically largest region) is the most influential.

As a remarkable (somewhat counter-intuitive) point, on the demand-side, Tohoku (economically middle sized) has the same features (i.e. less influenced) with that of Kanto. Also, the features regarding highly influenced sectors are quite different from those of highly influenced regions. In regional perspective, we found that highly influenced regions likely have small economic scales. By contrast, in sectoral perspective, the two highly influenced sectors, Machinery(05) and Services(12), have large economic scales.

Table 3: Summary of regional interdependency of information security

Demand-side region name (ID)	Region ID of supply-side region (Region ID)								
	A	B	C	D	E	F	G	H	I
Hokkaido(A)	○○	○	○○	○	○	○	•	•	–
Tohoku(B)	•	○○	○○	○	○	•	–	•	–
Kanto(C)	•	•	○○	○	○	•	•	•	–
Chubu(D)	•	•	○○	○○	○	○	•	○	–
Kinki(E)	•	•	○○	○	○○	○	•	•	–
Chugoku(F)	–	•	○○	○	○	○○	•	○	–
Shikoku(G)	–	•	○○	○	○○	○	○○	○	–
Kyushu(H)	–	•	○○	○	○	○	•	○○	–
Okinawa(I)	•	•	○○	○	○	○	•	○	○○

Table 4: ISBD reduction (in terms of the number of *missing* dependent pairs) from sectoral perspective in the investigation of the impact of The Great East Japan Earthquake.

	Supply-side Sector ID												
	01	02	03	04	05	06	07	08	09	10	11	12	Total
Case 1a	0	0	1	0	1	5	0	1	3	9	2	0	22
Case 1b	0	0	1	0	1	5	0	1	3	9	2	0	22
Case 2a	0	0	1	2	2	6	1	4	7	10	5	0	38
Case 2b	0	0	1	2	2	6	1	4	7	10	5	0	38

6.2 Impact of the Earthquake

Based on the government's announcement about the damage mentioned in Section 5, we set the following four testing scenarios:

Case 1a: Full damage from the earthquake. The full amount of 9 trillion yen is used as the damage value.

Case 1b: Damage from the earthquake with some reduction by investment in information security. The amount of 9 trillion yen with 10%-reduction is used as the damage value.

Case 2a: Full damage from the earthquake and the consequent Tsunami. The full amount of 16 trillion yen is used as the damage value.

Case 2b: Damage from the earthquake and the consequent Tsunami with some reduction by investment in information security. The amount of 16 trillion yen with 10%-reduction is used as the damage value.

In each of the four cases, we did the following.

1. Count the number of dependent (demand-side group in Tohoku, supply-side group in Sector i) pair before the earthquake.
2. Count this number after the earthquake.
3. Compute the reduction of this number. We refer to this reduction as the number of *missing* dependent pairs.

We obtained Table 4 by the above procedure. The reduction of interdependency occurs more likely with the following sectors: Financial, insurance, and real estate(10), Manufacturing-other(06), and Commerce and logistic(09). It should be noted that Manufacturing-other(06) and Commerce and logistic(09) are critical sectors identified by the basic analysis in 6.1.1 but that Financial, insurance, and real estate(10) is not a critical sector. The above characteristics are not changed by the reduction of damages by security investment.

Likewise, in each of the four cases, we did the following.

1. Count the number of dependent (demand-side group in Tohoku, supply-side group in Region q) pair before the earthquake.
2. Count this number after the earthquake.

3. Compute the reduction of this number. We refer to this reduction as the number of *missing* dependent pairs.

We obtained Table 5 by the above procedure. The reduction of interdependency is concentrated on two patterns: one is between sectors inside Tohoku(B), and the other is between sectors in Tohoku(B) and those in Kanto(C). Thus the earthquake impacted the most damaged region (Tohoku) and the economically largest region (Kanto) most significantly. This feature is not changed by the reduction of damages by security investment.

Table 5: ISBD reduction (in terms of the number of *missing* dependent pairs) from regional perspective in the investigation of the impact of The Great East Japan Earthquake.

