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**Abstract:** Regional economic models have been challenged to incorporate with structural changes in the economy. Especially, when a structural change is sudden, unpredictable, yet extensive, such as damages from a natural disaster, conventional models can hardly confront such significant changes due to their assumption of incremental changes. Sequential Interindustry Model (SIM) is an extension of the input-output framework that enables to trace the production process and the path of the impacts. SIM is particularly useful to simulate the dynamic process of impact propagation and of structural changes after a catastrophic disaster. In this paper, the issues and extensions of SIM are discussed with numerical examples.

## 1. Introduction

The damages and losses by unscheduled events, such as earthquakes, floods, tornadoes, and other major natural disasters, have significant and intense impacts on a region's economy. The impacts from the damages may also spread over time, and will bring serious economic effects to other regions. Furthermore, the impacts of unscheduled events are not only the negative effects from damages and losses, but also the positive economic effects from the recovery and reconstruction activities. Most analytical models and techniques cannot confront these significant changes, since they assume incremental, predictable changes in systems over time. In addition, the unexpected nature of events creates a further complication of measuring the indirect impacts.

Input-output analysis has been employed in many studies to evaluate economic impacts of unscheduled events (for example, Wilson, 1982; Kawashima *et al.*, 1991; Rose *et al.*, 1997; Rose and Benavides, 1998, Maruya *et al.*, 1995 among others). Although it provides useful information in terms of consequences in some specific aspects, *i.e.*, effects from the decreased final demand by damages and/or from the increase of reconstruction demand, many of these studies have failed to investigate the dynamism of impact path over space and time, due partly to the difficulties to obtain such data. This is an inherent problem for impact analysis of unscheduled events; as West and Lenz (1994) pointed out, the sophisticated regional impact models requiring precise numerical input have to be reconciled with imperfect measurements of the damages and losses. In terms of spatial impacts, Okuyama *et al.*, (1999) estimated the interregional impacts of the Great Hanshin Earthquake, which occurred in Kobe, Japan, 1995, using the two-region interregional input-output system, and found the significant spill-over effects of the impacts to the rest of Japan.

The Sequential Interindustry Model (SIM), introduced by Romanoff and Levine (1981), is an extension of input-output framework that can trace the production process and the path of an impact. The SIM framework turns the static framework of standard input-output table into a dynamic formulation, incorporating with production chronology. This framework of SIM is particularly useful to simulate the dynamic process of impact propagation and structural change in a short run. Moreover, the SIM provides an opportunity to connect the macroeconomic nature of input-output framework with the micro economic process of production process.

In order to account the effects from sudden occurrence of such an event and to measure indirect impacts of the “surprise”, SIM framework is employed in order to take into account production chronology. The issues and modifications of the SIM framework are discussed with an extension to interregional formulation. In the next section, the analytical methodology of SIM is presented. Section 3 presents the use of SIM framework to the impact analysis of unscheduled events. In Section 4, the SIM framework is extended to an interregional formulation to evaluate the impacts of an event in one of the regions. Finally, Section 5 summarizes and concludes this study, and presents some future research needs for handling unscheduled events.

## 2. Sequential Interindustry Models

Early interest in the dynamics of interindustry production with the framework of input-output analysis can be seen in Goodwin (1947) and Leontief (1951). These models were extended by Dorfman, Samuelson, Solow (1958) and Kuenne (1963) and further advanced by Morishima (1964). While this line of analysis diverted its attention to the integration with linear programming, or to Computable General Equilibrium (CGE) type modeling with more macroeconomic emphases, Romanoff (1984), and Romanoff and Levine (1981, 1986, 1990, and 1993 among others) introduced the Sequential Interindustry Model (SIM) in response to the need to analyze interindustry production in a dynamic economic environment. Assuming for simplicity that time is divided into discrete intervals of equal duration, the SIM framework enhances the static input-output model to the dynamic one by supplementing the structure of production with a production chronology.

In the SIMs, production is not simultaneous as in the static input-output model, but rather occurs sequentially over a period of time (Romanoff, 1984). In order to determine the dynamics of interindustry production, two simplified production modes are represented: anticipatory mode and responsive mode. The anticipatory mode is typical in agriculture and many manufacturing industries, in which the production is made in anticipation of future orders. Assuming intermediate output at $t$ to be linked to total output at $t+1$, where $t$ denotes a time interval (*i.e.* month, or quarter), the anticipatory model would be:

$$\mathbf{x_t} = \mathbf{A}\mathbf{x_{t+1}} + \mathbf{f_t} \tag{1}$$

Equation (1) can be transformed as follows:

$$\mathbf{x_t} = \sum_{\mathbf{r=0}}^{\infty} \mathbf{A^r f_{t+r}} \tag{2}$$

In this anticipatory model, total system output is expressed as a power series of future final demand stimuli weighted by powers of the $\mathbf{A}$ matrix. On the other hand, a responsive model, which can be seen in construction and ordinance industries, assumes that intermediate output (supply) at $t$ to be linked with total output (supply) at $t$-$1$, and may be written as:

$$\mathbf{x_t} = \mathbf{A}\mathbf{x_{t-1}} + \mathbf{f_t} \tag{3}$$

This can be transformed as follows:

$$\mathbf{x_t} = \sum_{\mathbf{r=0}}^{\infty} \mathbf{A^r f_{t-r}} \tag{4}$$

The total system output in the responsive model is indicated as a similar power series of past final demand stimuli.

