**Regional Macroeconomic loss Estimation of Earthquake: An Integrated Methodology – A Case Study of Tehran**

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**ABSTRACT**

 *The quantification of economic losses due to natural disasters such as earthquakes is one of the most important components of the mainstream of development theory which has been fallen outside in the most development studies. It is also necessary 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. In general, it can be stated that society has become more vulnerable. Natural disasters reveal the fact that our economic development is unacceptably brittle, too vulnerable to the normal behavior of Nature. Part of a reason for a lack of progress has been the complex manner of the interactions between physical damages and the regional economy. In many cases, this involves engineering as well as economic analysis. In this paper an integrated, operational methodology which allows a more holistic accounting for the macroeconomic impacts of earthquake considering physical damage, the dynamics of recovery, sectoral vulnerability of first-order losses, and higher-order effects which take into account the system-wide impact of flow losses through interindustry relationships is developed. In order to estimate probable future losses in an earthquake-prone region by developed methodology a case study of Tehran is considered and the findings show that future losses, caused by a severe earthquake will exceed the total damage up to 21 percent reduction in GDP. Finally, the importance of not perceiving of hazard loss estimation as a passive pursuit and major objective of actively reducing negative impacts is emphasized and a number of relatively costless mechanisms for doing so are introduced.*

***Keywords****: Disaster losses, Economic loss, equilibrium-oriented macroeconomic models*

**1. Introduction**

Unscheduled events, especially earthquakes, make dramatic changes in infrastructure and regional economic capacity and can have significant and intense impacts on a nation’s economy by disrupt or destroy many different kinds of functions and institutions all at once. Population growth, modern economic developments, real-time communication, and complex interdependency among various economic sectors have sharpened those impacts. Moreover, earthquakes can leave long-term impacts on the affected area. For example, the permanent change(s) in business/economic pattern, the residence migration out of the area, real estate value of the area, etc.

Certainly, earthquakes of different magnitudes and intensities will have differential effects, as will seismic events that take place in different types of geologic areas. Beside these geophysical conditions, however, it must be noted that the types of socio-economic and policy contexts in place in the communities which are struck by a major earthquake will also have an effect on the types of impacts that are sustained. These differential impacts may be related to:

* The extent to which production is localized or dispersed nationally.
* Vulnerability of infrastructure and services.
* The extent to which a major market is disrupted.
* Existence of appropriate and integrated seismic risk management system.
* The types of building stock in existence.
* Planning and development with respect to seismic hazard.
* The stage of the city’s life cycle (whether it is old and aging or new and robust).

A sudden-onset disaster, such as a serious earthquake, has a direct and immediate effect on the productive capital, including infrastructure, and may effectively destroy the means of production as well as stocks. These losses include not only the cost of repairing or replacing damaged buildings and infrastructure, but also costs associated with damaged contents, damaged inventory, removing debris, renting alternative space, moving to new locations and lost revenues resulting from business interruption. Then there is a long-run effect that follows the event as the expectations for future productivity of the region change. In addition there are social losses that cannot be directly measured in terms of monetary amounts, but instead can be quantified in terms of injuries, deaths, and the need for emergency shelter.

Although there is an increasing awareness of the impact of disasters on society, the existing literature on the cost of earthquakes is largely restricted to measurement of structure and contents losses and estimating the economic impacts of damages and losses in the aftermath of such events is challenging.

A wide range of economic models such as Input-Output, Social Accounting, Computable General Equilibrium and Econometric has been employed to evaluate the economic impacts of disasters. These equilibrium-oriented models are valuable guides for the measurement of disaster economic losses. The indirect loss module of HAZUS, a landmark disaster loss model developed in the late 1990s by the U.S Federal Emergency Management Agency (FEMA), is based on the same foundation as the input-output model and addresses both supply and demand shocks. It suggests that there may not be a simple relationship between different types of earthquake losses. Much depends upon the pattern of damage, which sectors sustain the greatest disruption and their relative importance in the economy, preexisting economic conditions and the amount of outside assistance received. Okuyama *et al.* highlighted the spatial and temporal distributions of the economic impacts of a disaster and overcame some of the drawbacks of the I-O model by utilizing an interregional I-O table within the Sequential Interindustry Model (SIM) framework. Building on the Social Accounting Matrix (SAM) framework; Cole developed an insurance accounting matrix to assess the ways that disasters affect social agents and propagate through the economy. Yamano *et al.* examined the economic impacts of natural disasters by integrating district level economic data and Japanese interregional input-output model. Their numerical example of Hyogo prefecture showed that the indirect economic loss was much greater than the direct output loss in most districts. Kundak used damage ratios of the most probable and the worst-case earthquake scenarios to find out economic effects of probable earthquake in Istanbul. Despite his loss estimation model did not include monetary losses in lifeline systems, centers of administration, emergency services and historical assets, his findings showed that future losses, caused by a severe earthquake in Marmara Sea, would exceed the total damage cost of Kocaeli earthquake in 1999. Rose and Guha presented one of the few attempts to implement a CGE for an actual regional economy. Their case study of Memphis, Tennessee simulation results revealed that in contrast to static I-O models, CGE models tend to exaggerate an economy’s flexibility and resiliency results in understate economic losses unless properly adjusted.