	Supply-side Region ID									
	A	B	C	D	E	F	G	H	I	Total
Case 1a	3	8	5	3	2	0	0	1	0	22
Case 1b	3	8	5	3	2	0	0	1	0	22
Case 2a	3	14	11	3	6	0	0	1	0	38
Case 2b	3	14	11	3	6	0	0	1	0	38

7 Conclusion

In this paper, we have presented our empirical study on sectoral and regional interdependencies under the influence of information security in Japan in demand-side perspective.

In our main study, first, the economic scale of a region has a great influence on the characteristics of the interdependency. For example, security problems of economically larger supply-side regions tend to affect demand-side firms more significantly. Second, we observed that there are three supply-side sectors which are *critical* in the sense that information security problems in the three sectors can highly affect the demand-side sectors. Another common feature of the three critical sectors (Manufacturing-other, Commerce and logistic, and Services) is that they have high self-dependencies.

As an extended study, we investigated the impact of The Great East Japan Earthquake by evaluating dependency reductions caused by the earthquake. The results are consistent with the results of our main study; the role of the critical sectors is very important in Japan. We also found that the earthquake impacted the most damaged region (Tohoku) and the economically largest region (Kanto) most significantly. These features are not changed by the reduction of damages by security investment.

Both in the basic study and in the extended study, we can see that considering not only sectoral perspective but also regional perspective is very helpful in empirical analyses related to the interdependency under the influence of information security. By analyzing sensitivity of interdependency to changes in an inter-regional input-output table in a wide variety of scenarios including simulations, there are many possibilities of more extended studies based on our methodology. For instance, an analysis regarding a large-scale earthquake in Kanto expected in the near future would bring important implications and suggestions since there are many predictions about such earthquakes.

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References

[1] Richard Pierre and Devinney Timothy. Modular Strategies: B2B Technology and Architectural Knowledge. *California Management Review*, Vol. 47, Issue 4, pp. 86–113, 2005.

[2] John Leslie King and Kalle Lyytinen. Automotive Informatics: Information Technology and Enterprise Transformation in the Automobile Industry. In *Transforming Enterprise: The Economic and Social Implications of Information Technology*, MIT Press, pp. 283–312, 2005.

[3] Jason Dedrick and Kenneth L. Kraemer. The Impacts of IT on Firm and Industry Structure: The Personal Computer Industry. *California Management Review*, Vol. 47, Issue 3, pp. 122–142, 2005.

[4] Arnoud W.A. Boot and Matej Marinc. The Evolving Landscape of Banking. *Industrial and Corporate Change*, Vol. 17, Issue 6, pp. 1173–1203, 2008.

[5] Colm Fearon and George Philip. Measuring Success of Electronic Trading in the Insurance Industry: Operationalising the Disconfirmation of Expectations Paradigm. *Behaviour & Information Technology*, Vol. 27, Issue 6, pp. 483–493, 2008.

[6] Kunsoo Han, Robert J. Kauffman, and Barrie R. Nault. Information Exploitation and Interorganizational Systems Ownership. *Journal of Management Information Systems*, Vol. 21, No. 2, pp. 109–135, 2004.

[7] Colm Fearon and George Philip. An Empirical Study of the Use of EDI in Supermarket Chains Using a New Conceptual Framework. *Journal of Information Technology*, Vol. 14, Issue 1, pp. 3–21, 1999.

[8] Richard Klein and Arun Rai. Interfirm Strategic Information Flows in Logistics Supply Chain Relationships. *Management Information Systems Quarterly*, Vol. 33, Issue 4, pp. 735–762, 2009.

[9] Yuko Aoyama and Samuel J. Ratick. Trust, Transactions, and Information Technologies in the U.S. Logistics Industry. *Economic Geography*, Vol. 83, Issue 2, pp. 159–180, 2007.

[10] Ross Anderson and Tyler Moore. The Economics of Information Security. *Science*, Vol. 314, No. 5799, pp. 610–613, 2006.

[11] Howard Kunreuther and Geoffrey Heal. Interdependent Security. *Journal of Risk and Uncertainty*, Vol. 26, Issue 2–3, pp. 231–249, 2003.

[12] Tridib Bandyopadhyay, Varghese Jacob, and Srinivasan Raghunathan. Information Security in Networked Supply Chains: Impact of Network Vulnerability and Supply Chain Integration on Incentives to Invest. *Information Technology and Management*, Vol. 11, No. 1, pp. 7–23, 2010.