The above formulations of the SIMs are based upon some critical assumptions: 1) final demand varies with time, but the structure of production, $A$, remains invariant; 2) in order to assume the linearity of the system, inventories, which serve as an adjustment mechanism between demand and supply, are adequate; and 3) in the anticipatory mode, the future final demands are perfectly predictable. As Romanoff and Levine (1981) indicated, assumptions 2) and 3) highly simplify the inventory (production) dynamics.

If the changes in the elements of $\mathbf{A}$ matrix can be identified over discrete time periods (*i.e.* damages on production facilities create a supply constraint), assumption 1) can be relaxed by the following manner. Suppose $\mathbf{A_t}$ is the production structure at interval *t*, in the anticipatory mode, equation (1) would be modified as:

$$\mathbf{x_t} = \mathbf{A_t}\mathbf{x_{t+1}} + \mathbf{f_t} \tag{5}$$

Then, equation (5) can be transformed as:

$$\mathbf{x_t} = \sum_{\mathbf{r=1}}^{\infty}\left(\prod_{\mathbf{k=1}}^{\mathbf{r}}\mathbf{A_{t+k-1}}\right)\cdot\mathbf{f_{t+r}} + \mathbf{f_r} \tag{6}$$

The total system output in this formulation is now indicated as a power series of future technology and final demand stimuli. Similarly, in the responsive mode, equation (3) would be altered as:

$$\mathbf{x_t} = \mathbf{A_t}\mathbf{x_{t-1}} + \mathbf{f_t} \tag{7}$$

Consequently, this expression can be transformed as:

$$\mathbf{x_t} = \sum_{\mathbf{r=1}}^{\infty}\left(\prod_{\mathbf{k=1}}^{\mathbf{r}}\mathbf{A_{t-k+1}}\right)\cdot\mathbf{f_{t-r}} + \mathbf{f_r} \tag{8}$$

The total system output is shown as a similar power series of past technology and final demand stimuli. With this formulation, assumption 3) can be relaxed in e*x post* impact analysis, such as the one illustrated in this chapter.

## 3. SIM and Unscheduled Events: Single Region Case

One of the useful advantages of SIM is to incorporate with production chronology, utilizing anticipatory and responsive modes. The SIM formulation is based on the assumption of perfect information: the trends of final demand are known. Such an assumption can only be valid under gradual changes in final demand over time; however, the occurrence of unscheduled event should not be predictable, *i.e.* the production side should have no information about the event until the moment when such an event occurs. Therefore, the reaction to the changes in final demand should begin only after the event. This is particularly important and is considerably different in the impact analysis of unscheduled events from the one for a public capital project, in which the schedule of the project can be anticipated.

In this section, a couple of attempts are carried out to fine-tune the SIM framework for the impact analysis of unscheduled events, utilizing a simple example employed in Romanoff, 1984. Consider a simple one-region three-sector input-output model which has the transaction table shown in Figure 1 and the matrices of direct input coefficients and Leontief Inverse are presented in Figure 2. Moreover, the production chronology (production digraph) is shown in Figure 3. In this example, sector 1 and 2 are considered as anticipatory mode production based on the production digraph.

| | 1 | 2 | 3 | $w_i$ | $y_i$ | $x_i$ |
|---|---|---|---|---|---|---|
| 1 | 0 | 4 | 2 | 6 | 2 | 8 |
| 2 | 0 | 0 | 6 | 6 | 6 | 12 |
| 3 | 0 | 0 | 0 | 0 | 16 | 16 |
| $u_j$ | 0 | 4 | 8 | 12 | 24 | 36 |
| $v_j$ | 8 | 8 | 8 | 24 | 0 | 24 |
| $x_j$ | 8 | 12 | 16 | 36 | 24 | |

Figure 1. Transaction Table (Romanoff, 1984)

$$\mathbf{A} = \begin{bmatrix} 0 & 0.33 & 0.125 \\ 0 & 0 & 0.375 \\ 0 & 0 & 0 \end{bmatrix} \qquad (\mathbf{I}-\mathbf{A})^{-1} = \begin{bmatrix} 1.0 & 0.33 & 0.25 \\ 0 & 1.0 & 0.375 \\ 0 & 0 & 1.0 \end{bmatrix}$$

Figure 2. Direct Input Coefficient Matrix (*A*) and its Leontief Inverse

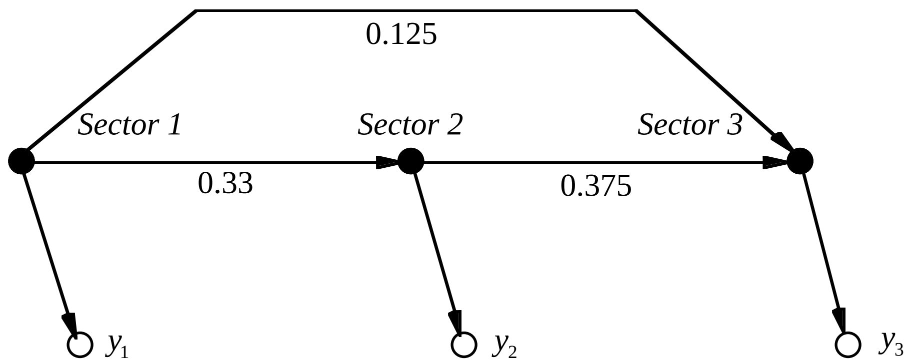


Figure 3. Production Digraph (Romanoff, 1984)