The major challenge which is obvious in earthquake economic loss estimation procedure is how to link different types of earthquake effects to each other and integrate them with these various macroeconomic models.

In this paper we developed an integrated, operational framework for evaluating the effects of earthquake on the economy. Specifically, we integrate first-order effects, higher-order effects, dynamics of recovery, and interindustry (input-output) models in order to achieve more holistic accounting for the macroeconomic impacts of earthquake. Studying Tehran as an earthquake-prone area by developed model results in considerable findings shows an urgent necessity to prepare an integrated seismic risk management system in order to mitigate possible devastating earthquake damages in Tehran.

**2. Theoretical Background: Definitions and Methodologies**

2.1. Categorization of Earthquake Induced Effects

Because of information scarcity and the lack of a universally accepted methodology for disaster impact, the distinction between different types of earthquake effects has been the subject of great confusion from the outset. The most important variables which are used to characterize earthquake induced effects are time dimension and stocks versus flows. By economics’ definition stocks refer to a quantity at a single point in time, whereas flows refer to the services or outputs of stocks over time.

The most preliminary effect of natural disasters is physical destruction to built-environment and networks, such as transportation and lifelines, and also casualties and injuries to human lives which are often called *damages* and by economists’ definition are the damages on stocks, which include physical and human capitals. The “consequences” of these damages called *first-order* losses which are interruptions of economic activities, such as production and/or consumption, and the losses from business interruptions. They also include lost production stemming from direct loss of public utility and infrastructure services. At the same time the extent of business interruption sets off a chain reaction resulted in *higher-order* effects which are all flow losses beyond those associated with the curtailment of output as a result of hazard-induced property damage in the producing facility itself. This system-wide impact of flow losses through interindustry relationships has great importance, especially if one considers its likely size. Higher-order losses measurement remains a major challenge for many hazard researchers because of various reasons. First, they cannot be as readily verified as direct losses. Second, modeling them requires utilizing simple economic models carefully, or, more recently, utilizing quite sophisticated economic models. Third, the size of higher-order effects can be quite variable depending on the resiliency of the economy and the pace of recovery. Fourth is the danger of manipulating these effects for political purposes.

2.2. Comprehensive Methodologies on Disaster Impact Estimation

There are several economic modeling frameworks which have been employed to estimate the effects of a disaster. It is generally considered that the sounder the data, the more reliable the results. These models are used both to evaluate losses after they have taken place and to predict potential losses. In general, approaches based on primary data are more applicable to direct loss estimation, and other methods more applicable to higher-order loss estimation. Flow analysis models estimating the higher-order impacts of a disaster, which are the effects on flows made most of hazard loss estimation methodologies. Flow measures are superior to stock measures and because of this reason flow analysis models are more popular in estimating disaster impacts. Flow measure is performance measure which can measure the impacts (business interruptions) without stock damages whereas stock measure involves the life-cycle assessment of capital with depreciation. It is also more consistent with other conventional macroeconomic indices, such as GDP or GRP and shows the short-run impact of a disaster, which is oftentimes convenient for policy discussions against disasters.

2.2.1. Input-Output Models

Input-output analysis was first formulated by Nobel laureate Wassily Leontief in the late 1920s and early 1930s and has gone through several decades of refinement by Leontief and many other economists. It is the most widely used tool of regional economic impact analysis which is utilized to assess the total (direct plus higher-order) economic gains and losses caused by sudden changes for a region’s products. At its core is a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. Input-output (I-O) modeling traces the flows of goods and services among industries and from industries to household, governments, investment, and exports. These trade flows indicate how much of each industry’s output is comprised of its regional suppliers’ products, as well as inputs of labor, capital, imported goods, and the services of government. The resultant matrix can be manipulated in several ways to reveal the economy’s interconnectedness, not only in the obvious manner of direct transactions but also in terms of dependencies several steps removed. Its focus on production interdependencies makes it especially well suited to examining how damage in some sectors can ripple throughout the economy.

As an example for a simple four industry economy, the shipments are presented as annual flows in table1.

