Chapter 13

ASSESSING THE ECONOMIC LOSS AND SOCIAL IMPACT OF INFORMATION SYSTEM BREAKDOWNS

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Abstract The pervasiveness of information systems raises security and business continuity issues related to their disruption. Policy makers involved in preventing and preparing for unexpected critical events need to understand the direct and indirect socio-economic impacts of potential information system disruptions. This paper presents a new methodology for assessing the sectors that are most vulnerable to critical information system breakdowns. The vulnerability of information systems (VIS) model, which is based on the well-known input-output paradigm, simulates information system disruptions and assesses their socio-economic impact in the dynamic framework of sector interdependencies and cascading failure effects. The VIS model represents an important step in research focused on the prevention, preparedness and impact assessment of unexpected information system breakdowns. It sheds light on how the effects of a disruption can spread and helps identify critical infrastructures from a socio-economic perspective.

Keywords: Information system breakdowns, socio-economic effects

1. Introduction

Information systems are an essential component of every critical infrastructure asset and, as such, are vital to the functioning of society. A major breakdown in information systems directly affects the individual infrastructures where they are used. However, the indirect effects of a breakdown in one infrastructure propagate and cascade throughout all the other infrastructures because of infrastructure interdependencies.

Information systems are considered to be the most strategic enabling factor for European socio-economic development. To this end, the European Commission [5] is implementing its i2010 strategy, which focuses on trustworthy, secure and reliable information and communication technologies. The European Commission [7] has emphasized the creation of plans for protecting Europe from large-scale cyber attacks and information system disruptions. It has issued a directive [6] that mandates the identification and designation of European critical infrastructures and the assessment of the need to improve their protection [6]. It has also created the European Programme for Critical Infrastructure Protection (EPCIP) [2], which seeks to counter threats and enhance preparedness, security and resilience.

Key components of these protection efforts are defining criteria for identifying critical infrastructures and developing a comprehensive knowledge base of disruptions and their effects on critical infrastructures. Equally important is the need to predict the economic effects (e.g., monetary loss and service degradation) and the social effects (e.g., fatalities and loss of public services) due to infrastructure disruptions.

Luiijf, *et al.* [15] have conducted an analysis of 1,749 serious infrastructure failures that have occurred in Europe since 2000. Their analysis underscores the importance of information systems as a component of national critical infrastructures. According to their study, telecommunications is the second ranked sector (after energy) that initiates cascading failures in other sectors. In particular, telecommunications caused 24.3% of the total identified sector outages – within the sector as well as in other sectors such as finance, government services, transportation, energy and health. A smaller number of critical events (3.6%) were caused by Internet failures, and these impacted government services, finance and telecommunications in addition to other sectors.

Although information system breakdowns are acknowledged to have severe effects, quantitative assessments of the impact at the sector, national and European levels are difficult to perform. The vulnerability of information systems (VIS) model, which is presented in this paper, helps address this issue. The model simulates information system disruptions and assesses their socio-economic impact on the affected sectors using several impact metrics. These metrics can be used to rank the sectors according to their vulnerability to an information system breakdown.

2. Related Work

Several research efforts have focused on investigating infrastructure interdependencies and the potential cascading effects due to critical infrastructure disruptions, but relatively few studies have examined the impact of critical infrastructure disruptions. Although it is generally agreed that an information system breakdown of short duration can lead to serious consequences that propagate throughout all the critical infrastructures, there is little understanding of the systemic damage and socio-economic effects of such breakdowns.

Due to the complexity of infrastructure interdependencies, critical infrastructures have mostly been studied as physical assets from an organizational perspective. These approaches provide useful knowledge to corporate decision makers, but are of limited value to policy makers focused on incident prevention and preparedness, and infrastructure resilience.

Haimes and Jiang [11] were among the first researchers to consider the socio-economic perspective by expressing industrial relationships using input-output data pertaining to the production and consumption of each sector in an economic system. Rinaldi [18] subsequently engaged input-output models of economic flows described by Leontief [13] to critical infrastructures. According to Sarriegi, *et al.* [21], input-output models are one of the most effective modeling paradigms for dealing with critical infrastructure interdependencies. In particular, these models help identify the economic sectors that are most vulnerable to a critical infrastructure breakdown.