For simplicity, the final demand schedule is set as constant over time if no unscheduled event occurs. The unit of time can be either a month, a quarter, or a half-year. The hypothetical scenario is set that a catastrophic disaster occurs in the beginning of the 5th period, and that final demand in each sector decreases 20% from the previous level and will start to increase at 3% per period from 6th period as recovery and reconstruction activities progress. The final demand schedule is shown in Table 1. If the assumption of perfect information holds, implying that the production side somehow knows the occurrence of the disaster in Period 5 and the damages and recovery schedule, the output can be calculated using this schedule based on the SIM framework. This is the usual way to calculate the indirect impacts of such an event for the period AFTER its occurrence. However, it is most unlikely for the production side to know such changes BEFORE the event, especially for anticipatory production mode sectors. On the other hand, the output derived based on this schedule can be considered as the ideal production level in each period, knowing the occurrence of the event and recovery. This ideal production level in each period is shown in Table 2. However, this looks very strange: the production levels, especially of Sectors 1 and 2—anticipatory production mode—need to be decreased to the equilibrium level BEFORE the event. This problem is usually neglected, since most impact analyses of unscheduled events employ a static production process and do not concern the fact that the production process started BEFORE the event. Or, these impacts may be included in the total impacts AFTER the event, on the contrary to the production chronology.

Table 1. Final Demand Schedule with a Catastrophic Disaster at Period 5

period

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $y_1$ | 2 | 2 | 2 | 2 | 1.60 | 1.65 | 1.70 | 1.75 | 1.80 | 1.85 | 1.91 | 1.97 | 2.03 |
| $y_2$ | 6 | 6 | 6 | 6 | 4.80 | 4.94 | 5.09 | 5.25 | 5.40 | 5.56 | 5.73 | 5.90 | 6.08 |
| $y_3$ | 16 | 16 | 16 | 16 | 12.80 | 13.18 | 13.85 | 13.99 | 14.41 | 14.84 | 15.28 | 15.74 | 16.21 |
| total | 24 | 24 | 24 | 24 | 19.20 | 19.78 | 20.37 | 20.98 | 21.61 | 22.26 | 22.93 | 23.61 | 24.32 |

Table 2. Output Schedule based on Perfect Information (Ideal Production Level)

Period

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 8 | 7.6 | 6.85 | 6.59 | 6.79 | 6.99 | 7.20 | 7.42 | 7.64 | 7.87 |
| $x_2$ | 12 | 12 | 10.8 | 9.74 | 10.04 | 10.34 | 10.65 | 10.97 | 11.3 | 11.63 |
| $x_3$ | 16 | 16 | 16 | 12.8 | 13.18 | 13.58 | 13.99 | 14.41 | 14.84 | 15.28 |
| total | 36 | 35.6 | 33.65 | 29.14 | 30.01 | 30.91 | 31.84 | 32.79 | 33.78 | 34.79 |

3-1. Adjustment of Anticipatory Mode

The problem with the perfect information case is that the production levels start to decline as early as in the second period, three periods prior to the occurrence of the event. This should never happen in the real world—unrealistic. The production side would not be able to anticipate such an event, thus would continue to produce their products as usual, expecting no changes, until the beginning of Period 5. In particular, Sector 1 anticipates the final demand stream three periods further in the future, while Sector 2 anticipates two periods further; thus, they cannot adjust the sudden changes in final demand caused by a disaster. In other words, in Period 4, Sector 1 produced their goods partly for the anticipated demand in Period 7, whereas Sector 2 produced the products for the anticipated demand in Period 6, without knowing that the final demand level considerably decreases due to the event. Due to the anticipatory production process, during Periods 2 through 5, the production level exceeds the equilibrium production level (perfect information case). Moreover, due to the uncertainty incorporated with the future trends after the event, the anticipatory mode sectors will change their anticipation practice to shorter period than before. It is assumed that, for production during Period 5, all the sectors can hardly forecast/anticipate the future demand schedule; instead, they can use only the anticipated demand in Period 6. Likewise, for the production during Period 6, the anticipatory sectors (Sectors 1 and 2) can only anticipate one period further, and use the expected demand in Periods 7 and 8. From the production during Period 7 and afterwards, the anticipation of the future demand stream returns to the previous state.

Based on these modifications, the estimated output level over time is shown in Table 3. Because of the nature of input-output framework, in each period, the market clears based on the production digraph, *i.e.* input-output relationship, $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f}$. Thus, the excess production during Periods 2 through 5 caused by the event will be wasted, or will disappear, under the SIM framework. Figure 4 displays the trends of total output over time for equilibrium levels (perfect information) and actual production levels. The area between equilibrium and actual levels indicates supply-demand mismatches, which may not be recognized at the moment (before the event). This area can be considered as the backward impact of the event. Additionally, in Periods 5 and 6, total output in this case is smaller than the one with perfect information, due to the shorter anticipation period during these periods.