[13] Kjell Hausken. Income, Interdependence, and Substitution Effects Affecting Incentives for Security Investment. *Journal of Accounting and Public Policy*, Vol. 25, Issue 6, pp. 629–665, 2006.

[14] Hulisi Ogut, Nirup Menon, and Srinivasan Raghunathan. Cyber Insurance and IT Security Investment: Impact of Interdependent Risk. *Workshop on the Economics of Information Security (WEIS05)*, 2005.

[15] Yacov Y. Haimes, and Pu Jiang. Leontief-Based Model of Risk in Complex Interconnected Infrastructures. *International Journal of Networking and Virtual Organizations*, Vol. 4, Issue 3, pp. 130–144, 2001.

[16] The Institute for Information Infrastructure Protection (I3P). Security Solution for the Oil and Gas Industry, Technology Fact Sheet. Inoperability Input-Output Model (IIM). Available at http://www.dartmouth.edu/ i3p/docs/publications/IIM-factsheet-Feb2007.pdf, 2007.

[17] Yacov Y. Haimes, Barry M. Horowitz, James H. Lambert, Joost R. Santos, Chenyang Lian, and Kenneth G. Crowther. Inoperability Input-Output Model for Interdependent Infrastructure Sectors. I: Theory and Methodology. *Journal of Infrastructure Systems*, Vol. 11, No. 2, pp. 67–79, 2005.

[18] Yacov Y. Haimes, Barry M. Horowitz, James H. Lambert, Joost Santos, Kenneth Crowther, and Chenyang Lian. Inoperability Input-Output Model for Interdependent Infrastructure Sectors. II: Case Studies. *Journal of Infrastructure Systems*, Vol. 11, No. 2, pp. 80–92, 2005.

[19] Office of the manager, National communications system. Supervisory control and data acquisition (SCADA) systems. In *Technical information bulletin 04-1, National communications system*, Available at http://www.ncs.gov/library/tech_bulletins/2004/tib_04-1.pdf, 2004.

[20] Hideyuki Tanaka. Quantitative Analysis of Information Security Interdependency between Industrial Sectors. In *Proceedings of the 3rd International Symposium on Empirical Software Engineering and Measurement*, pp. 574–583, 2009.

[21] Hideyuki Tanaka. Geography and Information Security: Does Location Affect Information Security Effort? In *Fourth Forum on Financial Systems and Cyber Security: A Public Policy Perspective*, 2007.

[22] Erik Dietzenbacher and Jan A. van der Linder. Sectoral and Spatial Linkages in the EC Production Structure. *Journal of Regional Science*, Vol. 37, No. 2, pp. 235–257, 1997.

[23] Ministry of Economic, Trade and Industry. Inter-Regional Input-Output Tables 2005, 2005. Available at http://www.meti.go.jp/statistics/tyo/tiikiio/result/result_02.html.

[24] Ministry of Economic, Trade and Industry. The 2006 Survey of Information Technology, 2005. Available at http://www.meti.go.jp/statistics/zyo/zyouhou/result-2/h18jyojitsu.html.

[25] Research Institute of Economy, Trade and Industry. Japan Industrial Productivity Database 2008, 2008. Available at http://www.rieti.go.jp/jp/database/JIP2008/index.html.

[26] Cabinet office, Government of Japan. Special cabinet meeting material on monthly economic report due to the earthquake, 2011. Available at http://www5.cao.go.jp/keizai3/getsurei-s/1103.pdf.

[27] Akihiro Shinozaki, Yusuke Yamamoto, and Shota Yamazaki. Technical papers on ICT related economics. No. 11-1: Estimation on the Amount of Damage on ICT-Related Capital Stock, 2011. Available at http://www.icr.co.jp/ICT/report/TP_201106.pdf.

[28] Cabineet office, Government of Japan. Gross Capital Stock by Industry, 2009. Available at http://www.esri.cao.go.jp/jp/sna/sonota/minkan/kekka/20110107/h21y_stock_all.xls.

