**ECONOMIC IMPACTS OF NATURAL DISASTERS:**

**DEVELOPMENT ISSUES AND EMPIRICAL ANALYSIS**[1]

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ABSTRACT

*The higher-order effects of ten recent disaster cases, drawn from a global sample, are estimated by employing Input–Output and Social Accounting Matrix methodologies. The results show that the higher-order effects of disasters are significant (almost 225 billion US dollars) and complex. The estimated impact multipliers are mostly around two, and in some cases, bordering three, implying that losses of a disaster can be doubled, or sometimes tripled, via ripple effects through interdependencies within an economy. These results therefore indicate the importance of appropriately evaluating and accounting for higher-order effects. We also find, perhaps surprisingly, there are no particular trends or correlations among damages, losses, and higher-order effects between the types of disaster and the intensity of disasters. Furthermore, analysis of the sectoral distribution of higher-order effects reveals that the manufacturing and services sectors suffer from larger higher-order effects than do other sectors, such as agriculture and mining. Since these two sectors rely more on interindustry relationships domestically and/or internationally and are located in the middle and at the end of production chains, respectively, the damages and losses on the other sectors propagate to these two sectors, resulting in larger higher-order effects.*

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## 1. Introduction

The damages and losses brought by disasters, such as earthquakes, floods, hurricanes and cyclones, and so on, can have significant and intense impacts on a nation's economy. However, despite the importance of assessing the economic impacts of damages and losses in the aftermath of such events, estimating impacts is challenging. For instance, most analytical economic models cannot confront typically unscheduled and significant changes, since, at best, they assume incremental changes in systems over time. The consequences associated with the event, moreover, will have many other aspects including damages on demand and supply sides, for example, since the event may affect a wide range of economic activities in different ways. The difficulties with impact analysis of disasters are, therefore, 1) disentangling the consequences stemming directly and indirectly from the event, 2) deriving possibly different assessments at each spatial level—cities, region, or nation—(Hewings and Mahidhara, 1996), and 3) evaluating the reaction of households which are poorly understood (West and Lenze, 1994). Data availability for the impact assessment is another issue. West and Lenze (1994) claim that sophisticated economic impact models requiring precise numerical input have to be reconciled with imperfect measurements of the damages. They proposed a systematic way to estimate the impacts from the available data; however, "impact assessment of unscheduled events is an inexact science" (Hewings and Mahidhara, 1996; p.216).

A wide range of economic models has been employed to evaluate the economic impacts of disasters. The most widely used has been Input-Output (IO) analysis. This paper aims to demonstrate how IO analysis together with Social Accounting Matrix (SAM) analysis can be employed to analyze the economic impacts of disasters. We select a set of ten recent disasters from a global sample, with particular attention paid to types of disaster and region, in order to illustrate how the IO / SAM methodology can handle the different set of damages and losses. Moreover, modifications of these standard models are presented to extend the analysis of impacts for including the effects to income generation. In addition, extreme disaster cases are added in order to show how an extremely large disaster can not only bring significant effects within the country (region) but also can spread over to other countries (regions).

In the following section, methodologies for impact estimation are reviewed briefly, with particular emphasis on input-output (IO) models and social accounting matrix (SAM). Section 3 presents the data sources of IO and SAM models used in this paper, and discusses the damage assessment data of the case studies. Then, the impact estimation of the case studies are presented and analyzed in Section 4. And, Section 5 compares the results of case studies to analyze tendencies among the damages, losses, and higher-order effects. The final section concludes the paper with some remarks on strengths and weaknesses of the impact estimation methodologies.

## 2. Methodologies for Disaster Impact Estimation

Natural disasters can cause physical destruction to built-environment and networks, such as transportation and lifelines, and can also cause casualties and injuries to human lives. These damages are often called *damages*, and are by economics' definition the damages on stocks, which include physical and human capitals. Then, these damages lead to the interruptions of economic activities, such as production and/or consumption, and the losses from business interruptions are called the *(first-order) losses* of a disaster. At the same time, there is another term called *higher-order effects*, which take into account the system-wide impact of flow losses through interindustry relationships. (Rose, 2004). And, *total impacts* are the total of flow impacts, adding (first-order) losses and higher-order effects. While some researchers critique that the higher-order effects of disaster are "more a possibility than a reality" (Albala-Bertrand, 1993, p. 104), the estimation of indirect effects has been attempted to "gauge individual and community vulnerability, evaluate the worthiness of mitigation, determine the appropriate level of disaster assistance, improve recovery decisions, and inform insurers of their potential liability" (Rose, 2004, p. 13). An accompanying paper, "Critical Review of Methodologies on Disaster Impact Estimation", discusses the details and issues related to the methodologies used for disaster impact analysis. Table 2-1 summarizes the strengths and weaknesses of the methodologies.

Table 2-1. Summary of Methdologies

| | Strengths | Weaknesses |
|---|---|---|
| IO | - simple structure<br>- detailed interindustry linkages<br>- wide range of analytical techniques available<br>- easily modified and integrated with other models | - linear structure<br>- rigid coefficients<br>- no supply capacity constraint<br>- no response to price change<br>- overestimation of impact |
| SAM | - more detailed interdependency among activities, factors, and institutions<br>- wide range of analytical techniques available<br>- used widely for development studies | - linear structure<br>- rigid coefficients<br>- no supply capacity constraint<br>- no response to price change<br>- data requirement<br>- overestimation of impact |
| CGE | - non-linear structure<br>- able to respond to price change<br>- able to cooperate with substitution<br>- able to handle supply capacity constraint | - too flexible to handle changes<br>- data requirement and calibration<br>- optimization behavior under disaster<br>- underestimation of impact |
| Econometric | - statistically rigorous<br>- stochastic estimate<br>- able to forecast over time | - data requirement (time series and cross section)<br>- total impact rather than direct and higher-order impacts distinguished |

Source: Okuyama (2009)

Input-Output (IO) model has been the most widely used methodology for disaster impact estimate for the recent decades (for example, Cochrane, 1974, 1997; Wilson, 1982; Kawashima *et al*. 1991; Boisvert, 1992; Gordon and Richardson, 1996; Rose *et al*. 1997; Rose and Benavides, 1998; and Okuyama *et al*., 1999). The popularity of IO models for disaster related research is based mainly on the ability to reflect the economic interdependencies within an economy in detail for deriving higher-order effects, and partly on its simplicity. The simplicity of the IO framework has enabled integrative approaches, in which IO models are combined with engineering models and/or data, in order to estimate higher-order effects that are more sensitive to the changes in physical destruction. Some examples of this approach include the links with transportation network models (Gordon *et al*., 1998, 2004; Cho *et al*, 2001; Sohn *et al*., 2004, among others), with lifeline network models (Rose, 1981; Rose *et al*. 1997; Rose and Benavides, 1998), and the comprehensive disaster assessment model, namely HAZUS (Cochrane *et al*., 1997).

On the other hand, this simplicity of the IO model creates a set of weaknesses, including its linearity, its rigid structure with respect to input and import substitutions, a lack of explicit resource constraints, and a lack of responses to price changes (Rose, 2004). In order to overcome these weaknesses in a disaster situation, several attempts of refinement and extension of the IO framework have been proposed. For instance, the shortage of regionally produced inputs in a disaster situation was dealt with by the integration of a methodology for more flexible treatment of imports (Boisvert, 1992; and Cochrane, 1997). The issue of supply-side constraints due to the damages to production facilities was addressed with the allocation model variant of IO model (Davis and Salkin, 1984); however, this modeling scheme has inherent deficiencies (Oosterhaven, 1988 and 1989; see Dietzenbacher, 1997, for a solution), and was later modified by Steinback (2004) to include only backward-linkage effects. The treatment of price has been transferred to computable general equilibrium (CGE) models.

The input-output (IO) framework was developed by Wassily Leontief in the late 1920s and early 1930s. The structure of IO mimics the double-entry style of bookkeeping scheme. For the production side, the output is determined as the sum of intermediate demand and final demand as follows:

$$x_i = \sum_j x_{ij} + f_i \tag{1}$$

where $x_i$ is the output of sector *i*, $x_{ij}$ is intermediate demand from sectors *j* to *i*, and $f_i$ is the final demand for sector *i*. Direct input coefficient, $a_{ij}$, is calculated by $a_{ij} = x_{ij} / x_j$, and equation (1) can be transformed as follows:

$$x_i = \sum_j a_{ij} x_j + f_i \tag{2}$$

In the matrix notation, (2) becomes:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f} \tag{3}$$

Solving this relationship for **x** yields:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{4}$$

$(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix. For the impact analysis, the impact of changes in final demand can produce the changes in output in the following manner:

$$\Delta\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{f} \tag{5}$$

Miyazawa's (1976) extended input-output analysis intends to analyze the structure of income distribution by endogenizing consumption demands in the standard Leontief model. In some sense, Miyazawa's system is considered the most parsimonious in terms of the way it extends the familiar input-output formulation. Miyazawa considered the following system:

$$\begin{pmatrix} \mathbf{x} \\ \hline \mathbf{y} \end{pmatrix} = \left(\begin{array}{c|c} \mathbf{A} & \mathbf{C} \\ \hline \mathbf{V} & \mathbf{0} \end{array}\right) \begin{pmatrix} \mathbf{x} \\ \hline \mathbf{y} \end{pmatrix} + \begin{pmatrix} \mathbf{f} \\ \hline \mathbf{g} \end{pmatrix} \tag{6}$$

where **x** is a vector of output, **y** is a vector of total income for some *r*-fold division of income groups, **A** is a block matrix of direct input coefficients, **V** is a matrix of value-added ratios for *r*-fold income groups, **C** is a corresponding matrix of consumption coefficients, *f* is a vector of final demands except households consumption, and *g* is a vector of exogenous income for *r*-fold income groups. Solving this system yields:

$$\begin{pmatrix} \mathbf{x} \\ \hline \mathbf{y} \end{pmatrix} = \left(\begin{array}{c|c} \mathbf{B}(\mathbf{I} + \mathbf{CKVB}) & \mathbf{BCK} \\ \hline \mathbf{KVB} & \mathbf{K} \end{array}\right) \begin{pmatrix} \mathbf{f} \\ \hline \mathbf{g} \end{pmatrix} \tag{7}$$

where:

$\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix;
**BC** is a matrix of production induced by endogenous consumption;
**VB** is a matrix of endogenous income earned from production;
**L=VBC** is a matrix of expenditures from endogenous income; and
$\mathbf{K} = (\mathbf{I} - \mathbf{L})^{-1}$ is a matrix of the Miyazawa interrelational income multipliers.

In this paper, IO models used are transformed to the Miyazawa's extended IO framework for the analysis of impact on income generation.

Other modeling frameworks have been also employed to estimate higher-order effects of disasters. Social accounting matrix (SAM) has been utilized to examine the higher-order effects across different socio-economic agents, activities, and factors. Notable studies using a SAM or one of its variants include Cole (1995, 1998, and 2004) among others. Like IO models, the SAM approach has rigid coefficients and it tends to provide upper bounds for the estimates. On the other hand, the SAM framework, as well as extended IO models[2] and CGE models, can derive the distributional impacts of a disaster in order to evaluate equity considerations for public policies against disasters.