Table 3. Output Schedule based on Anticipated Demand (Supply Side)

| | Period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 8 | 8 | 8 | 8 | 6.59 | 6.94 | 7.20 | 7.42 | 7.64 | 7.87 |
| $x_2$ | 12 | 12 | 12 | 12 | 9.89 | 10.34 | 10.65 | 10.97 | 11.3 | 11.63 |
| $x_3$ | 16 | 16 | 16 | 16 | 13.18 | 13.58 | 13.99 | 14.41 | 14.84 | 15.28 |
| total | 36 | 36 | 36 | 36 | 29.66 | 30.86 | 31.84 | 32.79 | 33.78 | 34.79 |

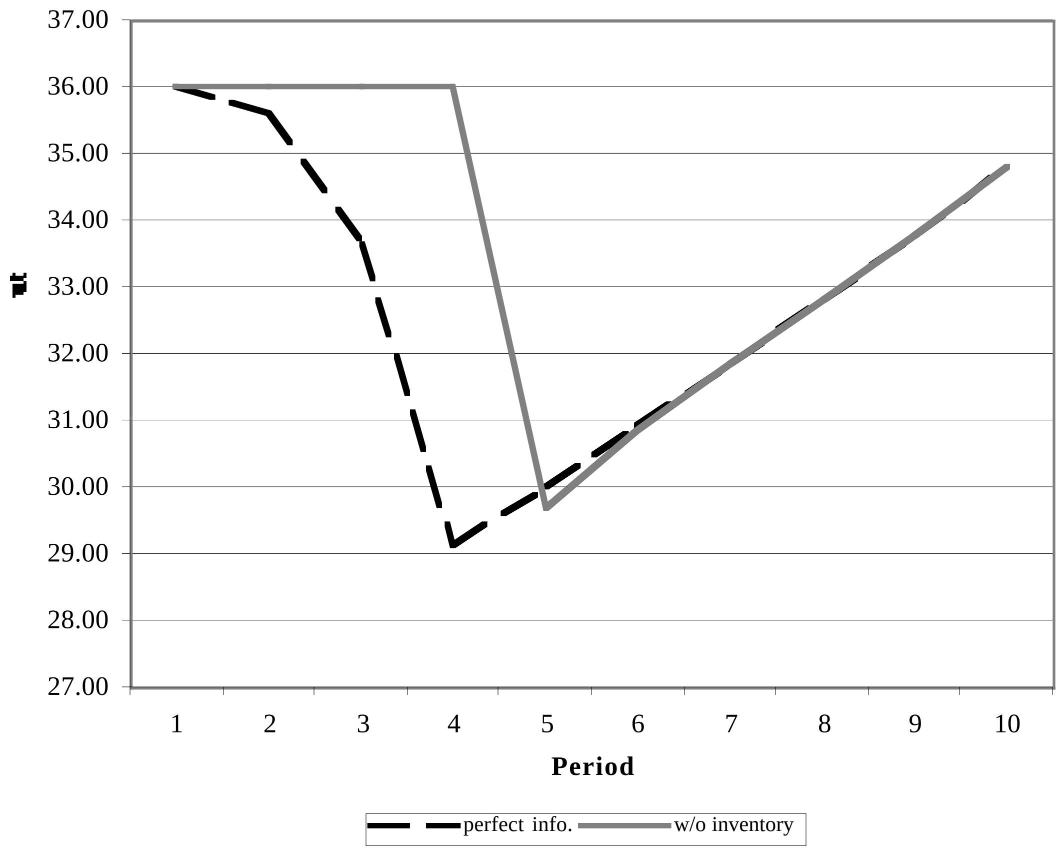


Figure 4. Comparison of Output Schedules between Demand and Supply

3-2. Inclusion of Inventory for Demand-Supply Mismatches

Romanoff and Levine (1986) further introduced the "Modified SIM", which extended the "Core SIM" by including the concept of capacity limitations and inventory in time-phased production framework. In this study, the concept of inventory is added to the framework of the Core SIM in order to deal with the issue of demand-supply mismatch[1] found in the previous sub-section. If excess supply exists, the products not consumed in a particular period can be stored and be consumed in the following period with the reduction of the production during that period. Since some commodities, like some of agricultural products and most of services, may not be stored for future consumption, for simplicity, the example case is set that the excess supply only from Sector 2 can be stored in the inventory for consumption in the next period. In addition, it is assumed that when excess supply of Sector 2 exists in a particular period, Sector 2 treats the level of final demand in the next period on Sector 2 as it decreases as much as the quantity of the excess supply from the anticipated level. Likewise in 3-1, anticipation period is shorted for the production during Periods 5 and 6 as described above. Table 4 shows the output levels over time with inventory capability in Sector 2. Because of the excess production in Period 4 and the inventory, Sector 2's output decreases significantly in Period 5, lower than the output level with perfect information. The comparison of output schedules of perfect information, supply side without inventory, and supply side with inventory are illustrated in Figure 5.

[1] Because the SIM is based on the input-output framework, which does not include price change for the market clearing mechanism, the presence of excess supply does not change the price in this analysis. This may be plausible in this case, since this excess supply is actually not realized in the market at the moment, because the event is unexpected and unscheduled.