Table 1- Intersectoral monetary flows of a simple four industry economy

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  To (j)From (i)  | 1 | 2 | 3 | 4 | FinalDemand | GrossOutput |
| 1 | X11 | X12 | X13 | X14 | Y1 | X1 |
| 2 | X21 | X22 | X23 | X24 | Y2 | X2 |
| 3 | X31 | X32 | X33 | X34 | Y3 | X3 |
| 4 | X41 | X42 | X43 | X44 | Y4 | X4 |
| V | V1 | V2 | V3 | V4 |  |  |
| M | M1 | M2 | M3 | M4 |  |  |
| Gross Outlay | X1 | X2 | X3 | X4 | Y | X |

Xij: The monetary value of the good or service shipped from the industry i to the industry j.

Yi: Shipments to consumers, businesses, government, other regions.

Vj: The values-added in each sector, representing payments to labor, capital, natural resources, and government.

Mj: Imports to each producing sector from other regions.

Total output of any good is sold as an intermediate input to all sectors and as final goods and services:

$X\_{i}= \sum\_{j=1}^{4}X \_{ij}+ Y\_{i}$ 1

Technical coefficients that comprise the structural I-O matrix are derived by dividing each input value by its corresponding total output.

$a\_{ij}= \frac{X\_{ij}}{X\_{j}} $ 2

$a\_{ij}: $The percent of industry j’s total output which is comprised of product i.

Rearranging terms, equation 1 can then be written as:

$X\_{i}= \sum\_{j=1}^{4}a\_{ij}X\_{j} + Y\_{i}$ 3

In matrix form equation 3 will be written as follows:

$X=AX+Y$ 4

Therefore, the gross output of each sector regarding to a set of final demand requirements is:

$(I-A)^{-1}Y=X$ 5

The amount each sector’s output must increase as a result of an additional unit of final goods and services demands of a sector is indicated by $(I-A)^{-1}$ which is known as the Leontief Inverse Matrix. Consequently, the column sums of the Leontief Inverse Matrix are sectoral multipliers specifying the total gross output of the economy directly and indirectly stimulated by a one unit change in final demand for each sector.

The very nature of the basic I-O model lays it open to some criticisms such as linearity, insensitivity to price changes, technological improvements, and lack of input and import substitution possibilities, lack of explicit resource constraints, rigid coefficients, lack of behavioral content and overestimation of impact.In fact, the simplicity of I-O is sometimes misleading, and many of the inaccuracies associated with it are due to the inability to use it correctly, rather than the shortcoming of the model itself. However, even with these limitations, I-O techniques are a valuable guide for the measurement of some indirect losses.

2.2.2. Social Accounting Matrices

Empirically, a social accounting matrix (SAM) is a large table showing the annual transactions (income and expenditures) of economic actors in a society. SAMs are an extension of the earlier input output models and provide a consolidated quantitative representation of the flows and distribution of goods between businesses, households and public service, and regions, or even between neighboring micro-economies.

A SAM is an especially useful way of representing the transactions in a region, before, during, and after a major disruption. During a period of disaster, some of the flows in the economic network described by the model are interrupted, with ramifications throughout the economy. Even when they are not impacted directly, people and businesses may be affected indirectly through damage to lifelines such as water supply or roads, or through the loss of livelihood or markets. Calculations with a SAM allow the consequences of this damage for all types of participant in an area’s economy, whether directly impacted or not, to be estimated. Moreover, because the SAM may incorporate a range of social, economic, and environmental variables, it is possible to provide more substantive indicators of the impacts on target populations and industries, such as changes in levels of output or household income.

Because of SAMs extension of the earlier input output models most of their strengths and weaknesses are the same, while SAM has been used more for development studies and also requires more data.

2.2.3. Computable General Equilibrium Models

CGE is a multi-market simulation model based on the simultaneous optimizing behavior of individual consumers and firms in response to price signals, subject to economic account balances and resource constraints. This approach is not so much a replacement for I-O as a mature cousin or extension, and it retains many of the latter’s advantages and overcomes most of its disadvantages. For example, CGE retains the multi-sector characteristics and emphasis on interdependence, but also incorporates input/import substitution, increasing or decreasing-returns-to-scale, behavioral content (in response to prices and changes in taste or preferences), working of markets (both factor and product) and non-infinite supply elasticities (including explicit resource constraints). Moreover, the empirical core of most CGE models is an I-O table extended to include disaggregated institutional accounts, *i.e.*, a social accounting matrix (SAM).

On the other hand, CGE models are too flexible to handle changes and assume that all decision-makers optimize and that the economy is always in equilibrium. They require extreme data and calibration and underestimate the impacts.