Haimes, *et al.* [12] have used input-output relationships as the foundation for risk analysis in interdependent infrastructures. Their inoperability input-output model (IIM) [11, 20] extends Leontief's static input-output model by expressing the effects of a shock to an infrastructure in terms of sector inoperability and economic impact. To overcome the time-invariant limitations of IIM, Lian and Haimes [14] proposed the dynamic input-output inoperability model (DIIM), which extends IIM by incorporating the time dimension to express sector recovery after a critical event. Despite its utility, DIIM does not completely capture the domino effects of a disruption that affects interdependent economic sectors.

Kujawski [16] has attempted to address the deficiencies in IIM and DIIM by proposing the multi-period model for disruptive events in interdependent systems (MPMDEIS). The premise of MPMDEIS is that a critical event affects an economic system according to a four-phase lifecycle, starting with a pre-event period and terminating in a post-recovery period. MPMDEIS models a critical event as a shock which, due to sector interdependencies, cascades from one sector to another and reduces their production capacities. MPMDEIS addresses the two main limitations of traditional Leontief input-output models [13]: the requirement that the technical coefficients of sector production remain constant during and after the shock, and the exogeneity (and the consequent perfect and immediate adjustment) of the demand side of the economy in the aftermath of a critical event.

3. VIS Model

The vulnerability of information systems (VIS) model [10] has two goals: (i) assess the socio-economic impact of unexpected critical breakdowns of information systems; and (ii) rank sectors in an economic system according to their vulnerability to information system disruptions.

The theoretical framework of the VIS model relies on input-output relationships and addresses the same limitations as MPMDEIS. The industrial sectors correspond to an economic representation of a national infrastructure. The structural input-output relationships among the various sectors and, in particular, data related to the intermediate consumption of technological goods and services represent the weights of information systems in the sectors.

The most detailed input-output tables provided by Eurostat [8] depict interdependencies among economic sectors according to two-digit NACE Rev. 1.1 classification levels [9]. Using the NACE classification of economic sectors (which yields 57 sectors in the VIS model) and input-output data for Year 2004 provided by Eurostat [8], the share of the Computer and Related Activities sector (NACE code 72) in the production function of each sector is considered to express the relevance of information systems to the specific sector. According to the NACE classification, Computer and Related Activities includes hardware consulting, software consulting and supply, data processing, database activities, maintenance and repair of office, accounting and computing machinery, and other computer related activities. Technically, the dependence of each sector on information systems is obtained by computing the share of information systems directly employed in the production function of the sector of interest and the shares that are indirectly employed in other sectors that produce intermediate goods for the sector of interest (i.e., information systems as a share of other productivity factors).

Interdependencies are modeled using the coefficients of the input-output tables. The economic system is represented in the VIS model in terms of a supply side and a demand side. The supply side is expressed using 57 simultaneous equations corresponding to the 57 sectors augmented with equations expressing labor and price effects. Each of the 57 equations represents a sector production function in which the output produced by the sector is defined by:

$$p_Y Y_j = f(p_1 X_{1,j},\ p_2 X_{2,j},\ \ldots,\ p_n X_{n,j},\ p_L L_j)$$

where $p_Y Y_j$ is the nominal price per quantity of the output of the sector j; $p_i X_{i,j}$ is the value of the production input i to sector j ($X_{i,j}$ is the amount of input i used by sector j and p_i is its price); and $p_L L_j$ is the value of labor in sector j.

The translog functional form of the sector production functions helps overcome the problem of fixed production coefficients and accounts for marginal substitution with other productivity factors and relative price effects in the event of a breakdown. In this way, the quantities of inputs employed during equilibrium conditions are the effective annual flows employed by each sector in the real world and are derived from the input-output tables provided by Eurostat for the geographical area of interest.

The supply side helps define a computational general equilibrium model along with the demand side, which expresses the consumption of each sector output based on monopolistic competition [1]. The demand D_j for the output of sector j is given by:

$$D_j = (\frac{p_j}{p})^{-\epsilon} D$$

where p_j is the price of the output of sector j in a monopolistic competition framework; p is the price index resulting from the Dixit-Stiglitz aggregator [4];

ϵ is the elasticity of substitution among differentiated products; and D is the aggregate demand.