Appendix

Table 6: Regional Production Values in Japan

Region name	**Region ID**	**Output (billion US$*)**
Kanto	C	8,175.19
Kinki	E	3,042.11
Chubu	D	2,341.25
Kyushu	H	1,576.64
Chugoku	F	1,176.51
Tohoku	B	1,136.39
Hokkaido	A	684.96
Shikoku	G	508.69
Okinawa	I	116.78

Source: Inter-Regional Input-Output table for 2005
*1 US($) = 76.75 JYP(¥). Rate on Oct 19, 11

Table 7: Japanese sectoral production values for 12 industrial sectors

Sector name	**Sector ID**	**Output (billion US$*)**
Services	12	3090.26
Commerce and Logistic	09	1916.02
Manufacturing-Machinery	05	1696.06
Financial, Insurance, and Real Estate	10	1404.47
Manufacturing-Other	06	1229.48
Construction	07	823.94
ICT	11	598.51
Manufacturing-Metal	04	593.76
Manufacturing-Food and Beverage	03	468.23
Utilities	08	349.05
Agriculture	01	171.40
Mining	02	13.14

Source: Inter-Regional Input-Output table for 2005
*1 US($) = 76.75 JYP(¥). Rate on Oct 19, 11

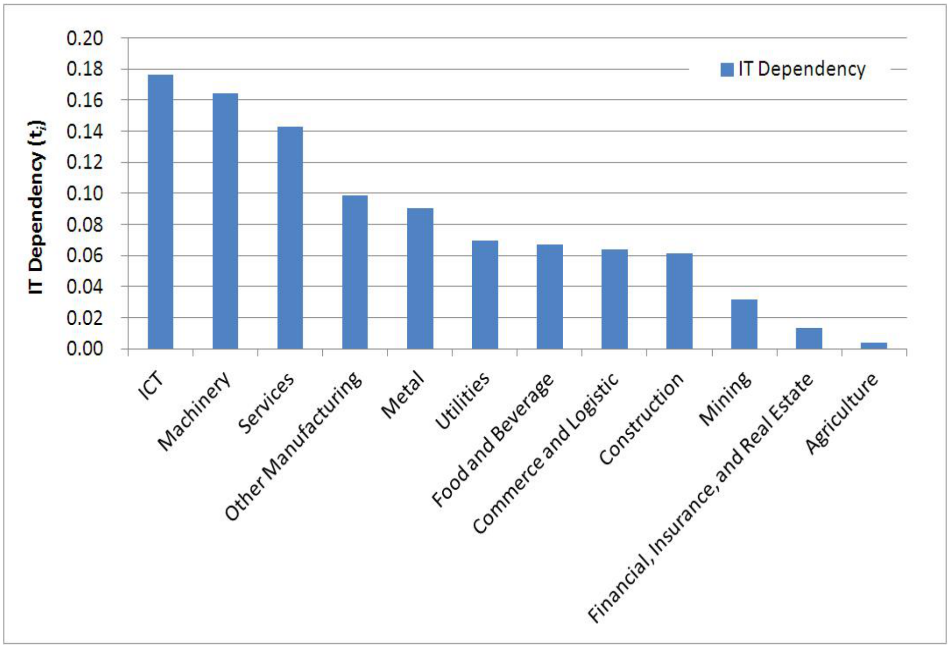

Figure 2: Level of IT dependency for 12 industrial sectors.