SAM was developed by Stone (1961) and further formalized by Pyatt and Thorbecke (1976) and Pyatt and Roe (1977) for policy and planning purpose. SAM is an extended version of IO (and more closely to Miyazawa formulation above), and the structure of a typical SAM is shown in Figure 2-1[3]. Similar to IO analysis, the accounting multiplier matrix can be derived in the following way. The relationships in Figure 2-1 can be transformed into the equation below:

$$\begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \end{pmatrix} = \begin{pmatrix} \mathbf{X}_{11} & \mathbf{0} & \mathbf{X}_{13} \\ \mathbf{X}_{21} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_{32} & \mathbf{X}_{33} \end{pmatrix} + \begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \\ \mathbf{f}_3 \end{pmatrix} \tag{8}$$

where $\mathbf{x_1}$ is gross output, $\mathbf{x_2}$ is income of factors, $\mathbf{x_3}$ is income of private sector (including household and companies), $\mathbf{X_{11}}$ is transaction between production activities (input-output relationships), $\mathbf{X_{13}}$ is private consumption, $\mathbf{X_{21}}$ is value added payments, $\mathbf{X_{32}}$ is income to private sector, $\mathbf{X_{33}}$ is inter-institution transfer, $\mathbf{f_1}$ is final demand for production activities, $\mathbf{f_2}$ is final demand for factor, and $\mathbf{f_3}$ is final demand for private sector. Then, equation (8) can be rewritten with direct input coefficient matrix as follows:

$$\begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \end{pmatrix} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{0} & \mathbf{A}_{13} \\ \mathbf{A}_{21} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A}_{32} & \mathbf{A}_{33} \end{pmatrix} \begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \end{pmatrix} + \begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \\ \mathbf{f}_3 \end{pmatrix} \tag{9}$$

[2] The disaster related studies using extended I-O model include Okuyama *et al.* (1999).

[3] In Figure 2-1, endogenous accounts are highlighted in blue, while exogenous accounts are in beige.

| | | 1 Production Activities | 2 Factor | 3 Institutions | | | | 4 Rest of the World | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 3a Households (current accounts) | 3b Companies (current accounts) | 3c Government (current accounts) | 3d Combined capital accounts | | |
| 1 | Production Activities | Intermediate goods purchase | | Household consumption of final goods | | Government expenditures | Investment expenditures | Exports | Gross outputs |
| 2 | Factors | Value added payments | | | | | | Net factor income from ROW | Incomes of factors |
| 3 | Institutions | | | | | | | | |
| 3a | Households (current accounts) | | Income to HHs | Current transfers b/w HHs | Profits distributed to HHs | Current transfers to HHs | | Net non-factor incomes from ROW | Income of HHs after transfer |
| 3b | Companies (current accounts) | | Allocation of operation surplus | | | Current transfers to companies | | Net non-factor incomes from ROW | Income of companies after transfer |
| 3c | Government (current accounts) | Indirect taxes on inputs | | Direct taxes on income and indirect taxes on current expenditures | Direct taxes on companies plus operating surplus of state enterprises | | Indirect taxes on capital goods | | Income of government |
| 3d | Combined capital accounts | | | HH savings | Undistributed profits after tax | Government current account surplus | | Net capital flows from ROW | Aggregate savings |
| 4 | Rest of the World | Imports | | HHs expenditure on imported final goods | | | Imports of capital goods | | Total foreign imports |
| Total | | Total costs | Incomes of domestic factors | Total outlay of HHs | Total outlay of companies | Total outlay of government | Aggregate Investment | Total foreign exchange receipt | |

Figure 2-1. Structure of a Typical Social Accounting Matrix

Solving this yields the accounting multiplier matrix:

$$\mathbf{x_n} = \left(\mathbf{I} - \mathbf{A_n}\right)^{-1} \mathbf{f_n} = \mathbf{M_a f_n} \tag{10}$$

where $\mathbf{x_n} = \begin{pmatrix} \mathbf{x_1} \\ \mathbf{x_2} \\ \mathbf{x_3} \end{pmatrix}$, $\mathbf{A_n} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{0} & \mathbf{A_{13}} \\ \mathbf{A_{21}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A_{32}} & \mathbf{A_{33}} \end{pmatrix}$, $\mathbf{f_n} = \begin{pmatrix} \mathbf{f_1} \\ \mathbf{f_2} \\ \mathbf{f_3} \end{pmatrix}$, and $\mathbf{M_a}$ is the accounting multiplier matrix. Use of SAM for impact analysis is similar to IO, changes in final demand lead to changes in output through accounting multiplier matrix.

## 3. Data for Case Studies and Models

This section presents the data sources for the case studies and the models used in this paper. The data used in this paper are mostly available for public as secondary data, but the definitions and/or format of them are not standardized to make direct comparison of the derived impacts.

### *3.1. Data for Case Studies*

The events for case study are chosen among the recent disasters (mostly after 1995). In order to illustrate a wide range of applications, the cases are selected from different types (but only between meteorological and geological), from different regions around the world (Africa, Americas, and Asia), and from different sizes of country. Also, the data availability of the event and/or model is one of the key factors for this case selection. Two extreme events (with extremely significant damages and large scale impact) are included. The disasters employed for case study in this paper are as follows:

| Year | Disaster | Country | Type | Region |
|---|---|---|---|---|
| 1998 | Hurricane Mitch | Honduras<br>Cost Rica | Meteorological | Central America |
| 2000 | Floods and Cyclone | Mozambique | Meteorological | Africa |
| 2001 | Gujarat Earthquake | India | Geological | Asia |
| 2001 | Earthquake | El Salvador | Geological | Central America |

| | | | | |
|---|---|---|---|---|
| 2004 | Floods | Bangladesh | Meteorological | Asia |
| 2005 | Hurricane Stan | El Salvador | Meteorological | Central America |
| 2006 | Central Java Earthquake | Indonesia | Geological | Asia |
| 2007 | Cyclone Sidr | Bangladesh | Meteorological | Asia |
| Extreme Cases | | | | |
| 1995 | Great Hanshin-Awaji (Kobe) Earthquake | Japan | Geological | Asia |
| 2004 | Indian Ocean Earthquake and Tsunami | Indonesia<br>Thailand<br>India<br>Sri Lanka | Geological | Asia |

The disaster data, namely the assessment of damages and losses (the definitions of them are discussed below), are based on various assessment reports carried out by the international organizations, for example the United Nations (UN), the World Bank, the Asian Development Bank (ADB), UN Economic Commission of Latin American and Caribbean (ECLAC), and/or the government of the affected country[4].

The assessment methodology used in the above reports is mostly based on the ECLAC methodology (UN ECLAC, 2003), except the 1995 Kobe Earthquake. ECLAC methodology classifies the damages and losses from a disaster into: a) direct damages (damage to asset); b) indirect losses (loss of flows for the production of goods and services); and c) macroeconomic effects (effect to the performance of the main macroeconomic aggregates of the affected country) (p. 9). Since this paper aims to estimate and to demonstrate the methodology for the higher-order effects of a disaster, 'macroeconomic effects', such as impact on investment, balance of payment, finance, and inflation, are not accounted for in the following analysis. In addition, the ECALC methodology and the assessment reports include the damages and losses on 'environment.' While the impact to environment can lead to economic impacts in many ways, the data for model used in this paper, IO and SAM, do not include impacts on the environment. Thus, the damages and losses on environment are excluded in the following analysis.

[4] The assessment report used for a particular disaster is listed in the following section.

According to the ECLAC handbook (2003), damages include "the total or partial destruction of physical infrastructure, buildings, installations, machinery, equipment, means of transportation and storage, furniture, damage to farmland, irrigation works, reservoirs and the like." (p. 11) Losses, on the other hand, is defined as the flow losses of goods and services "that will not be produced or rendered over a time span," and "losses result from the direct damage to production capacity and social and economic infrastructure." (p. 12) It should be noticed that this 'losses' are different from 'higher-order effects' discussed above: 'losses' in the ECLAC method is considered as output constraints (decreases) due to direct damages to a particular sector; 'higher-order effects' are the system-wide impact through interdependencies among sectors based on these output constraints.

The assessment reports using this ECLAC methodology often present the total impact of a particular disaster as adding the damages and losses above. However, this seems double-counting the damages (or losses), as suggested by Rose (2004). According to Rose (2004), "flow measures are superior to stock measures in many ways," (p.14), and thus in this paper, only the data for losses are used if listed in the report. When the damage data are reported but no loss data are listed, damage data (asset damage) are converted to loss data using capital-to-output ratio for simplicity.

The treatment of housing sector, especially for loss of housing sector, requires some attention[5]. It can be considered that destructions of or damages to housing (shelters) create hardships to the residents, especially homeowners, and may lead to lose income due to loss of lives, loss of job, or inability to go to work for some time, etc. Therefore, in some sense, the losses in housing sector should be counted as the loss of household income by an exogenous shock, namely a hazard. This loss of household income may be difficult to obtain the data, but, as discussed in the following section, the

[5] The ECLAC handbook (2003) indicates "direct damage refers to losses of assets and property. Essentially, it includes damage to, or the destruction of, housing, domestic furniture and equipment." (p. 65; Volume 1) On the other hand, the losses of housing sector are defined as: the cost of reconstruction-related demolition and debris removal; the cost of reducing the vulnerability of housing; the cost of purchasing land to relocate dwellings away from vulnerable places and to install basic services; and, temporary housing costs for the period. (p.71; Volume I) Even some assessment reports indicate "(s)ince the rental and formal sheltering sectors are small, the estimation of costs is considered negligible," (Government of Bangladesh, 2007; p. 91), and lists zero for the losses of housing sector. But this is a clear mistake to consider housing sector as real estate sector; housing sector is categorized under social sector (while some assessment reports categorize it under infrastructure sector), implying the human shelter or settlements, not a business.

effects of household income loss become significant in the impact estimate. In this paper, if the loss of housing sector is not listed, the damage data of housing sector is converted to household income loss based on the number of houses lost or damages, or on the number of affected population.

*3.2. Data for Models*

For the impact estimation for the cases above, Input-Output (IO) model or Social Accounting Matrix (SAM) model is employed, depending on the availability of models. It is ideal to employ the standardized modeling framework, sector aggregation, and so on and the model in the previous year of event's occurrence, for all the cases; however, it is difficult to obtain such models for the range of countries above for the detailed analysis. Hence, available models are used for the cases as shown below:

| Year | Disaster | Country | Model |
|---|---|---|---|
| 1998 | Hurricane Mitch | Honduras | 1997 IFPRI SAM[6] |
| | | Cost Rica | 1997 IFPRI SAM |
| 2000 | Floods and Cyclone | Mozambique | 2001 GTAP SAM[7] |
| 2001 | Gujarat Earthquake | India | 2001 GTAP SAM |
| 2001 | Earthquake | El Salvador | 2000 IFPRI SAM |
| 2004 | Floods | Bangladesh | 2001 GTAP SAM |
| 2005 | Hurricane Stan | El Salvador | 2000 IFPRI SAM |
| 2006 | Central Java Earthquake | Indonesia | 2001 GTAP SAM |
| 2007 | Cyclone Sidr | Bangladesh | 2001 GTAP SAM |
| Extreme Cases | | | |
| 1995 | Great Hanshin-Awaji (Kobe) Earthquake[8] | | |

[6] In collaboration with institutions throughout the world, International Food Policy Research Institute (IFPRI) provides a range of datasets, including SAM for several countries via their web page (http://www.ifpri.org/). The IFPRI SAMs use local currency, and the structure and sector aggregation schemes are slightly different for each country's SAM. Thus, IFPRI SAMs are converted in US$, and the sectors are so aggregated that among IFPRI SAMs the sectors are similar, but not identical.