The matching of supply and demand defines the equilibrium conditions that are perturbed by an information system breakdown. Upon solving the VIS model equations, the socio-economic effects of an information system breakdown are evaluated by negatively perturbing the production function of the Computer and Related Activities sector and, as a consequence, reducing the information systems input to all the other economic sectors, which, in turn, reduces their outputs and changes the prices accordingly. The VIS model recursively computes the impact at each time period (one day) taking into account the domino effects on the production of all the economic sectors and following a recovery path until the equilibrium conditions are established.

According to the hypothesis related to a specific information system breakdown scenario, featured by the extent of the shock and its persistence profile (e.g., duration and functional form of the recovery process), the socio-economic effects in each sector are measured in terms of deviations relative to the benchmark equilibrium scenario in which the shock does not occur. Damage at the sector level caused by an unexpected critical information system breakdown relative to the non-shock equilibrium situation is expressed using five impact variables:

- **Percentage Output Deviation (OD):** This variable (≤ 0) captures the reduction in the production output of each sector.
- **Monetary Loss (ML):** This variable (≤ 0) captures the absolute variation of the value of the sector production. It is computed as the output loss multiplied by the real-world price.
- **Percentage Labor Deviation (LD):** This variable ($-\infty$ to $+\infty$) captures the deviation in the labor employed in each sector. In some sectors, more labor is necessary to recover the "normal" production capacity; other sectors may lose human capital with respect to the equilibrium conditions.
- **Percentage Price Deviation (PD):** This variable (≥ 0) captures the deviation in the price necessary to restore equilibrium conditions (a reduction in the production output for a sector causes an increase in its price). The price variation is not the real-world value, but the deviation of the sector price index (Year 2000 = 100) consistent with equilibrium conditions.
- **Welfare Loss (WL):** This variable (≥ 0) synthesizes all the impacts of an information system breakdown and considers the damage from a societal perspective. The welfare analysis is performed by assuming a standard quadratic loss function that considers the output deviation, labor deviation and price deviation without any weights. The quadratic loss function ensures that negative argument values (e.g., percentage output deviations) contribute to an increase in the loss.

Table 1. Italian sectors ranked by dependence on information systems.

Rank	NACE	Economic Sector	Input
1	K72	Computer and Related Activities	25.02%
2	J65	Finance	17.54%
3	I64	Post and Telecommunications	15.05%
4	K73	Research and Development	12.97%
5	J67	Activities Auxiliary to Finance	8.82%
6	O91	Activities of Membership Organizations	8.05%
7	K74	Other Business Activities	7.90%
8	J66	Insurance and Pension Funds	7.15%
9	K70	Real Estate Activities	5.75%
10	I62	Air Transportation	4.93%

The final results are the rankings of the sectors according to the five socio-economic impact variables. The rankings enable policy makers to define the protection priorities for the sectors that are most affected by information system disruptions.

4. Italian Case Study

The vulnerability of an economic sector to an information system breakdown is estimated by computing the dependence of the sector on information systems in terms of the relevance of direct and indirect information systems input on the total productivity factor using the input-output table data (Year 2004).

Table 1 ranks the top ten Italian economic sectors according to their direct and indirect shares of information systems in their total inputs (based on the NACE two-digit codes). Note that the Computer and Related Activities sector is used as a proxy for information systems. The three most dependent Italian sectors are those that employ the largest share of information systems in their productivity factors: Computer and Related Activities (25.02%), Finance (17.54%) and Post and Telecommunications (15.05%). Note that the results in Table 1 and in all the subsequent tables are based on available Eurostat data.

By applying the VIS model, it is possible to obtain more refined evaluations of the vulnerabilities of the Italian economic sectors to information system breakdowns taking into account sector interdependencies and domino effects. The simulation scenario assumes that an unexpected breakdown lasting one day reduces the output of the Computer and Related Activities sector by 10% and that five days are required for the sector to recover 50% of the lost production capacity.

In the simulation, the recovery of production capacity of the Computer and Related Activities sector is assumed to follow an autoregressive first-order process (Figure 1). Feedback from case studies confirms that an unexpected, critical breakdown of information systems causes an immediate reduction in production followed by a gradual recovery that decreases over time [10].