2.2.4. Econometric Models

Macroeconometric models are statistically estimated simultaneous equation representations of the aggregate working of an economy, which have only rarely been used in regional economic loss estimation. The statistical rigor of these models requires time series data with at least ten observations (typically years) and preferably many more. Data needed are not usually available at the regional level for this purpose, so various data reduction strategies have been developed, as in the case of I-O and CGE models. Expense, huge data demands, and difficulty in distinguishing direct and higher-order effects (total impact rather than direct and higher-order impacts distinguished) are the main reasons for their lesser application to regional economic loss estimation in development studies. Moreover, the historical experience upon which these models are based is unlikely to be representative of experience and behavior during a disaster situation. Also, appropriate adjustments for this are much more difficult than in I-O and CGE models.

At the same time, the potential application of these models to hazard loss estimation is great. Their ability to forecast over time is especially useful in examining potential impacts of a future earthquake or in distinguishing the actual activity of an economy from what it would have been like in the absence of the shock. Also, uncertainty is inherently incorporated into econometric models by virtue of their stochastic estimation.

**3. Modeling Macroeconomic Impacts in An Interindustry Production: An Integrated Model**

Significant and intensive impacts from the damages and losses by disasters, such as earthquakes, on a region’s economy will spread over time, and will bring serious economic effects to other regions in a long run. The unexpected nature of these events creates a further complication of measuring the indirect impacts since most economic models and techniques assume incremental, predictable changes in systems over time. Furthermore, most available data for the direct damages and losses and of the recovery processes are engineering oriented and the dimension and unit of these data which are very detailed and short time span, are quite different from the economic counterpart with aggregated and longer time span. Consequently these differences pose great challenges in order to model economic impacts of disasters.

3.1. Design Methodology

The most effective way to overcome above mentioned challenges in modeling economic impacts of a disaster is to make connection between induced damages and losses and economic consequences by input the engineering data into an economic model considering various factors needed to cover different aspects as complete as possible. In addition, developing an appropriate economic model to measure and evaluate the economic impacts of disaster with the ability to reflect the structure of regional economy in great detail is necessary.

Following integrated developed methodology estimates regional macroeconomic losses of an earthquake by applying consecutive economic impacts evaluation results in equilibrium oriented macroeconomic model based on Input-Output analysis framework.

Macroeconomic losses

Equilibrium oriented macroeconomic model

Higher-order effects

Interaction with other economic sectors in terms of demandant

Insurance, financial & credit capabilities

Workforce specifications

Interaction with other economic sectors in terms of supplier

First-order losses

Degree of constraint

The dynamics of recovery

Sectoral demand & supply geographical area

Earthquake occurrence

Damages on stocks

Dependency on physical capitals

Figure 1- An integrated macroeconomic loss estimation module

In the next sections, inputs, operation and outputs of the developed methodology based on the input-output framework are presented and discussed. Finally, the results are summarized and some future research needs are addressed.

3.1.1. Model inputs

As mentioned before, one the most necessary requirements for precise loss estimation of natural disasters and especially earthquakes is sound data which are not usually available at the regional level for this purpose, so any data reduction strategy will be valuable and helpful. The majority of these required data are engineering oriented which are needed as preliminary inputs for many of existing loss estimation models. An innovation of the developed model is it’s needless to these kind of very detailed and short time span data considering various characteristics of each economic sector. These characteristics which have influence on the rate of damage on stocks, first order losses and higher order effects are identified by surveying on how the economic sector is performing in normal conditions.

The most important aspects of each economic sector which influence regional macroeconomic loss are as followings which are required inputs of developed macroeconomic loss module overcome lack of data existence at regional level:

1. Dependency on physical capitals.
2. The dynamics of recovery if any disaster happen.
3. Workforce specifications.
4. Sectoral demand & supply geographical area.
5. Degree of constraint.
6. Insurance, financial & credit capabilities.
7. Interaction with other economic sectors in terms of supplier.
8. Interaction with other economic sectors in terms of demandant.

 While all of the 8 items relate to sectoral specifications, some of them have direct relationship with sectoral economic loss and the rest has inverse. To consider these parameters for an economic sector every parameter is described by one or more definitions in two tables. Table 2 describes the inputs required and their allocated values for the first group (direct relationship) and table 3 does it for the second one (inverse relationship). Each table has five columns which determine the existence level of each rows definition and two columns for the time dimension and dynamics of recovery in terms of rapid (0-2 years) and slow (2-5 years).