[7] The Global Trade Analysis Project (GTAP; https://www.gtap.agecon.purdue.edu/) is coordinated by the Center for Global Trade Analysis, which is housed in the Department of Agricultural Economics at Purdue University. They also provide country SAMs based on corrected country IO tables and on their GTAP Model (a CGE model). Country IO tables received are based on different years, but they are converted to 2001 tables, since their GTAP model is for 2001. Thus, their country SAMs are also for 2001. The sectors in GTAP SAM are aggregated as much as possible to match with the data of damages and losses.

[8] For the 1995 Kobe Earthquake, the impact estimates draw on the study by Okuyama *et al.* (1999).

| | | |
|---|---|---|
| | Japan | 1985 MITI IRIO |
| 2004 Indian Ocean Earthquake and Tsunami[9] | | |
| | Indonesia | 2000 IDE AIO |
| | Thailand | 2000 IDE AIO |
| | India | 2001 GTAP SAM |
| | Sri Lanka | 2001 GTAP SAM |

As discussed in the previous section, these models, IO and SAM, are demand driven models so that the input to model should be changes in demand, and then changes in output will be derived. Therefore, losses (decreased output level) is converted to final demand change in each sector, using Miller and Blair's (1985) method—dividing the changes in output (output loss) by the diagonal term of the Leontief inverse matrix for IO model or of the accounting multiplier matrix for SAM model. Then, the derived changes in final demand model are multiplied with Leontief inverse matrix or accounting multiplier matrix to calculate impact by sector. Each model, either IO or SAM, yields the output impact (higher-order effects) and the impact on income generation (income impact) as results.

At the end of the analysis, the impact multiplier is calculated by dividing the total output impact (not including income impact) by total converted losses (sum of total output decease and total income decrease). While this is different from the standard output multiplier, where the changes in output are divided by the changes in final demand and usually income losses are converted to the changes in final demand, this impact multiplier aims to connect the calculated impact with the original loss data, and not to double-count between the impacts on output, which already take into account the income decrease and on income.

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The model used was the 1985 Interregional IO (IRIO) table of Japan, published by the Ministry of International Trade and Industry (now, Ministry of Economy, Trade and Industry (METI)). This table contains nine regions, and the regions are aggregated to two: Kinki, where the earthquake occurred; and Rest of Japan, including all other eight regions. The table is further modified to have the Miyazawa framework discussed above for the analysis of income generation and of interregional dependency.

[9] The 2004 Indian Ocean Earthquake and Tsunami was a multi-national incident, spreading the damages and losses to several countries. Thus, the 2000 Asian International IO (AIO) table, published by the Institute of Developing Economies (IDE), the Japan External Trade Organization (JETRO), is employed to cover the region and the surrounding regions. AIO includes eight countries and one region in Southeast and East Asia, and the United States. This AIO is also modified to the Miyazawa structure for more detailed analysis. India and Sri Lanka were also received damages from this event, but not include in AIO. Hence, 2001 GTAP SAM for each country is employed as separate analysis.

## 4. Case Studies

In this section, 10 cases of recent disasters around the world, including two extreme cases, are analyzed and the higher-order effects and total impacts are estimated. Based on the data and models described in the previous section, the estimation of higher-order effects is derived for each case, and at the end of this section, these cases are compared and discussed. It should be noted that positive demand injection of recovery and reconstruction activities, in-built counteractions, such as altruism, aid, economic resiliency, etc., and the effects of negative externalities discussed in the accompanying paper, "Critical Review of Methodologies on Disaster Impact Estimation", are not included for the estimated impact in this paper.

### *4.1. 1998 Hurricane Mitch*

Hurricane Mitch was one of the most violent meteorological hazards to have struck Central America in the 1990s. Its force upon reaching the coasts of the Mexican Gulf region was exceptional, as were its diameter, the amount of moisture and rain it carried and the erratic path it followed for several days (UN ECLAC, 1999). According to the Munich Re's NatCat Database, the total fatalities by this event were counted 9,976 and total economic losses were estimated around 5.5 billion US dollars (current), which mostly fell in Honduras and Nicaragua. Due to the data for damage assessment, however, the impact estimates of this event are carried out for Honduras and Costa Rica using the IFPRI 1997 SAM.

<u>Honduras</u>

Table 4-1 summarizes the damages, losses, and the impact estimates from the model. The total damages and losses were estimated to US$ 1,958 million and 1,789 million[10], respectively. The most significant damage in Honduras was to the agriculture sector, by the floods caused by the persistent rain and the overflowing of rivers that which

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[10] UN ECLAC (1999) states "lost output (US$1.8 billion) is equal to 33% of GDP, giving a clearer idea of the damage in the productive sectors. However, these losses will be felt over two years." (p. 69)

waterlogged fields and destroyed crops (reference, 'Hurricane Mitch Honduras 2.pdf'). The direct damages and losses to the agriculture sector were estimated US$ 1,226 and 805 million (current). The initial estimated losses were about 70% of all crops and shrimp harvests (ibid.). The second largest damages and losses were against transportation infrastructure, estimated damages and losses to be US$ 283 and 296 million, respectively. Most damages of the transportation infrastructure were against roads, especially to the national road system (main arterial roads) and particularly to concrete bridge structures. Housing was also significantly damaged, with the preliminary information indicating approximately 35,000 homes destroyed and 50,000 partly affected with damage ranging from 10% to 50% (ibid.). These figures were converted to the direct damages and losses, US$ 221 and 123 million, respectively. In terms of the extent to the losses (output constraints), the industry and commerce sectors have larger losses than their direct damages; the industry sector has US$ 361 million, while the direct damages were just US$ 16 million; and the commerce sector had US$ 135 million losses, whereas the direct damages were US$ 75 million.

These data of damages and losses are re-classified to the modeling sectors (for IFPRI sectors) as output losses, and are converted to demand decreases, as described in the previous section. The vector of demand decreases is multiplied with SAM multiplier matrix in order to derive the vector of total impacts (see Table 4-1 for results). The total impacts on output are estimated about US$ 3,554 million (68.3% of 1998 Honduras GDP), and this indicates the impact multiplier (equal to total impact on output divided by total output decrease or losses) of 1.99. The impact on income generation are estimated as US$ 1,376 million (33.7% of 1998 total household income), due to the output impacts and the income loss by housing damages (losses of income as input to the model is US$ 123 million). The most significant impact is on the agriculture sector, with US$ 1,254 million, followed by the manufacturing sector (883 million) and the services sector (640 million). While the services sector includes transportation service and health and education services, these sectors have large losses (especially in the transportation services, as mentioned above) and thus the services sector, as an aggregate of these industries, has a large impact. With these observations, the Honduras economy appears relatively less complex in terms of inter-industry relationships, and therefore the impacts appear not to spread across sectors much.

Table 4-1. 1998 Hurricane Mitch: Honduras

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 221 | 123 | Agriculture | 805 | 575 | 1,254 | |
| | Transport | 283 | 296 | Mining | 0 | 0 | 42 | |
| | Electricity | 10 | 19 | Manufacturing | 361 | 372 | 883 | |
| | Water and Sanitation | 51 | 7 | Utilities | 26 | 32 | 68 | |
| | Urban and Municipal | | | Construction | 0 | 0 | 35 | |
| | Water Resource | 25 | 0 | Commerce | 135 | 141 | 149 | |
| Social | Health and Nutrition | 26 | 37 | Services | 339 | 395 | 640 | |
| | Education | 27 | 6 | Governments | 0 | 0 | 77 | |
| Production | Agriculture | 1,226 | 805 | Others | 0 | 0 | 408 | |
| | Industry | 16 | 361 | HH Income decrease | 123 | | | 1,376 |
| | Commerce | 75 | 135 | | | | | |
| | Tourism | | | | | | | |
| Total | | 1,958 | 1,789 | | 1,789 | | 3,554 | 1,376 |

Costa Rica

Costa Rica's damages and losses were rather small, comparing to the Honduras', and the total damages and losses were US$ 54 and 37 million, respectively. And, most of the damages and losses were concentrated on transportation and agriculture (see Table 4-2). The damages of transportation, US$ 24 million, were mostly on roads and bridges, while the losses of transportation were not substantial, because traffic was only interrupted on a few sections and for very short periods (UN ECLAC, 1999). In 1997, agriculture accounted for 18 % of GDP and was the second most important sector in the country's economy (ibid.). The damages and losses on agriculture were estimated to US$ 26 million and 37 million, respectively.

These data are reclassified and converted to output decreases and then to demand decrease. The estimated impacts by modeling sector are shown in Table 4-2. The total impacts are US$ 77 million (0.55% of 1998 GDP), and this implies the impact multiplier of 2.07. The agriculture sector has the largest impact, US$ 37 million, as they have the largest losses across the sectors. The manufacturing sector does not have any damages and losses, but their impact becomes US$ 16 million (about 20% of total impact) through interindustry relationships in the economy. Meanwhile, the income losses are estimated to US$ 27 million (0.24% of total private income). Comparing to Honduras' case, Costa Rica's impacts were relatively small in volume, but were spread to a wider range of industries.

Table 4-2. 1998 Hurricane Mitch: Costa Rica

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 2.27 | 0.02 | Agriculture | 36.52 | 39.62 | 36.65 | |
| | Transport | 24.07 | 0.05 | Manufacturing | 0.00 | 0.00 | 16.34 | |
| | Electricity | 0.04 | 0.00 | Utilities | 0.16 | 0.18 | 7.11 | |
| | Water and Sanitation | 0.82 | 0.11 | Construction | 0.00 | 0.00 | 0.13 | |
| | Urban and Municipal | | | Commerce | 0.00 | 0.00 | 7.22 | |
| | Water Resource | | | Services | 0.62 | 0.48 | 9.60 | |
| Social | Health and Nutrition | 0.37 | 0.50 | Others | 0.00 | 0.00 | 0.13 | |
| | Education | 0.29 | 0.12 | | | | | |
| Production | Agriculture | 25.91 | 36.52 | | | | | |
| | Industry | | | HH Income decrease | 0.02 | | | 26.94 |
| | Commerce | | | | | | | |
| | Tourism | | | | | | | |
| Total | | 53.78 | 37.31 | | 37.31 | | 77.17 | 26.94 |

*4.2. 2000 Mozambique Floods and Cyclones*

During February 2000, two cyclones (Connie and Eline) brought massive rainfall to Mozambique, triggering extensive flooding. It was the first time in the recorded history that all three river-systems flooded at the same time in Mozambique. According to the preliminary assessment, 640 people have lost their lives due to the flooding and about two million people are experiencing severe economic difficulties, including 491,000 people who are either displaced or trapped in flood-isolated areas (World Bank, 2000).

The flood and cyclone damages affected substantial areas of agricultural production in southern and central Mozambique, resulting in the most significant damages and losses on the agriculture sector, around US$ 74 million and 70 million, respectively. Transportation infrastructure was also hit hard with damages and losses accounted for US$ 54 million and 41 million, respectively. Within this transportation infrastructure, greater than 80% of damages and more than 70% of losses were for roads, mostly primary and secondary roads, and the remaining was for rail system. The damages and losses are summarized in Table 4-3.