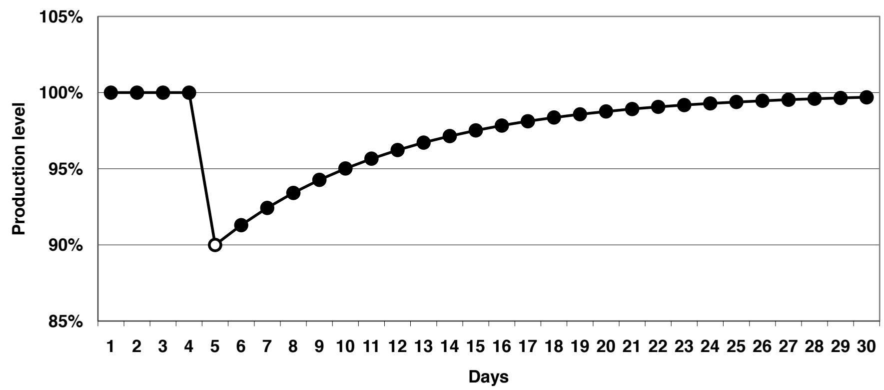

Figure 1. Recovery function for the Italian Computer and Related Activities sector.

Table 2. Sectors ranked by output deviation after an information system breakdown.

Rank	**NACE**	**Economic Sector**	**1 Day**	**90 Days**
1	K72	Computer and Related Activities	–11.01%	0.00%
2	K73	Research and Development	–1.87%	0.00%
3	I64	Post and Telecommunications	–1.38%	0.00%
4	J65	Finance	–1.25%	0.00%
5	J67	Activities Auxiliary to Finance	–1.20%	0.00%
6	I63	Supporting and Auxiliary Transportation Activities	–1.14%	0.00%
7	I62	Air Transportation	–1.09%	0.00%
8	J66	Insurance and Pension Funds	–1.08%	0.00%
9	K74	Other Business Activities	–1.07%	0.00%
10	K71	Renting of Machinery and Equipment	–1.05%	0.00%

Table 2 ranks the ten most vulnerable Italian economic sectors in terms of the output deviation (OD) percentage based on one-day data (two-digit NACE codes). The Computer and Related Activities sector has a deviation of –11.01% one day after the breakdown (instantaneous effect), followed by the Research and Development (–1.87%), Post and Telecommunications (–1.38%) and Finance (–1.25%) sectors.

The rankings in Tables 1 and 2 differ marginally for the top five sectors, all of which employ information systems to a significant degree. This shows the relationship between the intensity of use of information systems in a sector and its vulnerability to an information system breakdown. In the case of the top five sectors, 8% to 25% of the total production depends on the availability of information systems. The threshold of information systems usage relative to the other inputs can be assumed to represent the lower bound on the intensity of information systems adoption by a sector. Once this threshold is exceeded, any disruption in the Computer and Related Activities sector would cause major damage.

Table 3. Sectors ranked by output deviation after an information system breakdown.

Rank	NACE	Economic Sector	1 Day	90 Days
1	K72	Computer and Related Activities	–11.01%	–55.04%
2	J	Finance	–1.21%	–6.06%
3	I	Transportation, Storage and Communication	–1.12%	–5.60%
4	K	Real Estate and Business Activities	–1.04%	–5.19%
5	G	Wholesale and Retail Trade	–0.83%	–4.16%
6	E	Electricity, Gas and Water Supply	–0.74%	–3.72%
7	F	Construction	–0.70%	–3.51%
8	O	Other Services	–0.69%	–3.47%
9	C	Mining and Quarrying	–0.66%	–3.29%
10	A	Agriculture, Hunting and Forestry	–0.65%	–3.26%

NACE sectors can be aggregated at the one-digit level to provide a more comprehensive, albeit less detailed, view of the impact on the entire economic system. At the one-digit NACE level, the Italian economic system is represented in terms of sixteen macro-sectors.

Table 3 ranks the ten most vulnerable Italian economic sectors in terms of the output deviation (OD) percentage based on one-digit NACE codes. In particular, the table shows the cumulative effects after one day and after 90 days due to an unexpected 10% breakdown in information systems lasting one day with a 50% recovery after five days. Note that the ranking of the sectors is based on one-day data. Also, to simplify the analysis, the Real Estate and Business Activities sector (K) does not include the Computer and Related Activities sector (K72), which is shown separately.

The Computer and Related Activities sector (which is also affected by the initial 10% reduction), the Finance sector and the Transportation, Storage and Communication sector are impacted the most by the information system breakdown, with values of –11.01%, –1.21% and –1.12%, respectively. Note that the adverse effects on the economic sectors increase for a period of time. For example, the information system breakdown reduces the output of the Finance sector by 1.21% after one day and by 6.06% after 90 days; the adverse effects eventually converge to zero.