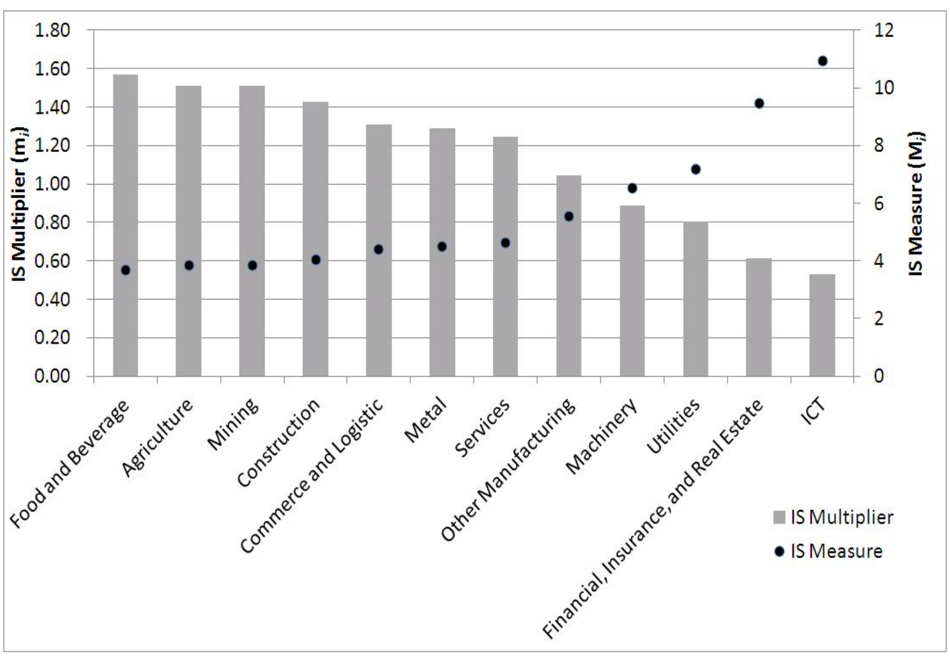

Figure 3: Level of IS measures and IS multipliers for 12 industrial sectors.

Table 8: List of Industrial Sectors

12 Industrial sectors			53 Industrial sectors	
Sector ID	**Sector name**		**Sector ID**	**Sector name**
01	Agriculture		0010	Agriculture
02	Mining		0020	Mining
			0030	Coal, oil, and natural gas
03	Manufacturing	Food and Beverage	0040	Food and beverage
04	Manufacturing	Metal	0170	Iron and steel
			0180	Nonferrous metal
			0190	Metal products
05	Manufacturing	Machinery	0200	General machinery
			0210	Office and service equipment
			0220	Industrial electrical equipment
			0230	Other electrical machinery
			0240	Household electric appliances
			0250	Telecommunications equipment and related equipment
			0260	Computer and accessories
			0270	Electronic components
			0280	Car
			0290	Other cars
			0300	Auto parts accessories
			0310	Other transportation equipment
			0320	Precision machinery
06	Manufacturing	Other	0050	Textile industry products
			0060	Apparel and other textile products
			0070	Lumbering, wood, and furniture
			0080	Pulp, paper, paperboard, and processed paper
			0090	Printing, plate making, and bookbinding
			0100	Chemical products
			0110	Plastics
			0120	Final chemical products
			0130	Pharmaceutical products
			0140	Petroleum and coal products
			0150	Plastic products
			0330	Other manufactured products
			0160	Clay products
			0340	Renewable resources and processing treatment
07	Construction		0350	Construction
08	Utilities		0360	Electricity
			0370	Gas and heat supply
			0380	Waste water treatment
09	Commerce and Logistic		0390	Commerce
			0430	Transportation
10	Financial, Insurance, and Real Estate		0400	Finance and Insurance
			0410	Real estate
			0420	Rental housing
11	ICT		0440	Other information and communications
			0450	Information service

Table 8: List of Industrial Sectors (Cont'd)

12 Industrial sectors		53 Industrial sectors	
Sector ID	**Sector name**	**Sector ID**	**Sector name**
12	Services	0460	Public service
		0470	Educational research
		0480	Health care and social security
		0490	Advertisement
		0500	Goods rental and leasing services
		0510	Other business services
		0520	Personal service
		0530	Other

Table 9: List of information security measures

Category	Information security measures
Implementation of organizational measures	– Risk analysis – Security policy – Examination of specific measures based on security policy – Creation of information security report – Creation of Business Continuity Plan (BCP) – Deployment of an corporate-wide security management – Sectoral deployment of security management – Information security training for employees – Confirmation on information security measures of trading partners (including outsourcing)
Implementation of technical solutions/Defense measures	– Access control of important computer rooms – Access control of important systems – Data encryption (including Public Key Infrastructure (PKI)) – Firewall installation against external connection – Installation of ISO/IEC15408 certified product
System monitoring	– Installation of security monitoring software – Full–time monitoring by external professionals
Assessment	– Use of information security benchmark – Regular system auditing by external professionals – Regular system auditing by internal experts – Regular information security auditing by external professionals – Regular information security auditing by internal experts – Obtaining certification of information security management system (ISO/IEC27001)