The impact estimates based on the above data show that the transportation and commerce sector has the largest impact of US$ 113 million, followed by the agriculture sector with US$ 88 million and the manufacturing sector (total of light manufacturing and heavy manufacturing) with US$ 74 million. These sectors with large impacts correspond to the sectors having large damages and losses, and the other sectors seem not receiving sizable spill-over impacts, indicating a simple structure of the Mozambique economy. The total impact is estimated to US$ 372 million (8.7% of 2000 GDP) and the impact multiplier is 1.73. Private household income losses are estimated to US$ 106 million (4.7% of total household income).

Table 4-3. 2000 Floods and Cyclone in Mozambique

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 29 | 0 | Agriculture | 70 | 57 | 88 | |
| | Transport | 54 | 41 | Mining | 0 | 0 | 8 | |
| | Electricity | 14 | 11 | Processed Food | 0 | 0 | 15 | |
| | Water and Sanitation | 13 | 0 | Light Manufacturing | 11 | 11 | 14 | |
| | Urban and Municipal | 5 | 0 | Heavy Manufacturing | 57 | 54 | 60 | |
| | Water Resource | 0 | 0 | Utilities and Construction | 11 | 10 | 42 | |
| Social | Health and Nutrition | 16 | 0 | Transp. & Comm. | 56 | 37 | 113 | |
| | Education | 19 | 0 | Services | 11 | 9 | 31 | |
| Production | Agriculture | 74 | 70 | Government Services | 0 | 0 | 1 | |
| | Industry | 26 | 68 | Others | 0 | 0 | 2 | |
| | Commerce | 16 | 15 | HH Income decrease | 0 | | | 106 |
| | Tourism | 2 | 11 | | | | | |
| Total | | 268 | 215 | | 215 | | 372 | 106 |

*4.3. 2001 Gujarat Earthquake, India*

The western and central Gujarat, India suffered a devastating earthquake in 2001, and the preliminary report indicated that the death toll was estimated over 20,000, and about 167,000 people were injured. Nearly one million homes were damaged or destroyed. Health and education infrastructure was severely damaged. There were similar destructions in both rural and urban water supply systems. Over 240 earthen dams for small reservoirs providing water for irrigation, rural and urban domestic needs, and industry were also damaged. In addition, other infrastructure services, like electricity and telecommunications, were extensively damaged (World Bank and Asian Development Bank, 2001).

The total damages were calculated around US$ 2 billion and the output losses were estimated between US$ 491 and 655 million[11] (ibid.). The severest damages were on housing with about US$ 1 billion of asset lost. Manufacturing (industry) and service sectors had direct damages to some extent and large output losses, due to the losses by disruption of their operations. These loss data are rearranged to the modeling sectors (GTAP sectors), and are converted as demand decreases. Then, the calculated total impacts are shown in Table 4-4. Agriculture, transportation and commerce, and services sectors have the largest effects, a little less than US$ 500 million, while these sectors have the large output losses, followed by light- and heavy-manufacturing sectors with more than US$ 300 million. While the areas affected by the earthquake were relatively poor and was not a major contributor to the state economy (p. 13, ibid.), the total impacts derived are for the national economy, spreading through production chains and trades within the country. The total impacts are estimated to be US$ 2,709 million (0.6 % of 2001 India GDP), and the impact on income generation is accounted as US$ 1,114 million (0.4% of total household income in India, 2001). The impact

[11] The World Bank and Asian Development Bank report (2001) employs two methods to estimate output losses: the one is an incremental capital-output ratio (ICOR) and the other is a 'bottom-up' method by industry. While the ICOR approach derived the loss estimates for social, infrastructure, and productive sectors with the total losses equal to US$ 491 million over three years, the bottom-up approach's estimates are for primary, secondary (industry), and tertiary (service) sectors deriving the total losses as US$ 655 million. With these two different aggregation schemes and without the detailed description of sectors in the report, the original data was combined and modified to include social and infrastructure sectors from the ICOR method and productive sector was replaced with the three sectors from the bottom-up approach. This may cause potential double counting of losses (and it may be the case since the total losses in this paper become about US$ 1,000 million, where the original estimation is raging from US$ 491 to 655 million. This paper's results should be seen as the worst case.

multiplier for this case becomes 2.71. Whereas there was little large-scale industry in the affected areas (p. 13, ibid.), this relatively higher impact multiplier indicates that economic interdependence of the affected areas might be connected closely with the other areas through consumption of goods and services so that the extensive damages to housing had led to the decline in the demand to the other areas and then to the production decreases, and so on.

Table 4-4. 2001 Gujarat Earthquake in India

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 1,111 | 223 | Agriculture | 49 | 29 | 494 | |
| | Transport | 101 | 25 | Mining | 0 | 0 | 66 | |
| | Electricity | 40 | 10 | Processed Food | 0 | 0 | 166 | |
| | Water and Sanitation | 50 | 13 | Light Manufacturing | 125 | 93 | 313 | |
| | Urban and Municipal | 103 | 26 | Heavy Manufacturing | 105 | 68 | 360 | |
| | Water Resource | 40 | 10 | Utilities and Construction | 59 | 49 | 193 | |
| Social | Health and Nutrition | 47 | 9 | Transp. & Comm. | 25 | 17 | 462 | |
| | Education | 144 | 29 | Services | 376 | 307 | 482 | |
| Production | Agriculture | 117 | 49 | Government Services | 38 | 36 | 85 | |
| | Industry | 73 | 230 | Others | 0 | 0 | 88 | |
| | Service | 250 | 376 | HH Income decrease | 223 | | | 1,114 |
| | Tourism | | | | | | | |
| Total | | 2,076 | 1,000 | | 1,000 | | 2,709 | 1,114 |

*4.4. 2001 El Salvador Earthquake*

The earthquake caused more than 280 landslides resulting in approximately 650 deaths; buildings were buried and a large number of urban and rural roads were blocked. As a result of the earthquake and its aftermath, numerous incidents of power outages and disruptions in the water supply were reported. According to the preliminary report (World Bank, 2001), the earthquake directly affected around 360,000 people; about 700 deaths were confirmed, along with 3,900 injured and over 68,000 left homeless. It was also estimated that over 63,000 homes were destroyed and 105,000 damaged by the earthquake.

According to the preliminary government estimates, the losses from the earthquake were on the order of US$ 1 billion, and this figure is nearly 50% of the country's general budget for 2001 (ibid.) In the mean time, more detailed quantitative assessment of the damages and losses were a bit vague in the preliminary report. For example, the damages to social sectors were described as 'nearly 19% of the country's school infrastructure' was damaged and 'approximately 39% of the country's hospitals have been destroyed' (p. 5, ibid.). The damages to housing are also indicated as 'the earthquake destroyed over 64,000 houses and partially damaged another 105,000' (p. 5, ibid.). On the other hand, a few other sectors have the monetary assessment: for agriculture sector, 'the Ministry of Agriculture has estimated that losses may become total US$ 11 million in the crops sector and US$ 9.5 million in the fisheries sector'; and 'a primary damage estimate for roadway infrastructure is US$ 100 million' (p. 4, ibid.). With these figures, the output losses are calculated via capita-to-output ratio for transportation and social sectors. And, the converted total output losses are US$ 708 million, including the household income loss[12] of US$ 229 million.

The output losses and the calculated impacts for modeling sectors are summarized in Table 4-5. The total impacts are estimated to be US$ 1,890 million (13.69% of GDP in 2001), and the impact multiplier is 2.67. The impacts are spread across sectors, and manufacturing sector has the largest impact of US$ 442 million, followed by governments sector with 385 million and Services 352 million. It should be noted that the governments sector has the output constraints of 385 million and the

[12] Household income losses are derived based on the number of houses destroyed or damaged noted above.

impacts are almost equivalent amount indicating less interactions with other sectors. The impact on income generation is estimated as US$ 1,334 million (9.4% of total household income in 2001). These results imply that, even though the damages and losses are concentrated on a few sectors (of course, the damages of housing cause a wide range of consumption decrease), the total impacts are spread across the sectors through the complexity of interindustry relationships.

Table 4-5. 2001 Earthquake in El Salvador

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | | | Agriculture | 21 | 22 | 167 | |
| | Transport | 100 | | Mining | 0 | 0 | 5 | |
| | Electricity | | | Manufacturing | 0 | 0 | 442 | |
| | Water and Sanitation | | | Utilities & Construction | 0 | 0 | 58 | |
| | Urban and Municipal | | | Commerce | 0 | 0 | 279 | |
| | Water Resource | | | Transp. & Comm. | 74 | 65 | 203 | |
| Social | Health and Nutrition | 39% | | Services | 0 | 0 | 352 | |
| | Education | 19% | | Governments | 385 | 384 | 385 | |
| Production | Agriculture | | 21 | Others | 0 | 0 | 0 | |
| | Industry | | | HH Income decrease | 229 | | | 1,334 |
| | Commerce | | | | | | | |
| | Tourism | | | | | | | |
| Total | | 100 | 21 | | 708 | | 1,890 | 1,334 |

*4.5. 2004 Floods in Bangladesh*

In April 2004, the northeast areas in Bangladesh suffered from flash floods that destroyed a substantial portion of rice fields. Furthermore, the main wave of monsoon flooding started in early July, eventually affecting 36 million people (almost a quarter of the total population) living in the northwest, northeast, and central areas, including Dhaka. The inundation caused nearly 800 deaths, affected 2 million acres of agricultural land, and damaged and destroyed infrastructure and social and educational facilities as well as private assets. Furthermore, in early September, while several areas were still experiencing an emergency situation, a localized monsoon depression swept over Bangladesh. This resulted in flooding in Dhaka and the southwest and central areas of the country (Asian Development Bank and World Bank, 2005).

The damages and losses were estimated as US$ 1,353 million and 927 million, respectively (ibid.). The direct damages were substantial in sectors, such as housing, transport infrastructure, and agriculture sectors. The output losses were mostly incurred by the productive sector (agriculture, industry, and commerce sectors) as well as transport sector. These data are then rearranged to modeling sectors and household income, and the total converted losses (output decrease and household income decrease) are set to be US$ 1,695 million, including 568 million of household income decrease[13] (see Table 4-6 for the details).

The calculated total impacts are US$ 4,650 million for output (8.2% of GDP in 2004) and 2,125 million for household income (4.8% of total household income in 2004). The most significant impact is realized at the transportation and commerce sector with US$ 1,279 million, followed by the agriculture sector with 1,007 million. Other sectors have relatively small impact. The impacts appear to spread across sectors to some extent, and this tendency is reflected as the relatively high impact multiplier of 2.74.

[13] The household income decrease is derived from the housing damage numbers. According to the damage assessment report (ibid.), "about 900,000 housing units were fully damaged and 3.4 million were partially damaged" (p. 12). Based on this figure, the number of affected population is calculated and multiplied by average income to derive the household income decrease.