Table 4 ranks the ten most vulnerable Italian economic sectors in terms of the monetary loss (millions of euros) based on one-digit NACE codes. The table shows the cumulative effects after one day and after 90 days due to an unexpected 10% breakdown in information systems lasting one day with a 50% recovery after five days. Note that the ranking of the sectors is based on one-day data.

The Manufacturing sector suffers the most monetary loss compared with all the other sectors – 14.55 million euros after one day. In contrast, the output deviation for the Manufacturing sector is just –0.61% (Rank 11). The reason

Table 4. Sectors ranked by monetary loss after an information system breakdown.

Rank	**NACE**	**Economic Sector**	**1 Day**	**90 Days**
1	D	Manufacturing	–14.55	–72.74
2	K72	Computer and Related Activities	–13.53	–67.67
3	K	Real Estate and Business Activities	–10.68	–53.40
4	G	Wholesale and Retail Trade	–8.40	–42.03
5	I	Transportation, Storage and Communication	–6.94	–34.70
6	J	Finance	–3.57	–17.85
7	F	Construction	–3.51	–17.55
8	L	Public Administration and Defense	–1.91	–9.58
9	H	Hotels and Restaurants	–1.64	–8.20
10	N	Health and Social Work	–1.49	–7.49
Total (16 Sectors)			–70.89	–354.47

for the disparity is the significance of the Manufacturing sector in the Italian economy (i.e., proportion of the gross domestic product).

Monetary loss is undoubtedly the best measure for expressing the economic effects of a breakdown in information systems. After a 10% breakdown, the immediate monetary impact (one day) on the Italian economy exceeds 70 million euros. After 90 days, the monetary loss is more than 350 million euros. The Manufacturing sector, on the average, suffers 20% of the total monetary loss to the Italian economy.

Table 5. Rankings of the Italian economic sectors.

NACE	**Economic Sector**	**OD**	**ML**	**LD**	**PD**	**WL**
K72	Computer and Related Activities	**1**	**2**	**1**	**1**	**1**
J	Finance	**2**	6	5	4	**3**
I	Transportation, Storage and Communication	**3**	5	**2**	**2**	**2**
K	Real Estate and Business Activities	4	**3**	4	**3**	4
G	Wholesale and Retail Trade	5	4	7	6	6
E	Electricity, Gas and Water Supply	6	12	6	5	5
F	Construction	7	7	8	8	8
O	Other Services	8	11	10	9	9
H	Mining and Quarrying	9	15	**3**	7	7
N	Agriculture, Hunting and Forestry	10	13	11	11	10

Table 5 ranks the Italian sectors (one-digit NACE level) for each of the five impact variables. The top three ranks for each impact variable are highlighted using a bold font.

The sectors that are the most vulnerable to an information system breakdown (across the five impact variables) are Computer and Related Activities and Transport, Storage and Communication. The other sectors differ considerably, especially when comparing the impact variables based on labor and price. However, when labor deviations, price increases and shortages of produced outputs are viewed as proxies for welfare reduction (WL), the Italian sectors that are the most affected after an information system breakdown are Transportation, Storage and Communication; Finance; Real Estate and Business Activities; and Electricity, Gas and Water Supply.

Rankings of the sectors based on the share of information systems as direct and indirect inputs in the sector production functions and using the five impact variables indicate that, regardless of the perspectives and objectives of public policy makers, a limited number of sectors can be considered to be highly vulnerable to information system breakdowns. These sectors are Transportation, Storage and Communication, which has tight interconnections with information systems; and Finance, which uses significant amounts of technology in its strategic business processes.

5. European Case Study

The impact of an unexpected information system breakdown on the Italian economic sectors strongly depends on the intensity of the use of information systems in the sectors of interest as well as in the national economy as a whole. The VIS model relies on data related to input-output relationships, prices and labor for the various sectors. Thus, the sector rankings for the Italian economy can be compared with the sector rankings for the entire European economy using input-output tables aggregated at the EU27 level.

The European information system breakdown scenario considered in this section is the same as that used in the Italian case study. The scenario involves a 10% disruption to information systems lasting for one day with a 50% recovery in capacity after five days.