Table 4. Output Schedule based on Anticipated Demand with Inventory (Sector2)

| | Period | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $x_1$ | 8 | 8 | 8 | 8 | 6.59 | 6.94 | 7.20 | 7.42 | 7.64 | 7.87 |
| $x_2$ | 12 | 12 | 12 | 12 | 7.63 | 10.49 | 10.65 | 10.97 | 11.3 | 11.63 |
| $x_3$ | 16 | 16 | 16 | 16 | 13.18 | 13.58 | 13.99 | 14.41 | 14.84 | 15.28 |
| total | 36 | 36 | 36 | 36 | 27.41 | 31.01 | 31.84 | 32.79 | 33.78 | 34.79 |

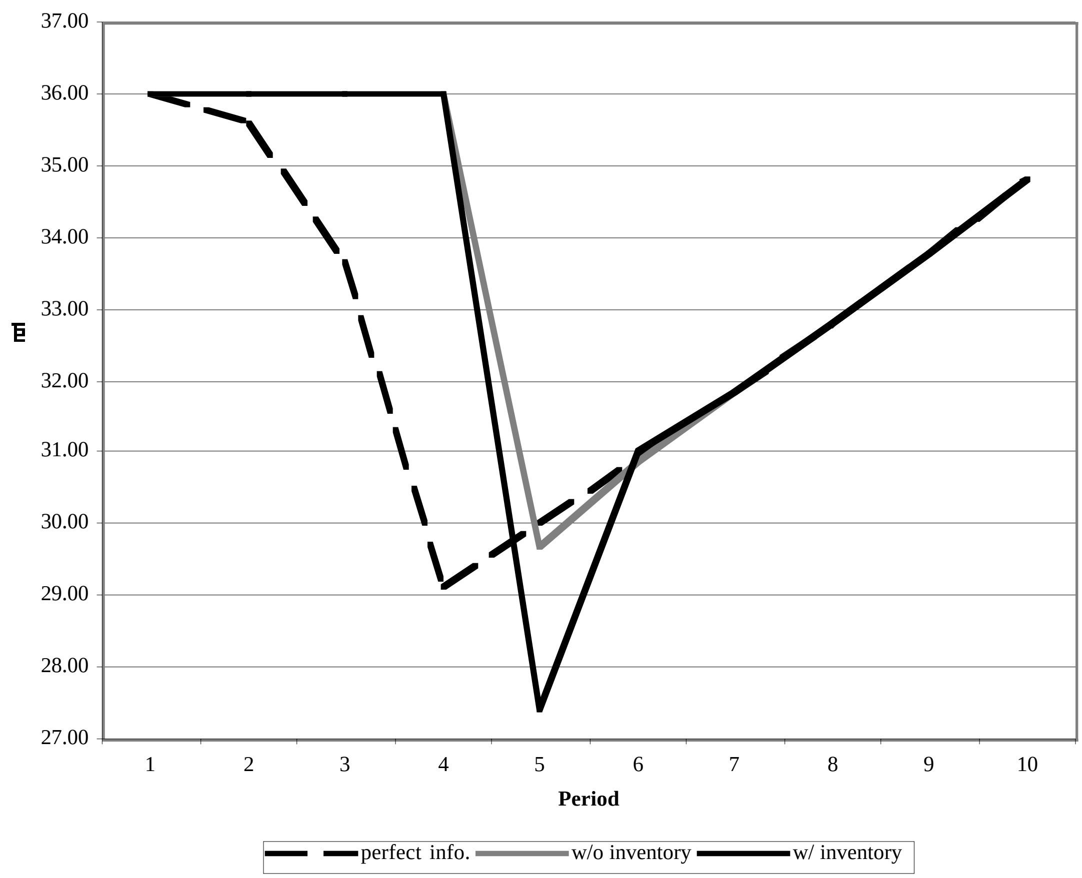


Figure 5. Comparison of Output Schedule among Demand (perfect info.), Supply (w/o inventory), and Supply (w/ inventory)

The results here indicate important information regarding the impact analysis of unscheduled events in the following points: 1) a catastrophic disaster creates not only forward impacts after the event to significantly decrease output levels in the future but also backward impacts to the past (before the event), producing temporary demand-supply mismatches of goods that may be wasted due to the production schedule; 2) inventory may be able to utilize excess production created in the previous period, but the production level becomes significantly lower than the perfect information level and even than the supply level without inventory. These indirect impacts are usually neglected in the impact analysis of unscheduled events due to the static nature and market clearing mechanism of models. Note that the total output with inventory during Period 6 becomes slightly larger than the level with perfect information. This is resulted from the fact that the total output without inventory is lower than the level with perfect information, and this causes a temporary excess demand. This excess demand may or may not be realized in the market, since the perfect information level is not known in the market.

In the following section, this simple model is extended to a two-region interregional model, because the fluctuations of production level will further create interregional ripple effects.

## 4. Interregional Impacts of Unscheduled Events: Two-Region Model

The previous study (Okuyama *et al.*, 1999) found that the impacts of a catastrophic disaster, the Great Hanshin Earthquake, spread over to the other regions (the Rest of Japan) through interregional trades, and the total impacts on the other region became lager than the impacts in the region with the earthquake (Kinki Region). Although this magnitude of disaster rarely occurred, it is still important to trace the interregional impacts of such an event.