Table 4-6. 2004 Floods in Bangladesh

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 466 | | Agriculture | 451 | 275 | 1,007 | |
| | Transport | 339 | 195 | Mining | 0 | 0 | 272 | |
| | Electricity | 27 | | Processed Food | 0 | 0 | 610 | |
| | Water and Sanitation | 39 | | Light Manufacturing | 72 | 46 | 356 | |
| | Urban and Municipal | 68 | | Heavy Manufacturing | 23 | 18 | 211 | |
| | Water Resource | 68 | | Utilities and Construction | 144 | 133 | 243 | |
| Social | Health and Nutrition | 7 | | Transp. & Comm. | 381 | 229 | 1,279 | |
| | Education | 71 | | Services | 0 | 0 | 322 | |
| Production | Agriculture | 200 | 451 | Government Services | 56 | 52 | 131 | |
| | Industry | 68 | 95 | Others | 0 | 0 | 217 | |
| | Commerce | 0 | 186 | HH Income decrease | 568 | | | 2,125 |
| | Tourism | | | | | | | |
| Total | | 1,353 | 927 | | 1,695 | | 4,650 | 2,125 |

*4.6. 2005 Hurricane Stan in El Salvador*

Hurricane Stan brought severe flooding and landslides to several Central American countries and southern Mexico. In particular, El Salvador and Guatemala were severely hit as they were not only struggling with the flooding and landslides but also with recent volcanic activity and earthquakes. In El Salvador – the combined emergencies of the eruption of the Santa Ana volcano on October 1 and flooding caused by Hurricane Stan resulted in 68 deaths and the sheltering of 26,000 people, according to the Government of El Salvador. Based on the report by the United Nations' World Food Program (WFP), as of November 11, the number of people in shelters as a result of the volcanic eruption and flooding or landslides caused by Hurricane Stan remained at a stable 12,000 (American Red Cross, 2005).

The preliminary damage assessment report (UN ECLAC, 2006) indicates that the total damages and losses were counted as US$ 175 million and 150 million[14], respectively. The most significant damages were on the transport infrastructure sector (US$ 96 million), but the losses were relatively minor (7 million). The housing sector had the largest losses with (77 million). The agriculture sector also had relatively large damages and losses (22 and 27 million, respectively), affecting private farmers; many of them are small and medium size farmers (ibid.).

The estimated total impacts are US$ 363 million (2.12% of 2005 GDP) for output and 287 million (1.64% of total household income) for income generation (see Table 4-7). The impact multiplier is 2.42. The impacts appear distributed across sectors: the manufacturing sector, with a very small losses (3 million), having the largest impact of 94 million, followed by the service sector with 70 million and the commerce sector with 69 million. This wide-spread of impacts resulted from the decrease of household income (77 million) thus causing the decrease of demand for final goods, as well as from the interindustry relationships.

[14] The ECLAC report (2006) estimated a positive impact for Electricity sector, since "(e)lectricity provision, given the increased water in reservoirs, may have a positive effect in the short run decreasing the need to import energy" (p. 12). However, in the analysis here, the positive effects are not included for the impact calculation.

Table 4-7. 2005 Hurricane Stan in El Salvador

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 36 | 77 | Agriculture | 27 | 29 | 53 | |
| | Transport | 96 | 7 | Mining | 0 | 0 | 1 | |
| | Electricity | 1 | ** | Manufacturing | 3 | 3 | 94 | |
| | Water and Sanitation | 8 | 3 | Utilities & Construction | 3 | 3 | 14 | |
| | Urban and Municipal | | | Commerce | 8 | 6 | 69 | |
| | Water Resource | | | Transp. & Comm. | 7 | 6 | 37 | |
| Social | Health and Nutrition | 7 | 12 | Services | 0 | 0 | 70 | |
| | Education | 5 | 12 | Governments | 24 | 24 | 25 | |
| Production | Agriculture | 22 | 27 | Others | 0 | 0 | 0 | |
| | Industry | 0 | 3 | HH Income decrease | 77 | | | 287 |
| | Commerce | 0 | 4 | | | | | |
| | Tourism | 0 | 4 | | | | | |
| Total | | 175 | 150 | | 150 | | 363 | 287 |

*4.7. 2006 Central Java Earthquake in Indonesia*

The earthquake, occurring in early morning, caused over 5,700 casualties. Injury estimates ranged from 37,000 to 50,000, and hundreds of thousands were rendered homeless (BAPPENAS *et al.*, 2006). Between 60 and 80% of the buildings in the affected area were damaged, including government buildings, schools, hospitals and railway stations (American Red Cross, 2006).

According to the preliminary assessment of damage and loss (ibid.), the damages and losses are estimated to be US$ 2,434 million and 676 million, respectively (see more details in Table 4-8). The damages are concentrated on the housing sector with 1,496 million (61% of the total damages). The social sectors (including health and education) and industry (manufacturing industries) also have the relatively large damages. On the other hand, in terms of losses, the industry sector accounts for 62% of the total losses (419 million out of 676 million), while the housing sector has 149 million losses. These assessment data are converted to output decrease in modeling sectors as shown in Table 4-8. The losses of the housing sector is converted as household income decrease.

The calculated total impacts are US$ 1,470 million (0.4% of 2006 GDP) for output and 521 million for income (0.3 % of total household income). It appears that the total impacts are spread across sectors: the most significant impact is for the manufacturing sector with 585 million (combining light- and heavy-manufacturing); transportation & commerce, processed food, and agriculture also have relatively large impact, around 160 million. The services sector follows these sectors with the impact of 132 million. While these distributed impacts suggest a large extent of higher-order effects, the impact multiplier is relatively small, 2.13. This may be caused by the relatively small magnitude of household income decrease (149 million), which may cause the decrease in final demand.

Table 4-8. 2006 Central Java Earthquake in Indonesia

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 1,496 | 149 | Agriculture | 69 | 54 | 161 | |
| | Transport | 10 | | Mining | 0 | 0 | 97 | |
| | Electricity | 24 | 16 | Processed Food | 0 | 0 | 168 | |
| | Water and Sanitation | 9 | 0 | Light Manufacturing | 253 | 190 | 318 | |
| | Urban and Municipal | 15 | | Heavy Manufacturing | 166 | 128 | 267 | |
| | Water Resource | | | Utilities and Construction | 24 | 22 | 74 | |
| Social | Health and Nutrition | 169 | 2 | Transp. & Comm. | 18 | 14 | 170 | |
| | Education | 239 | 6 | Services | 2 | 1 | 132 | |
| Production | Agriculture | 7 | 69 | Government Services | 8 | 8 | 23 | |
| | Industry | 437 | 419 | Others | 0 | 0 | 59 | |
| | Commerce | 20 | 13 | HH Income decrease | 149 | | | 521 |
| | Tourism | 9 | 2 | | | | | |
| Total | | 2,434 | 676 | | 689 | | 1,470 | 521 |

*4.8. 2009 Cyclone Sidr in Bangladesh*

The damages and losses from Cyclone Sidr were concentrated on the southwest coast of Bangladesh. Of the 2.3 million households affected to some degree by Cyclone Sidr, about one million were seriously affected. The number of deaths caused by Sidr is estimated at 3,406, and over 55,000 people sustained physical injuries. Most of the destruction and related social and economic losses resulted from the harsh storm conditions and the subsequent failure of an extensive embankment system. The cyclone was the second natural disaster to hit Bangladesh in twelve months. Monsoon floods had previously caused extensive agricultural production losses and destruction of physical assets, totaling near US$ 1.1 billion (Government of Bangladesh, 2008).

According to the preliminary assessment of damages and losses (ibid.), the damages were estimated at US$ 1,152 million and the losses were 517 million. The largest damages were accounted for the housing sector, while the losses of this particular sector was not included[15]. The largest losses were on the agriculture sector with 416 million. These data of damages and losses are converted to output decrease across modeling sectors and to household income decline, and the total decrease is 845 million (572 million for total output decrease and 273 million[16] for income decrease).

Based on the above converted data, the total impacts are calculated. The estimated total impact is US$ 2,332 million (3.4% of 2007 GDP) and the income impact is 1,045 million (2.0% of total household income) (see Table 4-9). The largest output impact falls on to the agriculture sector with 639 million (416 million of output decrease as input data), followed by the transportation & commerce sector with 561 million. A casual observation of impact distribution across sectors points out that the total imapcts are spread among sectors. And this observation reflects the relatively large value of impact multiplier, 2.76. Again, it seems that the sectors in the Bangladesh economy

[15] The assessment report (Government of Bangladesh, 2008) indicates "(s)ince the rental and formal sheltering sectors are small, the estimation of costs is considered negligible" (p. 91). However, this is a misleading classification of the losses in housing sector. Damages to houses create the income loss due to inability to work or sometimes to lost job, leading to the loss of household income, as discussed in the previous section.

[16] This income decrease was estimated based on the preliminary assessment report (ibid.). It indicates "(a)s many as nine million people were without shelter initially, and 3.5 million were without shelter over a significant period" (p. 18) and "about 2 million people have lost income and employment in the more affected districts" (p. xviii). These numbers are used to derive the affected population and then the decrease in total household income.

are interwoven and interdependent so that the impact, either positive or negative, can spread to the wide range of sectors via supply and demand chains.

Table 4-9. 2007 Cyclone Sidr in Bangladesh

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 839 | | Agriculture | 416 | 254 | 639 | |
| | Transport | 116 | 25 | Mining | 0 | 0 | 133 | |
| | Electricity | 8 | 5 | Processed Food | 0 | 0 | 304 | |
| | Water and Sanitation | 2 | 1 | Light Manufacturing | 22 | 14 | 161 | |
| | Urban and Municipal | 25 | | Heavy Manufacturing | 7 | 6 | 104 | |
| | Water Resource | 71 | | Utilities and Construction | 62 | 57 | 110 | |
| Social | Health and Nutrition | 2 | 15 | Transp. & Comm. | 43 | 26 | 561 | |
| | Education | 63 | 6 | Services | 1 | 1 | 157 | |
| Production | Agriculture | 21 | 416 | Government Services | 21 | 20 | 58 | |
| | Industry | 4 | 30 | Others | 0 | 0 | 105 | |
| | Commerce | 0 | 18 | HH Income decrease | 273 | | | 1,045 |
| | Tourism | 0 | 1 | | | | | |
| Total | | 1,152 | 517 | | 845 | | 2,332 | 1,045 |

*4.9. Extreme Case 1: 1995 Great Hanshin-Awaji (Kobe) Earthquake*[17]

On January 17, 1995, the worst disaster in postwar Japan struck the second largest region of Japan—the Kinki region. The City of Kobe and surrounding municipalities experienced massive destruction of houses, buildings, roads, rails, and infrastructure. The direct damages from the Great Hanshin Earthquake were estimated at about 10 trillion yen (US$ 100 billion) according to the Hyogo Prefecture Government, equivalent to about 2.1% of Japan's GDP and 11% of Kinki's GRP (Gross Regional Product). These direct damages were concentrated in the destruction of buildings (including houses and production facilities), transportation facilities, and utilities. Although the damaged area is geographically only 4% of Kinki, it includes 15% of Kinki's population. The damages to capital stocks were about 0.8% of Japan's total (Okuyama *et al*., 1999).