Table 2- Business features which have direct relationship with sectoral economic loss

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| How to recover if compeletly disrupted | Extensive5 | Major4 | Moderate3 | Little2 | None1 | Description | No. |
| Slow(2 – 5)years | Rapid(0-2)years |
|  |  |  |  |  |  |  | Dependency on building and physical spaces:Building and defined physical spaces requirement level to do the business | 1 |
|  |  |  |  |  |  |  | Interaction with other economic sectors in terms of receiving goods andservices : Business dependency level on other sectors goods and services | 2 |
|  |  |  |  |  |  |  | Interaction with other economic sectors in terms of offering goods andservices : Other sectors dependency level on business goods and services | 3 |
|  |  |  |  |  |  |  | Application rate of equipments, machinery, tools, etc. in doing business:The rate of technical and technological complexity in performing business procedure | 4 |
|  |  |  |  |  |  |  | Time dimension of strategic and basic planning:Time duration of different business related matters decision making  | 5 |
|  |  |  |  |  |  |  | The contract paper work:Commitment rate rules and adopted regulations in doing business | 6 |
|  |  |  |  |  |  |  | Professional workforce:Specific knowledge and professional training requirement level  | 7 |
|  |  |  |  |  |  |  | Geographical area of required business inputs (goods, services) supplier source:Providing required business inputs such as raw materials, services, goods, etc. from inside of study region | 8 |
|  |  |  |  |  |  |  | Geographical area of presented business outputs (goods, services):The study region share in target markets of business and use rate of produced goods and presented services  | 9 |
|  |  |  |  |  |  |  | Lifelines dependency:Rate of dependency on lifelines (water, gas, electricity, etc.) in doing business | 10 |
|  |  |  |  |  |  |  | Native workforce:The use rate of native workforce who reside inside the study region  | 11 |

Table 3- Business features which have inverse relationship with sectoral economic loss

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| How to recover if compeletly disrupted | Extensive5 | Major4 | Moderate3 | Little2 | None1 | Description | No. |
| Slow(2 – 5)years | Rapid(0-2)years |
|  |  |  |  |  |  |  | Financial and credit decision making:Easiness of expending financial resources | 1 |
|  |  |  |  |  |  |  | Insurance companies interaction rate:Risk transference to insurance companies | 2 |
|  |  |  |  |  |  |  | Absorbing governmental and private sector financial aids:Capability in absorbing governmental and private sector trust in order to receive loans and financial resources | 3 |
|  |  |  |  |  |  |  | Alternative spaces for doing business:Existence of other suitable spaces for doing business outside of study region | 4 |
|  |  |  |  |  |  |  | Alternative potentials and facilities:Existence of other potentials and facilities to do business outside of study region | 5 |
|  |  |  |  |  |  |  | Geographical area of required business inputs (goods, services):Providing required business inputs such as raw materials, services, goods, etc. from outside of study region | 6 |
|  |  |  |  |  |  |  | Geographical area of presented business outputs (goods, services):Use rate of produced goods and presented services at theoutside of study region  | 7 |
|  |  |  |  |  |  |  | Inputs storage:Existence of required raw materials, goods and input products of business procedure | 8 |
|  |  |  |  |  |  |  | Outputs storage:Existence of business outputs storage | 9 |
|  |  |  |  |  |  |  | Monetary savings and finanacial background:Existence of monetary savings for business continuity in the case of market disorder  | 10 |

3.1.2. Model operation

The model operation could be described as following steps:

1. Filling the designed tables for adequate number of businesses who are active in different parts of each economic sector.
2. Assigning related value of each question for the studied businesses in the related economic sector and performing statistical analysis on the results to calculate approximate estimated value of that specific question.
3. Calculating sectoral loss of function percentage considering all of the related economic sector questions estimated values computed in the previous step.
4. Considering input-output table of the study region and define level of required aggregation in terms of economic sectors number.
5. Producing pre-disaster specifications for considered input-output table of the study region such as Technical Coefficients Matrix - Leontief Inverse Matrix – GDP.
6. Considering loss of function percentage of each sector as a result of earthquake occurrence estimated in step 3.
7. Reproduce Technical Coefficients Matrix and Leontief Inverse Matrix considering estimated sectoral loss of function percentage.
8. Applying estimated loss of function percentage in final demand value of each sector leaving the other sectors with no change (*∆Y*).
9. Specifying the total gross output of the economy directly and indirectly stimulated (*∆X*) by a certain reduction in final demand of each sector which was mentioned in the previous step (*∆Y*), through the following formula :

$(I-A)^{-1}∆Y= ∆X$ 6

1. Specifying the total gross output reduction of the economy as a result of simultaneous final demand reduction in all of the included sectors.
2. Computation of GDP reduction percentage through dividing the total gross output reduction of the economy as a result of simultaneous final demand reduction in all of the included sectors which was specified in step 8 by the total gross output of the economy in normal conditions.
3. Calculation of new GDP considering its related reduction percentage.