In this section, the previous simple example is extended to a two-region interregional model[2] with the SIM framework. Consider the following simple two-region input-output model:

$$\begin{pmatrix} \mathbf{x_{1,t}} \\ \mathbf{x_{2,t}} \end{pmatrix} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{A_{12}} \\ \mathbf{A_{21}} & \mathbf{A_{22}} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{x_{1,t+1}} \\ \mathbf{x_{2,t+1}} \end{pmatrix} + \begin{pmatrix} \mathbf{f_{1,t}} \\ \mathbf{f_{2,t}} \end{pmatrix} \tag{9}$$

where $\mathbf{x_{i,t}}$ is the total output (input) vector of region *i* at time *t*, $\mathbf{f_{i,t}}$ is the final demand vector of region *i* at time *t*, and $\mathbf{A_{ij}}$ is the block matrix of direct input coefficient from region *i* to *j*. This is a two-region version of anticipatory model in equation (1). However, if we assume that interregional trade takes some time to transport the goods produced in one region and consumed in another region and that the time for transportation between regions is one period, the relationship in equation (9) will be modified as follows:

$$\begin{pmatrix} \mathbf{x_{1,t}} \\ \mathbf{x_{2,t}} \end{pmatrix} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{0} \\ \mathbf{0} & \mathbf{A_{22}} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{x_{1,t+1}} \\ \mathbf{x_{2,t+1}} \end{pmatrix} + \begin{pmatrix} \mathbf{0} & \mathbf{A_{12}} \\ \mathbf{A_{21}} & \mathbf{0} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{x_{1,t+2}} \\ \mathbf{x_{2,t+2}} \end{pmatrix} + \begin{pmatrix} \mathbf{f_{1,t}} \\ \mathbf{f_{2,t}} \end{pmatrix} \tag{10}$$

Or, using the reduced formulation,

$$\mathbf{x_t} = \widehat{\mathbf{A}}\mathbf{x_{t+1}} + \breve{\mathbf{A}}\mathbf{x_{t+2}} + \mathbf{f_t} \tag{11}$$

where $\widehat{\mathbf{A}} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{0} \\ \mathbf{0} & \mathbf{A_{22}} \end{pmatrix}$ and $\breve{\mathbf{A}} = \begin{pmatrix} \mathbf{0} & \mathbf{A_{12}} \\ \mathbf{A_{21}} & \mathbf{0} \end{pmatrix}$. Furthermore, the use of forward operator (analogous to "lag operator" in time series model), $\Phi$, equation (11) becomes as follows:

$$\mathbf{x_t} = \widehat{\mathbf{A}}\mathbf{x_{t+1}} + \breve{\mathbf{A}}\Phi\mathbf{x_{t+1}} + \mathbf{f_t} = \left(\widehat{\mathbf{A}} + \breve{\mathbf{A}}\Phi\right)\mathbf{x_{t+1}} + \mathbf{f_t} \tag{12}$$

where $\Phi\mathbf{x_{t+1}} = \mathbf{x_{t+2}}$. Set $\left(\widehat{\mathbf{A}} + \breve{\mathbf{A}}\Phi\right) = \overline{\mathbf{A}}$, then equation (12) becomes:

$$\mathbf{x_t} = \overline{\mathbf{A}}\mathbf{x_{t+1}} + \mathbf{f_t} \tag{13}$$

Thus, this model can be transformed as below:

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[2] Strictly speaking, this is not a pure Isard-type fully specified interregional model, since the final demand vector and total input and output vectors are aggregated regional ones, while the direct input coefficient matrix is specified as full interregional. Hence, this model can be classified between a pure interregional model and a trade pool model.

$$\mathbf{x_t} = \sum_{\mathbf{r=0}}^{\infty} \overline{\mathbf{A}}^{\mathbf{r}} \mathbf{f_{t+r}} \tag{14}$$

This is a simple extension of equation (2), and this formulation is similar to the use of delay matrix, $\Phi(z)$, introduced to the modified SIM in Romanoff and Levine (1986).

Using this version of SIM formulation, a numerical example is created and has the transaction table shown in Figure 6. The matrices of direct input coefficients and Leontief inverse are presented in Figure 7.

| | A-1 | A-2 | A-3 | B-1 | B-2 | B-3 | $w_i$ | $f_i$ | $x_i$ |
|---|---|---|---|---|---|---|---|---|---|
| A-1 | 0 | 3 | 2 | 0 | 2 | 1 | 8 | 2 | 10 |
| A-2 | 0 | 0 | 5 | 0 | 0 | 2 | 7 | 5 | 12 |
| A-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 16 |
| B-1 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 2 | 6 |
| B-2 | 0 | 0 | 1 | 0 | 0 | 4 | 5 | 7 | 12 |
| B-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 16 |
| $u_j$ | 0 | 4 | 8 | 0 | 4 | 8 | 24 | 48 | 72 |
| $v_j$ | 10 | 8 | 8 | 6 | 8 | 8 | 48 | | |
| $x_j$ | 10 | 12 | 16 | 6 | 12 | 16 | 72 | | |