The initial damages on production activities by sector are estimated based on the various sources and preliminary indications (see the details and sources in Okuyama *et al.*, 1999). The damages and effects from the event are then classified into four categories according to their characteristics: a) direct input coefficient change, b) final demand change, c) consumption coefficient change, and d) value-added (wages and salaries) coefficient change. A direct input coefficient in IO table changes because some sector was damaged and cannot supply their goods to other sector. In this context, direct input coefficient is assumed to be a regional supply coefficient. The final demand decreases because the damages to some sector affect the demand on that sector, and the demand side will change the location of purchase. The consumption coefficient changes, because people in the damaged area might change their consumption habitat by postponing purchases. The value-added (wages and salaries) coefficient changes, because companies in some sector may lay off some or all of their workforce or may close as a result of the extensive damages in that sector. The damages losses are evaluated and classified into these four categories (see the details of assumptions and settings in Okuyama *et al*., 1999).

The total impacts on output are derived as shown in Table 4-10a. Kinki's output decreases more substantially than the rest of Japan's; however, the difference

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[17] This sub-section draws on Okuyama *et al.* (1999).

between the effects in Kinki and in the rest of Japan appears strikingly narrow, US$ 73 billion and 70 billion, respectively. Of course, the size of economy between Kinki and Rest of Japan are quite different, thus the direct comparison of these results is tricky. The largest impact is at the exports from Kinki to Rest of Japan, followed by the intra-regional transactions in Rest of Japan. These results imply that the impact can spill over substantially to other region(s) via domestic trade and interindustry relationships. Also, the negative externalities caused by the event may have extended to Rest of Japan for decreasing the final demand, and thus created further decline in outputs in both regions.

Table 4-10a. Changes in Gross Output

| | Region of Demand Origin | | (US$ million) |
|---|---|---|---|
| | Kinki | Rest of Japan | Total |
| Region of Production | | | |
| Kinki | -32,236 | -40,750 | -72,987 |
| Rest of Japan | -31,093 | -39,387 | -70,480 |
| Total | -63,329 | -80,138 | -143,467 |

Table 4-10b shows the impacts on income formation in Kinki and Rest of Japan. The striking result is that the decrease of income formation in Kinki originating in the rest of Japan has the largest negative impacts. Since the size of the economy in the rest of Japan is substantially larger than that in Kinki and about 83% of income in Japan is generated from the rest of Japan, this seems a reasonable result. Among the categorized influences, the effects from consumption decrease yield the largest negative effects on income formation. Again, the changes in consumption behavior appear to bring a large impact not only to the affected region but also to the other regions in the country.

Table 4-10b. Changes of Direct and Indirect Income-Formation

| | Region of Demand Origin | | (1995 US$ million) |
|---|---|---|---|
| | Kinki | Rest of Japan | Total |
| Region of Income Receipt | | | |
| Kinki | -9,362 | -11,688 | -21,050 |

| | | | |
|---|---|---|---|
| Rest of Japan | -7,387 | -9,371 | -16,758 |
| Total | -16,749 | -21,059 | -37,808 |

*4.10. Extreme Case 2: 2004 Indian Ocean Earthquake and Tsunami*

The December 2004 Indian Ocean disaster was caused by an earthquake, and the earthquake generated a tsunami, carrying many million tons of water in a series of very large waves that traversed the Indian Ocean in a matter of hours. These waves hit beaches, flooding low-lying lands coastal areas. The destruction was widespread: the most seriously affected areas were Banda Aceh, Indonesia, as well as in tourism resorts in Thailand, Sri Lanka, and the Maldives. Many small and medium sized rural villages located along the beachside in the five countries were also wiped out (ADPC, 2005).

According to the preliminary assessment of damages and losses (ibid.), total of 281,900 persons died as a result of the earthquake and tsunami; 189,500 persons were injured, physically and psychologically, and required immediate or medium term treatment; and, 1.2 million persons became homeless and even a year after the tsunami many were still housed in temporary camps, a sizable fraction of which still requires shelter, food and health services. The total economic effects of this event were estimated as US$ 5.6 billion of damages and 4.3 billion of losses over five countries—Indonesia, India, Sri Lanka, Maldives, and Thailand. In this subsection, the total impacts of this event are estimated and analyzed below for Indonesia and Thailand using the 2000 Asian International IO table, and India and Sri Lanka separately employing the 2001 GTAP SAMs.

<u>Indonesia</u>

The total damage and loss in Indonesia were estimated as US$ 2,664 million and 1,136 million, respectively (ibid.). The housing sector had the largest damage with 1,398 million (52% of total damage). The transport sector had the second largest damage, 409 million. The productive sector, especially agriculture and industry (manufacturing) sectors, also had some sizable damages. On the other hand, the losses were concentrated on these productive sectors, 550 million for agriculture and 280 million for industry, and together, they had about 73% of total loss. These data are converted to modeling sectors, as shown in Table 4-11.

The derived total impacts are US$ 2,386 million (0.93% of 2004 GDP) for output and 1,219 million for income. The most significant output impact falls on manufacturing with 814 million (with 280 million of output decrease as loss), followed by agriculture with 672 million. The sectors with large impact tend to be accompanied with large losses, while the other sectors with small or no losses, such as mining, utilities, and construction, have limited higher-order effects. This may lead to the relatively small impact multiplier of 2.10.

Table 4-11. 2004 Indian Ocean Earthquake and Tsunami: Indonesia

| Indonesia Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | Income impact |
| Infrastructure | Housing | 1,398 | 39 | Agriculture | 550 | 410 | 672 | |
| | Transport | 409 | 148 | Mining | 0 | 0 | 69 | |
| | Electricity | 68 | 0 | Manufacturing | 280 | 158 | 814 | |
| | Water and Sanitation | 27 | 3 | Utilities | 3 | 3 | 30 | |
| | Urban and Municipal | 132 | 89 | Construction | 0 | 0 | 20 | |
| | Water Resource | | | Trade and Transport | 148 | 113 | 370 | |
| Social | Health and Nutrition | 111 | 9 | Services | 116 | 80 | 412 | |
| | Education | 166 | 18 | HH Income decrease | 39 | | | 1,219 |
| Production | Agriculture | 186 | 550 | | | | | |
| | Industry | 167 | 280 | | | | | |
| | Service | | | | | | | |
| | Tourism | | | | | | | |
| Total | | 2,664 | 1,136 | | 1,136 | | 2,386 | 1,219 |

Thailand

The total damages and losses in Thailand were estimated to US$ 509 million and 1,690 million, respectively. The damages were concentrated on tourism with 376 million (74% of the total damage), resulted from the washed out resorts and hotels on the beaches. Other noticeable damages were on agriculture. The losses were also mostly on tourism with 1,470 million (87% of the total loss), and agriculture and industry had some losses around 100 million each.

The derived impact on output and income are US$ 3,205 million (1.99% of 2004 GDP) and 1,240 million, respectively. As seen in Table 4-12, the total impacts fall mostly on services (including tourism industry) with 1,535 million (48% of the total output impact). Meanwhile, manufacturing has a sizable impact of 872 million (27% of the total output impact), indicating that the Thailand's domestic industries are interwoven and interdependent to some extent so that the total impacts spread across the sectors. However, the calculated impact multiplier is 1.90, a relatively low value. This implies that while the tourism industry is one of the major industries in Thailand, the losses are concentrated on one industry (Tourism) and thus the total impacts are somehow limited and not widely spread to the entire economy.

Table 4-12. 2004 Indian Ocean Earthquake and Tsunami: Thailand

| Thailand Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | Income impact |
| Infrastructure | Housing | 22 | 0 | Agriculture | 102 | 89 | 228 | |
| | Transport | 7 | 9 | Mining | 0 | 0 | 33 | |
| | Electricity | 4 | 10 | Manufacturing | 93 | 58 | 872 | |
| | Water and Sanitation | 1 | 3 | Utilities | 13 | 10 | 132 | |
| | Urban and Municipal | 15 | | Construction | 0 | 0 | 3 | |
| | Water Resource | | | Trade and Transport | 9 | 7 | 401 | |
| Social | Health and Nutrition | 9 | 3 | Services | 1,473 | 946 | 1,535 | |
| | Education | | | HH Income decrease | 0 | | | 1,240 |
| Production | Agriculture | 75 | 102 | | | | | |
| | Industry | | 93 | | | | | |
| | Service | | | | | | | |
| | Tourism | 376 | 1,470 | | | | | |
| Total | | 509 | 1,690 | | 1,690 | | 3,205 | 1,240 |

International Analysis (including Indonesia and Thailand)

As seen above, the impacts of the event appear not so large within the two countries (0.93% of GDP in Indonesia and 1.99% of GDP in Thailand). With increased economic dependency between countries through international trades, this simultaneous damages and losses in multiple neighboring countries may bring the higher-order effects to other surrounding countries. As described in the previous section, the model used for this particular event (Asian International IO table) includes the above two countries and six other Asian countries and one region, and the United States so that the impacts to those countries can be estimated.

Table 4-13 indicates the impacts for these countries. Except those directly affected countries, Indonesia and Thailand, Japan has the largest total impacts (thus the largest higher-order effects, since there is not first-order losses in Japan) in this system, with US$ 428 million. The United States has the second largest total impacts of 306 million. China follows these two countries and has 156 million of the total impacts. Among the sectors, manufacturing has the most significant impact in total (2,307 million) and for each country in this system. This also is an evidence of tight interdependence among manufacturing firms through international trades. Comparing to the total impacts in Indonesia and Thailand and to their own GDPs, these impacts in the other countries can be considered as negligible. At the same time, for the system as a whole, the aggregated total impacts become 6,761 million with the impact multiplier of 2.39, and these numbers are noticeably larger than the total of the above two countries. For the multi-country disaster case such as this Indian Ocean Earthquake and Tsunami, this type of international analysis is crucial to capture the comprehensive picture of the impacts.

Table 4-13. 2004 Indian Ocean Earthquake and Tsunami: International

| | Sectors in model | *Indonesia* | *Thailand* | Malaysia | Philippines | Singapore | China | Taiwan | Korea | Japan | USA | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output Impact | Agriculture | *672* | *228* | 2 | 1 | 0 | 19 | 2 | 3 | 8 | 13 | 948 |
| | Mining | *69* | *33* | 5 | 0 | 0 | 7 | 0 | 0 | 1 | 4 | 118 |
| | Manufacturing | *814* | *872* | 36 | 7 | 33 | 96 | 42 | 59 | 230 | 120 | 2,307 |
| | Utilities | *30* | *132* | 1 | 1 | 1 | 6 | 1 | 2 | 11 | 7 | 192 |
| | Construction | *20* | *3* | 0 | 0 | 0 | 1 | 1 | 0 | 4 | 2 | 30 |
| | Trade and Transport | *370* | *401* | 5 | 2 | 7 | 14 | 9 | 7 | 64 | 47 | 926 |
| | Services | *412* | *1,535* | 9 | 2 | 9 | 14 | 15 | 19 | 110 | 114 | 2,239 |
| | Total | *2,386* | *3,205* | 58 | 14 | 50 | 156 | 69 | 90 | 428 | 306 | 6,761 |
| Income Impact | | *1,219* | *1,240* | 22 | 5 | 12 | 39 | 24 | 26 | 154 | 143 | 2,885 |

India

According to the preliminary assessment report (ADB *et al.*, 2005a), the total damages and losses were calculated as US$ 532 million and 448 million[18], respectively. The largest damages were on agriculture with US$ 245 million., followed by housing with 193 million. The losses were concentrated more on agriculture, with 361 million (81% of the total loss).