3.1.3. Model outputs

As a result of running designed model produced outputs are as follows:

1. Specifying the total gross output of the studied economy directly and indirectly stimulated by a one unit change in final demand for each sector.
2. Finding how damage in sectors can ripple throughout the economy.
3. Reduction amount of total gross output of economy as a result of simultaneous change in final demand for all economic sectors.
4. GDP’s reduction percentage.
5. New GDP amount of economy.

**4. Running the model: A case study of Tehran**

4.1. Introduction

The Greater Tehran Area is located at the foot slope area of the Alborz Mountains, which form part of the Alps-Himalayan Orogenic Zone. This zone is one of high seismic potential with many peculiar active faults.

According to historical seismic data, Tehran has suffered from several strong earthquakes with return periods of 150 years. The city of Manjil, located 200 km west of Tehran, suffered from a strong earthquake in 1990, which killed approximately 14,000 people. Seismologists believe that a strong earthquake will strike Tehran in the near future because the city has not experienced a disastrous earthquake since 1830.

Urban development has been rapidly progressing in Tehran without the development of proper disaster prevention systems against potential earthquakes. It is urgently necessary to prepare a regional/urban earthquake disaster prevention plan in order to mitigate possible seismic damages in Tehran. On the other hand, it is political and economic capital of the Islamic republic of Iran which contains more than 35% of Iran economy. Consequently, in addition to catastrophic results of likely disastrous earthquake on human lives its economic impacts will also be devastating regarding high concentration rate of different economic sectors.

4.2. Calculating Model Inputs

4.2.1. Tehran Input-Output table

In order to running developed model the main requirement is the input-output table of study region. Following Tehran input-output table has been used in this study which contains 9 economic sectors.

Table 4- Tehran Input-Output table 2001 (Amounts in million Rials)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt | Sum | Final Demand | Gross Output |
| Ag | 220848 | 1464 | 1364 | 1023792 | 733 | 3041 | 3530 | 18613 | 5970 | 1279353 | 7099781 | 8379134 |
| Mine | 1510 | 96 | 10986 | 43468 | 104 | 229 | 1336 | 329 | 256 | 58312 | 600041 | 658353 |
| Cnst | 10540 | 2036 | 301213 | 29993 | 14040 | 44317 | 939925 | 46814 | 16095 | 1404972 | 24292183 | 25697155 |
| Mfg | 976622 | 16172 | 1570822 | 12239954 | 906290 | 1085504 | 517928 | 999271 | 599290 | 18911852 | 113592913 | 132504765 |
| Trns | 246442 | 5412 | 747827 | 1023979 | 1392209 | 916609 | 215927 | 189208 | 92057 | 4829671 | 25685591 | 30515262 |
| Trde | 393820 | 2934 | 824187 | 2791630 | 850470 | 394577 | 149869 | 256846 | 186378 | 5850711 | 44686580 | 50537291 |
| FIRE | 113871 | 6825 | 662496 | 1078643 | 265499 | 515910 | 1281051 | 365297 | 436266 | 4725857 | 54103938 | 58829794 |
| Serv | 14487 | 2071 | 14453 | 165193 | 75517 | 71176 | 67044 | 225325 | 60172 | 695437 | 26138510 | 26833947 |
| Govt | 1115 | 429 | 23137 | 27855 | 10127 | 9195 | 16108 | 11880 | 12149 | 111996 | 18784154 | 18896150 |
| Sum | 1979255 | 37439 | 4156485 | 18424506 | 3514988 | 3040557 | 3192717 | 2113582 | 1408633 | 37868162 | 314983689 | 352851851 |
| V | 4000384 | 425601 | 10618587 | 34307876 | 19026044 | 37410314 | 51038406 | 19644936 | 14830307 | 191302455 |  |  |
| M | 2399495 | 195313 | 10922083 | 79772383 | 7974230 | 10086420 | 4598671 | 5075429 | 2657210 | 123681234 |  |  |
| Gross outlay | 8379134 | 658353 | 25697155 | 132504765 | 30515262 | 50537291 | 58829794 | 26833947 | 18896150 | 352851851 |  |  |

4.2.1.1. GDP

Regarding the above mentioned table GDP of Tehran which is calculated through summation of sectors values-added will be equal to 191302455 million Rails. It can also be computed by subtracting total import from the summation of final demand in the table which will be again exactly equal to 191302455 million Rials which can be used as main criteria for examining that the table is set correctly.