Table 6 shows the top ten impacted sectors in the European and Italian economies based on the percentage output deviations after an information system breakdown (two-digit NACE codes). As before, the top three ranks and the corresponding deviations are highlighted using a bold font. Note that the percentage output deviations for the European economy are uniformly lower than those for the Italian economy. Moreover, the sectors in the European economy that are related to finance are the most vulnerable to an information system breakdown.

Table 7 shows the top ten sectors in the European economy for four impact variables (two-digit NACE codes). As expected, the sector rankings for the European economy exhibit less variation compared with the Italian sector rankings (Table 5). After, the Computer and Related Activities sector, the European sectors that are the most vulnerable to an information system breakdown are the Finance and the Real Estate and Business Activities sectors. The main difference in the top rankings for the European and Italian economies for the percentage output deviation variable is the reversed rankings of the Real Estate and Business Activities and the Transportation, Storage and Communication

Table 6. Rankings of the European and Italian economic sectors.

NACE	Economic Sector	EU27 Rank	EU27 OD	Italy Rank	Italy OD
K72	Computer and Related Activities	**1**	**–10.36%**	**1**	**–11.1%**
J67	Activities Auxiliary to Finance	**2**	**–0.63%**	5	–1.20%
J65	Finance	**3**	**–0.57%**	4	–1.25%
J66	Insurance and Pension Funds	4	–0.50%	8	–1.08%
I64	Post and Telecommunications	5	–0.48%	**3**	**–1.38%**
K71	Renting of Machinery and Equipment	6	–0.44%	10	–1.05%
K73	Research and Development	7	–0.43%	**2**	**–1.87%**
DL30	Manufacture of Office Machinery and Computers	8	–0.40%	27	–0.66%
K74	Other Business Activities	9	–0.40%	9	–1.07%
DA16	Manufacture of Tobacco Products	10	–0.36%	32	–0.62%

Table 7. Rankings of the European economic sectors.

NACE	Economic Sector	OD	LD	PD	WL
K72	Computer and Related Activities	**1**	**1**	**1**	**1**
J	Finance	**2**	**2**	**2**	**2**
K	Real Estate and Business Activities	**3**	**3**	**3**	**3**
I	Transportation, Storage and Communication	4	5	5	4
G	Wholesale and Retail Trade	5	7	7	6
E	Electricity, Gas and Water Supply	6	4	4	5
L	Public Administration and Defense	7	14	13	9
O	Other Services	8	10	10	8
A	Agriculture, Hunting and Forestry	9	6	6	7
C	Mining and Quarrying	10	9	9	10

sectors, which are ranked 3 and 4 in the European economy, but 4 and 3 in the Italian economy. Also, the Public Administration and Defense sector features in the European rankings, but not in the Italian rankings. The rankings of the European and Italian sectors based on the impact variables related to price and labor changes are similar. The main difference is the higher rankings of the Transportation, Storage and Communication, and the Financial sectors in the European economy compared with the Italian economy, A similar situation is seen for the welfare loss (WL) impact variable. The top six positions are held by the same sectors with slight changes – Transportation, Storage and Communication is ranked fourth in Europe, but second in Italy. Furthermore, as in the case of the percentage output deviation variable, the European sectors related to social services (Other Services, and Public Administration and Defense) are more vulnerable to an information system breakdown.

6. Conclusions

Due to the pervasiveness of information and communications technologies in the critical infrastructure, an information system breakdown can propagate throughout a nation's economic system, causing significant socio-economic damage. In general, the analysis indicates that the impact of an information system breakdown on a sector depends on the intensity of technology adoption.

The VIS model assists policy makers in understanding and preparing for unexpected critical events by ranking the economic sectors in terms of their vulnerability to an information system breakdown. Different impact variables incorporate perspectives ranging from economic loss to societal damage. In the Italian economy, the Computer and Related Activities, Finance, and Transportation, Storage and Communications sectors are most vulnerable to an information system breakdown when the impact is measured in terms of the percentage output deviation. In contrast, the Manufacturing sector is most vulnerable when monetary loss is used as a measure. For all the impact variables, the Finance sector is more critical at the European level than it is at the Italian level. The differences in the sector rankings are, nevertheless, useful because they provide valuable perspectives to policy makers in their decision making. For example, policy actions focused on labor can be more effective in a national economy in the long term than actions that merely minimize monetary losses.