The derived total impacts and impact on income are US$ 1,011 million (0.1% of 2004 GDP) and 415 million (0.1% of total household income), respectively (see the details in Table 4-14). The largest total impact falls on the agriculture sector with 411 million (41% of the total output impact), and the rest of total impacts seems distributed across the sectors. The impact multiplier is 2.25.

[18] These estimated damages and losses are slightly different from the numbers compiled by ADPC (2005).

Table 4-14. 2004 Indian Ocean Earthquake and Tsunami: India

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 193 | 35 | Agriculture | 361 | 212 | 411 | |
| | Transport | 35 | 0 | Mining | 0 | 0 | 20 | |
| | Electricity | | | Processed Food | 0 | 0 | 64 | |
| | Water and Sanitation | | | Light Manufacturing | 0 | 0 | 66 | |
| | Urban and Municipal | 28 | 2 | Heavy Manufacturing | 0 | 0 | 88 | |
| | Water Resource | | | Utilities and Construction | 2 | 1 | 59 | |
| Social | Health and Nutrition | 11 | 13 | Transp. & Comm. | 0 | 0 | 156 | |
| | Education | | | Services | 38 | 31 | 84 | |
| Production | Agriculture | 245 | 361 | Government Services | 13 | 12 | 30 | |
| | Industry | | | Others | 0 | 0 | 33 | |
| | Service | 20 | 38 | HH Income decrease | 35 | | | 415 |
| | Tourism | | | | | | | |
| Total | | 532 | 448 | | 448 | | 1,011 | 415 |

Sri Lanka

Based on the preliminary report (ADB *et al.*, 2005b), the total damages and losses were estimated to US$ 977 million and 330 million[19], respectively. The largest damage was on the housing sector with 324 million, followed by the tourism sector with 250 million. Agriculture and some infrastructures (urban and municipal) also received the noticeable damages. The losses were on agriculture (200 million) and tourism (130 million). These data are converted to output decrease across the modeling sectors (502 million in total) and household income loss (91 million[20]).

The calculated impacts on output and income are US$ 1,093 million (5.3% of 2004 GDP) and 652 million (4.4% of total household income), respectively, as shown in Table 4-15. The largest total impact is on the agriculture sector with 343 million, while this particular sector has output decrease of 200 million as loss. The second largest impact falls on transportation & commerce with 202 million, followed by services with 153 million, whereas the services sector includes tourism that has the loss of 130 million. As in the Thailand case, tourism industry relies more on natural resources (beaches, etc.) than on hotels and restaurants, which require inputs from other sectors and thus can create impact on a wide range of other sectors, so that the damages and losses to this particular sector appear not to create a large multiplier effects. In fact, the impact multiplier is 1.85, a relatively low value.

19 These estimates are also different from the numbers in the ADPC report (2005).

20 The household income loss is estimated based on the damage estimate on Housing and the assessment report, indicating that the tsunami "destroyed around 99,480 homes and partially damaged about 44,290. (p. 16)"

Table 4-15. 2004 Indian Ocean Earthquake and Tsunami: Sri Lanka

| Sector | | Data | | Converted | | | Calculated | |
|---|---|---|---|---|---|---|---|---|
| | | Damages | Losses | Sectors in model | Output decrease | Demand decrease | Output impact | HH Income impact |
| Infrastructure | Housing | 324 | | Agriculture | 200 | 147 | 343 | |
| | Transport | 75 | | Mining | 0 | 0 | 37 | |
| | Electricity | 10 | | Processed Food | 0 | 0 | 77 | |
| | Water and Sanitation | 42 | | Light Manufacturing | 0 | 0 | 36 | |
| | Urban and Municipal | 90 | | Heavy Manufacturing | 0 | 0 | 64 | |
| | Water Resource | | | Utilities and Construction | 29 | 28 | 69 | |
| Social | Health and Nutrition | 60 | | Transp. & Comm. | 42 | 33 | 202 | |
| | Education | 26 | | Services | 130 | 123 | 153 | |
| Production | Agriculture | 100 | 200 | Government Services | 99 | 99 | 100 | |
| | Industry | | | Others | 0 | 0 | 12 | |
| | Service | | | HH Income decrease | 91 | | | 652 |
| | Tourism | 250 | 130 | | | | | |
| Total | | 977 | 330 | | 593 | | 1,093 | 652 |

## 5. Comparison of Cases

Table 5-1 summarized the above case studies for comparison. The values of damage, loss, total impact are converted to 2007 US$ million (upper row; lower row indicates the current value). In terms of impact multiplier that may indicate the extent of disaster impact, there are no particular tendencies found between types of disaster—either meteorological or geological, or among regions. Each disaster is unique in terms of the extent and significance of damages and losses, as well as the total impacts.

Some countries have the similar multipliers for different disasters over time: for example, Bangladesh has the impact multiplier of 2.74 for 2004 Floods and 2.76 for 2007 Cyclone Sidr, while the distributions of damage, loss, and total impact across sectors are somewhat different; Indonesia has 2.13 for 2006 Central Java Earthquake and 2.10 for 2004 Earthquake and Tsunami, even though these multipliers are derived using different methodologies (2001 GTAP SAM and 2000 AIO, respectively) and the distributions of damage, loss, and total impact are different between them. El Salvador has slightly different size of impact multipliers: 2.67 for 2001 Earthquake (a geological event) and 2.42 for 2005 Hurricane Stan (a meteorological event), based on the same 2000 IFPRI SAM. This may imply that different types of disaster lead to different size of impact multiplier, due to different ranges of damages and losses; however, more observations should be required to test this hypothesis. India shows a wide difference between impact multipliers in two different cases: 2.71 for 2001 Gujarat Earthquake and 2.25 for 2004 Earthquake and Tsunami. Since India is quite a large and diverse country geographically and economically, the fact that these events occurred in different parts of the country might explain the difference between the two impact multipliers.

# Table 5-1. Summary of Case Studies

| Disaster Name | Country | Year of Disaster | Disaster Type | Country Type | Region | Total Economic Damages / Losses (2007 US$ million *[current US$ million]*) | | Total Impact (2007 US$ million [*current US$ million*]) | Impact Multiplier (Higher-Order Impact / Losses) | Model Used |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Damages | Losses | | | |
| Hurricane Mitch | Honduras | 1998 | Meteorological | Developing Countries | Caribbean | 2,491<br>*1,958* | 2,275<br>*1,789* | 4,521<br>*3,554* | 1.99 | IFPRI 1997 SAM |
| | Costa Rica | | | | | 68<br>*54* | 47<br>*37* | 98<br>*77* | 2.07 | |
| 2000 Floods and Cyclone | Mozambique | 2000 | Meteorological | Developing Country | Africa | 322<br>*268* | 259<br>*215* | 448<br>*372* | 1.73 | GTAP 2001 SAM |
| Gujarat Earthquake | India | 2001 | Geological | Developing Country | Asia | 2,431<br>*2,076* | 1,171<br>*1,000* | 3,173<br>*2,709* | 2.71 | GTAP 2001 SAM |
| 2001 Earthquake | El Salvador | 2001 | Geological | Developing Country | Caribbean | 117<br>*100* | 829<br>*708* | 2,214<br>*1,890* | 2.67 | IFPRI 2000 SAM |
| 2004 Floods | Bangladesh | 2004 | Meteorological | Developing Country | Asia | 1,485<br>*1,353* | 1,860<br>*1,695* | 5,104<br>*4,650* | 2.74 | GTAP 2001 SAM |
| Hurricane Stan | El Salvador | 2005 | Meteorological | Developing Country | Caribbean | 186<br>*175* | 159<br>*150* | 385<br>*363* | 2.42 | IFPRI 2000 SAM |
| Central Java Earthquake | Indonesia | 2006 | Geological | Developing Country | Asia | 2,503<br>*2,434* | 709<br>*689* | 1,512<br>*1,470* | 2.13 | GTAP 2001 SAM |
| Cyclone Sidr | Bangladesh | 2007 | Metorological | Developing Country | Asia | 1,152<br>*1,152* | 845<br>*845* | 2,332<br>*2,332* | 2.76 | GTAP 2001 SAM |
| **Extreme Cases** | | | | | | | | | | |
| Great Hanshin-Awaji Earthquake | Japan | 1995 | Geological | Developed Country | Asia | 136,068<br>*100,000* | 92,683<br>*68,115* | 195,213<br>*143,467* | 2.11 | MITI 1985 Intereregional IO Table |
| Indian Ocean Earthquake and Tsunami | Overall | 2004 | Geological | Developing Countries | Asia | 5,139<br>*4,682* | 4,244<br>*3,867* | 9,730<br>*8,865* | 2.29 | |
| | Indonesia | | | | | 2,924<br>*2,664* | 1,247<br>*1,136* | 2,619<br>*2,386* | 2.10 | IDE 2000 AIO (International Analysis) |
| | Thailand | | | | | 559<br>*509* | 1,855<br>*1,690* | 3,518<br>*3,205* | 1.90 | |
| | India | | | | | 584<br>*532* | 492<br>*448* | 1,110<br>*1,011* | 2.25 | GTAP 2001 SAM |
| | Sri Lanka | | | | | 1,072<br>*977* | 650<br>*593* | 1,200<br>*1,093* | 1.85 | GTAP 2001 SAM |

Figures 5-1 and 5-2[21] show the comparison among damage, loss, and total impact for case studies. It appears in Figure 5-1 that there is a tendency that total impact is the largest among them, except the 2006 Central Java Earthquake, in which most of the damages were in the housing sector (61% of the total damages) and the losses were comparatively small, implying therefore the higher-order effects were limited. On the other hand, it is also clear that there are no particular relationships among damage, loss, and total impact, indicating the necessity to employ some methodology to estimate total impact. Figure 5-2 shows the comparison of damage, loss, and total impact in the case of the 2004 Indian Ocean Earthquake and Tsunami. The comparison of impacts between Indonesia and Thailand illustrates why these three estimates need to be analyzed all together. Indonesia, near the epicenter, had extensive physical destructions on housing and infrastructure as damages, but the relatively small losses on productive activities. On the other hand, Thailand was struck by a series of tsunami and had sizable damages (but smaller than in Indonesia), and had much larger losses through the damages on tourism sector; thus, the larger total impacts are estimated.

It should be noted that those cases with estimated income loss (rather than the cases with the loss data for Housing in the original data) have relatively high impact multipliers: 2001 Gujarat Earthquake with 2.71; 2001 Earthquake in El Salvador with 2.67; 2004 Flood in Bangladesh with 2.76; and 2007 Cyclone Sidr in Bangladesh with 2.76; except 2004 Earthquake and Tsunami in Sri Lanka with 1.85. This might indicate the impact estimate is very sensitive to household income declines, which in turn becomes the overall demand (consumption of final goods) decrease. As indicated in the previous section, the losses of housing should not only be the losses of the real estate sector; but also, it should be the loss of household income due to destroyed or damaged houses and thus unable to go to work. However, it must be careful how to count household income loss due to housing damages, since it may create a double counting issue between income loss by labor side (damage of housing) or employer side (damage of work place)—oftentimes, in the disaster areas, damage of housing and

[21] The case of the 1995 Great Hanshin-Awaji (Kobe) Earthquake is not included in these figures, since the damages, losses, and higher-order effects of the Kobe Earthquake are exceptionally larger than any other cases.

damage of work place occur simultaneously. Nevertheless, it appears that, because of the importance of household income, the assessment of damages and losses needs to include a more appropriate methodology for evaluating household income loss.