4.2.1.2 Technical coefficients Matrix

Technical coefficients that comprise the structural I-O matrix are derived by dividing each input value by its corresponding total output. That is:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt |
| 0.02635687 | 0.002223 | 5.30728E-05 | 0.007726452 | 2.40193E-05 | 6.01708E-05 | 6.00064E-05 | 0.000693627 | 0.000315922 |
| 0.00018021 | 0.000145 | 0.000427503 | 0.000328048 | 3.39607E-06 | 4.52863E-06 | 2.27073E-05 | 1.22462E-05 | 1.35526E-05 |
| 0.00125789 | 0.003092 | 0.011721643 | 0.000226357 | 0.000460106 | 0.000876909 | 0.015977017 | 0.001744563 | 0.000851751 |
| 0.11655404 | 0.024565 | 0.061128251 | 0.092373687 | 0.029699556 | 0.02147926 | 0.008803834 | 0.03723906 | 0.031714912 |
| 0.02941141 | 0.008221 | 0.02910154 | 0.007727864 | 0.045623361 | 0.018137285 | 0.003670375 | 0.007051084 | 0.004871752 |
| 0.04700013 | 0.004457 | 0.032073081 | 0.021068145 | 0.027870308 | 0.007807646 | 0.002547498 | 0.009571678 | 0.009863292 |
| 0.0135898 | 0.010366 | 0.025780911 | 0.008140412 | 0.008700526 | 0.010208496 | 0.021775544 | 0.013613225 | 0.023087545 |
| 0.00172891 | 0.003146 | 0.000562449 | 0.001246691 | 0.002474728 | 0.001408379 | 0.001139622 | 0.008397003 | 0.003184375 |
| 0.00013308 | 0.000651 | 0.000900378 | 0.00021022 | 0.000331879 | 0.000181947 | 0.000273812 | 0.000442729 | 0.000642928 |

4.2.1.3. Leontief Inverse Matrix

The term $(I-A)^{-1 }$ which is known as Leontief inverse indicates how much each sector’s output must increase as a result of (direct and indirect) demands to deliver an additional unit of final goods and services of each type. It can then be calculated as:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt |
| 1.02814705 | 0.002513 | 0.000621318 | 0.008765192 | 0.00031096 | 0.000261559 | 0.000155411 | 0.001056629 | 0.000614808 |
| 0.00023099 | 1.000157 | 0.000457029 | 0.000364372 | 1.59122E-05 | 1.3557E-05 | 3.41092E-05 | 2.77254E-05 | 2.66772E-05 |
| 0.00167076 | 0.003335 | 1.012379797 | 0.000450619 | 0.00069059 | 0.001090633 | 0.01654727 | 0.002042429 | 0.001280644 |
| 0.134758 | 0.028317 | 0.070503769 | 1.103994902 | 0.035343068 | 0.024799779 | 0.011352766 | 0.042341136 | 0.035952953 |
| 0.0339089 | 0.009202 | 0.032252652 | 0.009735469 | 1.048757632 | 0.019472767 | 0.004613537 | 0.00815757 | 0.005784632 |
| 0.05263681 | 0.005646 | 0.035249473 | 0.024188575 | 0.03030236 | 1.009035254 | 0.003554126 | 0.011016435 | 0.011038136 |
| 0.0163365 | 0.011159 | 0.027970011 | 0.009689859 | 0.010007357 | 0.010968096 | 1.022895517 | 0.01465532 | 0.024171738 |
| 0.00214251 | 0.003261 | 0.000831169 | 0.001475265 | 0.002718502 | 0.001527281 | 0.001217151 | 1.008578778 | 0.003318453 |
| 0.00019319 | 0.00067 | 0.000952483 | 0.000244987 | 0.000365857 | 0.000200101 | 0.000300319 | 0.00046645 | 1.000664181 |

4.2.2. Computing Sectoral Vulnerability

In order to run the model, we need to have sectoral loss of function percentage caused by an extensive earthquake occurrence. As described in section 3.1.2, this achieved through filling the designed tables for adequate number of businesses who are active in different parts of each economic sector by performing complete field investigations.

After Assigning related value of each question for the studied businesses and performing statistical analysis on the results to calculate approximate estimated value of that specific question for related economic sector, sectoral loss of function percentage considering all of related economic sector questions estimated values was calculated. The results are as following:

Table 5 - Sectoral Loss Of Function Percentage

|  |  |
| --- | --- |
| Economic Sector | Loss Of Function (Percentage Points) |
| Agriculture | 2 |
| Mine | 2 |
| Construction | 10 |
| Manufacturing | 20 |
| Transportation | 20 |
| Trade | 20 |
| Finance, Insurance and Real Estate | 10 |
| Service | 20 |
| Government | 20 |

4.3. Model Operation

4.3.1. Final Demand Reduction

Above estimated sectoral loss of function percentage will be resulted in the same certain reduction in the final demand value of each sector. Consequently, the same table will be produced for sectoral final demand reduction amount.