Figure 6. Transaction Table of Two-Region Model

$$\mathbf{A} = \begin{bmatrix} 0 & 0.25 & 0.125 & 0 & 0.167 & 0.063 \\ 0 & 0 & 0.313 & 0 & 0 & 0.125 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.083 & 0 & 0 & 0.167 & 0.063 \\ 0 & 0 & 0.063 & 0 & 0 & 0.25 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (\mathbf{I}-\mathbf{A})^{-1} = \begin{bmatrix} 1 & 0.25 & 0.214 & 0 & 0.167 & 0.135 \\ 0 & 1 & 0.313 & 0 & 0 & 0.125 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0.83 & 0.36 & 1 & 0.167 & 0.115 \\ 0 & 0 & 0.63 & 0 & 1 & 0.25 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 7. Direct Input Coefficient Matrix and Leontief Inverse Matrix of Two-Region Model

For simplicity and comparison with the single-region model, the final demand schedule and event schedule are set to use the similar hypothetical scenario: final demand is constant without the event;

the event occurs in Region A (first region) at the beginning of Period 5; no damages in Region B (second region); by the event, the final demand level in Period 5 decreases 20% in each sector; the final demand in each sector then is going to recover at the rate of 3% per period from Period 6. This final demand schedule is shown in Table 5. As indicated above and in equation (10), interregional trade between two regions require one period for transportation. In addition, the similar uncertainty restriction on anticipation of future final demands after the event, employed in the single-region model, also applies to this two-region case: the production level during Period 5 is based only on the anticipated final demand in Period 6; the production in Period 6 only uses the anticipated final demand in Periods 7 and 8; and the production level during Period 7 will be decided based on the anticipated final demand in Periods 8, 9, and 10. Moreover, Sector 2 can use inventory to stock their goods, when supply-demand mismatch occurs. Thus, the results from the hypothetical scenario and settings are comparable to the ones from the single-region case.

Table 5. Final Demand Schedule for Two-Region Model with a Disaster in Region A

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $f_{A1}$ | 2 | 2 | 2 | 2 | 1.6 | 1.65 | 1.7 | 1.75 | 1.8 | 1.85 | 1.91 | 1.97 | 2.03 | 2.09 |
| $f_{A2}$ | 5 | 5 | 5 | 5 | 4 | 4.12 | 4.24 | 4.37 | 4.5 | 4.64 | 4.78 | 4.92 | 5.07 | 5.22 |
| $f_{A3}$ | 16 | 16 | 16 | 16 | 12.8 | 13.18 | 13.58 | 13.99 | 14.41 | 14.84 | 15.28 | 15.74 | 16.21 | 16.7 |
| $f_{B1}$ | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| $f_{B2}$ | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| $f_{B3}$ | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| total | 48 | 48 | 48 | 48 | 43.4 | 43.95 | 44.52 | 45.11 | 45.71 | 46.33 | 46.97 | 47.68 | 48.31 | 49.01 |

The resulted total output trends in Region A is shown in Figure 8. The trends of total output level appear to be very similar to the ones of the single-region case: build-up of excess production before the event, and sharp decline in total output in Period 5 due to the excess production and use of inventory; possible excess demand in Period 5; and resulted increased output in Period 6. Since Region A is with the event and depends less on interregional import from Region B, this similarity is expected.