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References

[1] O. Blanchard and N. Kiyotaki, Monopolistic competition and the effects of aggregate demand, *American Economic Review*, vol. 77(4), pp. 647–666, 1987.

[2] Directorates-General for Justice and Home Affairs, EPCIP – European Programme for Critical Infrastructure Protection, European Commission, Brussels, Belgium (ec.europa.eu/justice_home/funding/2004_2007/epcip/funding_epcip_en.htm).

[3] Directorates-General for Justice and Home Affairs, Prevention, Preparedness and Consequence Management of Terrorism and Other Security Related Risks, European Commission, Brussels, Belgium (ec.europa.eu/justice_home/funding/cips/funding_cips_en.htm).

[4] A. Dixit and J. Stiglitz, Monopolistic competition and optimum product diversity, *American Economic Review*, vol. 67(3), pp. 297–308, 1977.

[5] European Commission, i2010: A European Information Society for Growth and Employment, Commission Communication COM(2005)229 Final, Brussels, Belgium, 2005.

[6] European Commission, On the Identification and Designation of European Critical Infrastructures and the Assessment of the Need to Improve Their Protection, Council Directive 2008/114/EC, Brussels, Belgium, 2008.

[7] European Commission, Protecting Europe from Large-Scale Cyber Attacks and Disruptions: Enhancing Preparedness, Security and Resilience, Commission Communication COM(2009)149 Final, Brussels, Belgium, 2009.

[8] Eurostat, European Commission, Luxembourg (epp.eurostat.ec.europa.eu).

[9] FiFo Ost, Statistical classification of economic activities: Concordance tables NACE-ISIC, Munich, Germany (www.fifoost.org/database/nace/nace-en_2002c.php).

[10] FORMIT Foundation, VIS – The Vulnerability of Information Systems and its Inter-Sectoral, Economic and Social Impacts, Project Final Report, Rome, Italy, 2009.

[11] Y. Haimes and P. Jiang, Leontief-based model of risk in complex interconnected infrastructures, *Journal of Infrastructure Systems*, vol. 7(1), pp. 1–12, 2001.

[12] Y. Haimes, J. Santos, K. Crowther, M. Henry, C. Lian and Z. Yan, Risk analysis in interdependent infrastructures, in *Critical Infrastructure Protection*, E. Goetz and S. Shenoi (Eds.), Springer, Boston, Massachusetts, pp. 297–310, 2007.

[13] W. Leontief, *Input-Output Economics*, Oxford University Press, Oxford, United Kingdom, 1986.

[14] C. Lian and Y. Haimes, Managing the risk of terrorism to interdependent infrastructure systems through the dynamic inoperability input-output model, *Systems Engineering*, vol. 9(3), pp. 241–258, 2006.

[15] E. Luiijf, A. Nieuwenhuijs, M. Klaver, M. van Eeten and E. Cruz, Empirical findings on critical infrastructure dependencies in Europe, *Proceedings of the Third International Workshop on Critical Information Infrastructure Security*, pp. 302–310, 2009.

[16] E. Kujawski, Multi-period model for disruptive events in interdependent systems, *Systems Engineering*, vol. 9(4), pp. 281–295, 2006.

[17] P. Pederson, D. Dudenhoeffer, S. Hartley and M. Permann, Critical Infrastructure Interdependency Modeling: A Survey of U.S. and International Research, Technical Report INL/EXT-06-11464, Idaho National Laboratory, Idaho Falls, Idaho, 2006.

[18] S. Rinaldi, Modeling and simulating critical infrastructures and their interdependencies, *Proceedings of the Thirty-Seventh Annual Hawaii International Conference on System Sciences*, 2004.

[19] S. Rinaldi, J. Peerenboom and T. Kelly, Identifying, understanding and analyzing critical infrastructure dependencies, *IEEE Control Systems*, vol. 21(6), pp. 11–25, 2001.

[20] J. Santos and Y. Haimes, Modeling the demand reduction input-output inoperability due to terrorism of interconnected infrastructures, *Risk Analysis*, vol. 24(6), pp. 1437–1451, 2004.

[21] J. Sarriegi, F. Sveen, J. Torres and J. Gonzalez, Adaptation of modeling paradigms to the critical infrastructure interdependencies problem, *Proceedings of the Third International Workshop on Critical Information Infrastructure Security*, pp. 295–301, 2009.