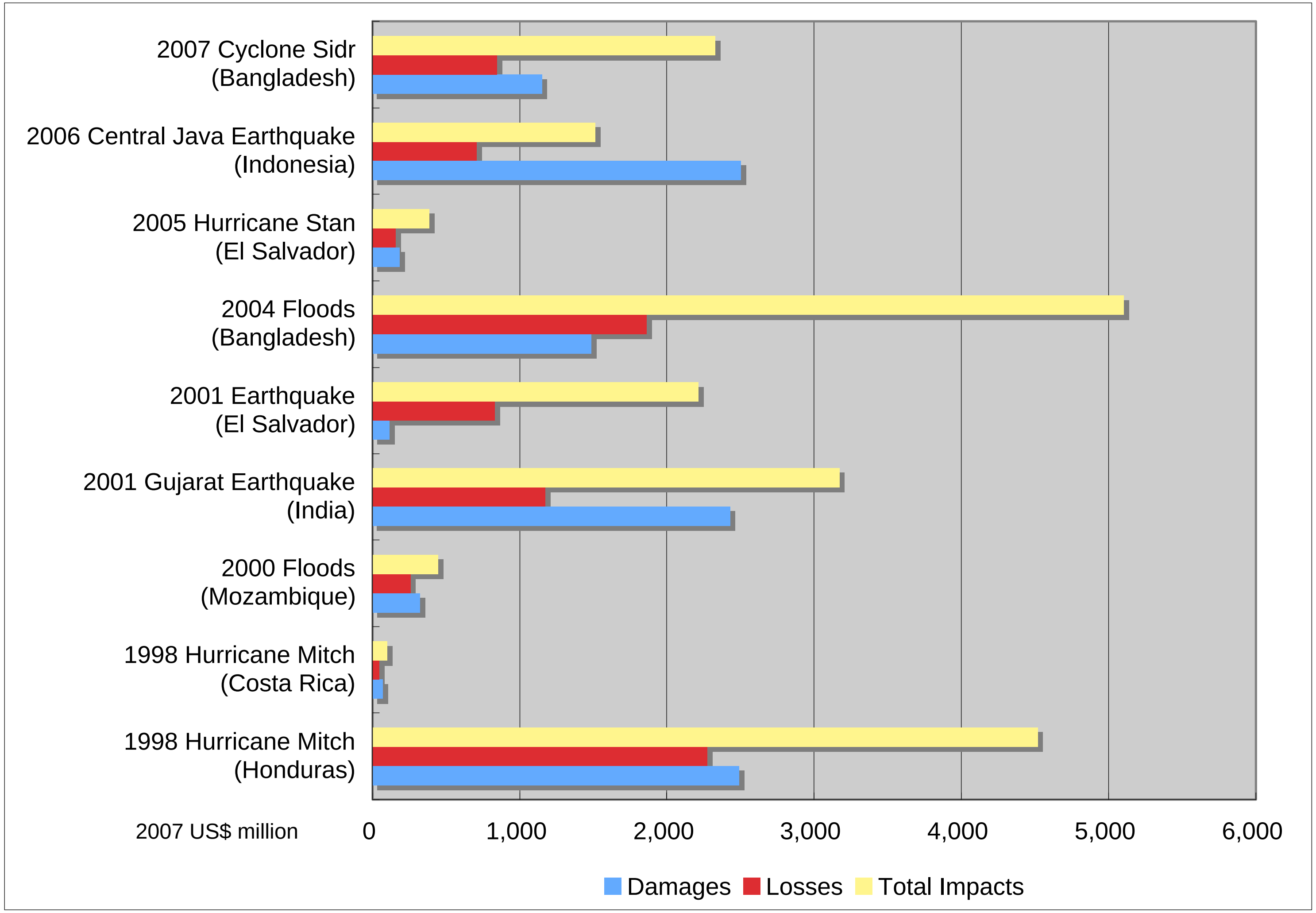


Figure 5-1. Comparison of Cases

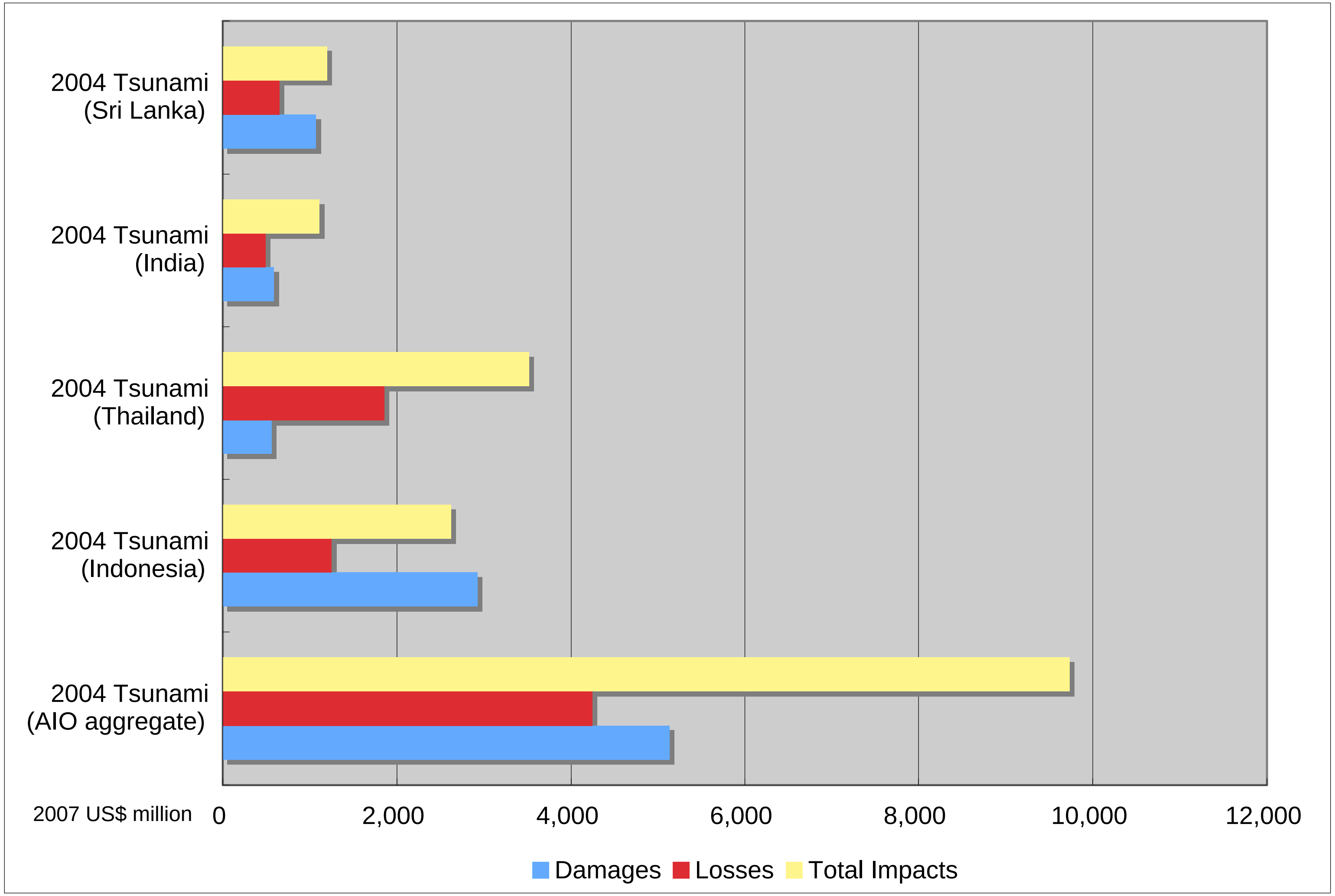


Figure 5-2. Comparison of Impacts in 2004 Indian Ocean Earthquake and Tsunami

## 6. Summary and Conclusions

In this paper, the total impacts of ten recent disaster cases are estimated using IO and SAM methodologies. The results show that the higher-order effects and total impacts of disasters are significant and complex. The estimated impact multipliers are mostly around 2, and in some cases, bordering 3, implying that losses of a disaster can be doubled, or sometimes tripled, via ripple effects through interdependencies within an economy. These results therefore indicate the importance of appropriately evaluating and accounting for higher-order effects. We also find, perhaps surprisingly, there are no particular trends or correlations found among damages, losses, and total impacts between the types of disaster and the intensity of disasters. Furthermore, analysis of the sectoral distribution of total impacts reveals that the manufacturing and services sectors suffer from larger higher-order effects than do other sectors, such as agriculture and mining. Since these two sectors rely more on interindustry relationships domestically and/or internationally and are located in the middle and at the end of production chains, respectively, the damages and losses on the other sectors propagate to these two sectors, resulting in larger higher-order effects. However, the intensity of interindustry relationships, or interdependencies, in economy varies significantly, as do the impact multipliers.

Some researchers claim that the short-term impact of disasters are negligible since the positive impact of relief, recovery, and reconstruction activities starts immediately after the occurrence of hazards and the counteraction measures that a society inherently has against such a calamity would respond to reduce the higher-order effects (Albala-Bertrand, 1993 and 2008). This may be true, if the negative impact of higher-order effects and the positive impact of relief and reconstruction are added up to show the total impact; in the empirical disaster studies reviewed in the accompanying paper, “Critical Review of Methodologies on Disaster Impact Estimation”, the total impacts are indeed sometimes negligible, offsetting negative and positive impacts, or even positive in some cases. However, these results do not lead to the conclusion that disasters have no impact on the economy. A thorough investigation of disaster impacts requires a detailed analysis, which separates negative and positive impacts, and not merely adding them up, in order to assess how negative and positive impacts interact each other and affect different segments of society differently. Negative impacts of higher-order effects surely exist as seen in this paper, and their proper recognition and estimation can enable policy makers to contemplate how ex-ante loss reduction measures can be formed effectively and efficiently.

As indicated in the accompanying paper, "Critical Review of Methodologies on Disaster Impact Estimation", disaster impacts are methodologically difficult to assess, because of their spatially uneven effects; behavioral changes due to extreme circumstances; and negative externalities. These issues have been tackled and dealt with the extensions and/or modifications of conventional methodologies. The wide availability of national IO and SAM data, the standardized damage and loss assessment, and the significance of the estimated results point out that these methodologies can, indeed, be practically employed in the disaster community for policy related discussions. In addition, IO and SAM have a long tradition of impact analysis with a wide variety of analytical techniques that have been devised and applied. These techniques can be employed to investigate the impact of disasters in a great detail and from many different aspects. In addition, the analysis of distributional impacts of a disaster can be investigated with extended IO (such as the Miyazawa framework used in this paper) and SAM, and can be further extended to include inter-income group analysis. However, as West and Lenz (1994) cautioned, the more sophisticated and/or detailed the methodologies become, the more precise input data are required.

The data for damages and losses used as input for estimation are based on the ECLAC methodology (UN ECLAC, 2003). This methodology standardizes the assessment of damages and losses of a disaster, and this standardization not only enables inter-disaster comparison but also encourages the discussion of mitigation, preparedness against disasters, and vulnerability analysis of economies based on the common framework. An important next step would be to make the estimation methodology of higher-order effects a part of a standardized methodology – such as the ECLAC methodology – evaluating a more accurate measure of disaster impacts.

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