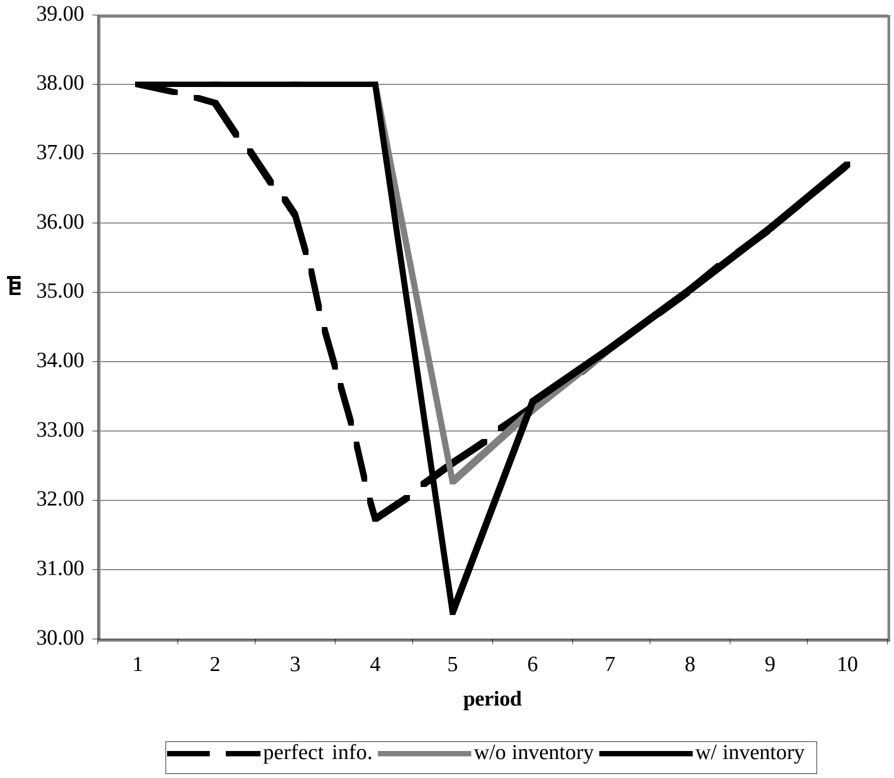


Figure 8. Comparison of Output Schedules in Region A

On the other hand, the trends of total output schedule of Region B is noticeably different from of Region A. The comparison of output schedules in Region B is illustrated in Figure 9. Although the volume of impacts in Region B is relatively smaller than in Region A, the forward impact is larger in earlier periods, especially in Period 2, than right before the event. This is resulted from the fact that the production level of exports from Region B to Region A is determined based on the final demand stream of the further future with the anticipation period and transportation time; thus, the production level with perfect information in Region B is responded earlier to the event and recovery. In other words, the event brings a different stream of forward impacts in Region B from in Region A. The fluctuations of output level after the event due to the supply-demand mismatch and inventory adjustment persist longer (up to Period 7) in Region B than in Region A. This is caused partly by the uncertainty (shortened anticipation period) after the event and partly by the delayed adjustment due to transportation time to Region A.

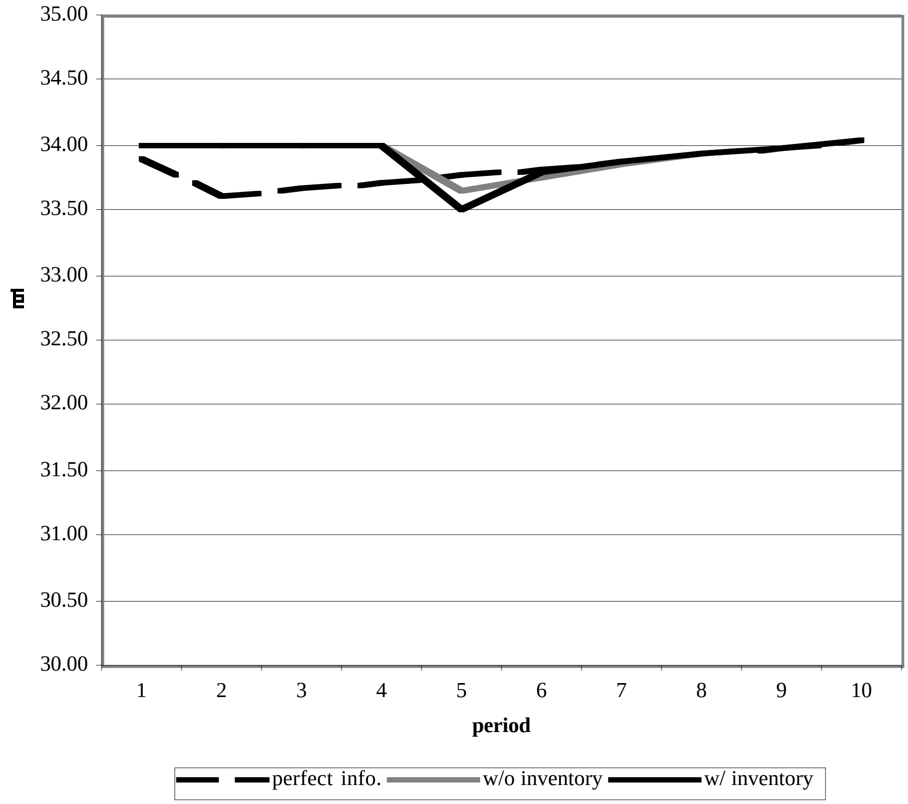


Figure 9. Comparison of Output Schedules in Region B

The above analysis can be summarized into the following points: 1) the impacts of a catastrophic disaster in a region will be spread through interregional trade to other regions; 2) the impacts in other regions take a different trend from the impacts in the region with disaster, due to requirement of transportation time; and 3) the fluctuation of output trends becomes longer in other regions, due to the uncertainty after the disaster and transportation period. Again, the "surprise" by the disaster creates unexpected changes in the stream of final demand and brings the forward impacts before the event in the region and other regions.

## 5. Conclusions

Comparing with the static input-output modeling, the intertemporal processes of economic impacts from an unscheduled event were examined in this study. The Sequential Interindustry Model can effectively introduce the dynamic process of production chronology in the static input-output framework. This modeling scheme is especially valuable to analyze the impacts of an unscheduled event and its recovery and reconstruction processes over time, such as this study. Some refinements of mode selection among \anticipatory, responsive, and just-in-time (neither anticipatory nor responsive) sectors and the period of anticipation/response might be necessary for more detailed studies of interindustry relationship, as the Modified SIM. Romanoff and Levine (1986, and 1990) further extended their SIMs to include the mechanisms of capacity limitations, inventory, and transportation delay. Application of their extended models may provide more detailed analysis of effects from such an event.

Furthermore, the analysis using simple one-region and two-region models in Sections 3 and 4 revealed that the impact analysis of unscheduled events should treat the production information (stream of future final demand) more carefully and differently from the impact analysis of a typical capital project, because of the nature of such events—events are never scheduled in prior to its occurrence. Due to the unexpected nature of events and following sudden and intense demand injection in a short period of time, the mismatch between demand and supply may become unavoidable. In this context, further investigation and modification of the SIM framework is necessary to incorporate with this issue by inventory and capacity adjustment, especially incorporating with intense demand injection for recovery and reconstruction activities after an event, with supply constraint resulted from the direct damages on production facilities, and with changes in interregional trade relationship.

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