Table 6- Sectoral Final Demand Reduction (∆FD)

|  |  |
| --- | --- |
| Economic Sector | Final Demand Reduction ∆FD (Percentage Points) |
| Agriculture | 2 |
| Mine | 2 |
| Construction | 10 |
| Manufacturing | 20 |
| Transportation | 20 |
| Trade | 20 |
| Finance, Insurance and Real Estate | 10 |
| Service | 20 |
| Government | 20 |

4.3.2. Recalculating studied I-O table specifications

4.3.2.1. Technical coefficients Matrix - Leontief Inverse Matrix – Final Demand reduction

For each economic sector technical coefficients matrix and Leontief inverse matrix should be reproduced as a result of estimated sectoral loss of function percentage for that special sector leaving other sectors with no change. Final demand value of each sector reduction also considered leaving the other sectors with no change. For each sector, computations are showed by related sectoral tables:

4.3.2.1.1. Agriculture

Technical Coefficients Matrix considering 2% Loss of Function in Agriculture sector only, will be computed as follows:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt |
| **0.025829729** | **0.002179** | **5.20114E-05** | **0.007572** | **2.35389E-05** | **5.89674E-05** | **5.88063E-05** | **0.000679754** | **0.000309604** |
| **0.000176604** | 0.000145 | 0.000427503 | 0.000328 | 3.39607E-06 | 4.52863E-06 | 2.27073E-05 | 1.22462E-05 | 1.35526E-05 |
| **0.001232728** | 0.003092 | 0.011721643 | 0.000226 | 0.000460106 | 0.000876909 | 0.015977017 | 0.001744563 | 0.000851751 |
| **0.114222955** | 0.024565 | 0.061128251 | 0.092374 | 0.029699556 | 0.02147926 | 0.008803834 | 0.03723906 | 0.031714912 |
| **0.028823184** | 0.008221 | 0.02910154 | 0.007728 | 0.045623361 | 0.018137285 | 0.003670375 | 0.007051084 | 0.004871752 |
| **0.046060125** | 0.004457 | 0.032073081 | 0.021068 | 0.027870308 | 0.007807646 | 0.002547498 | 0.009571678 | 0.009863292 |
| **0.013318007** | 0.010366 | 0.025780911 | 0.00814 | 0.008700526 | 0.010208496 | 0.021775544 | 0.013613225 | 0.023087545 |
| **0.001694332** | 0.003146 | 0.000562449 | 0.001247 | 0.002474728 | 0.001408379 | 0.001139622 | 0.008397003 | 0.003184375 |
| **0.00013042** | 0.000651 | 0.000900378 | 0.00021 | 0.000331879 | 0.000181947 | 0.000273812 | 0.000442729 | 0.000642928 |

Leontief Inverse Matrix considering 2% Loss of Function in Agriculture sector only will then be calculated as:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt |
| 1.027547485 | 0.002461 | 0.000608536 | 0.008585 | 0.000304563 | 0.000256179 | 0.000152214 | 0.001034893 | 0.00060216 |
| 0.000226237 | 1.000157 | 0.000457024 | 0.000364 | 1.59094E-05 | 1.35547E-05 | 3.41078E-05 | 2.77159E-05 | 2.66717E-05 |
| 0.001636393 | 0.003335 | 1.012379756 | 0.00045 | 0.00069057 | 0.001090616 | 0.01654726 | 0.00204236 | 0.001280604 |
| 0.131985829 | 0.028303 | 0.070500498 | 1.103949 | 0.035341431 | 0.024798402 | 0.011351948 | 0.042335574 | 0.035949716 |
| 0.033211348 | 0.009198 | 0.032251829 | 0.009724 | 1.048757221 | 0.019472421 | 0.004613331 | 0.008156171 | 0.005783818 |
| 0.051553994 | 0.005641 | 0.035248195 | 0.024171 | 0.030301721 | 1.009034716 | 0.003553807 | 0.011014262 | 0.011036872 |
| 0.016000434 | 0.011158 | 0.027969615 | 0.009684 | 0.010007159 | 0.010967929 | 1.022895418 | 0.014654646 | 0.024171346 |
| 0.002098439 | 0.003261 | 0.000831117 | 0.001475 | 0.002718476 | 0.001527259 | 0.001217138 | 1.008578689 | 0.003318401 |
| 0.000189213 | 0.00067 | 0.000952478 | 0.000245 | 0.000365854 | 0.000200099 | 0.000300318 | 0.000466442 | 1.000664176 |

 Expanding estimated sectoral loss of function percentage to final demand value of Agriculture sector leaving other sectors with no change, resulted in below findings:

Table 7- 2% Final demand Reduction in Agriculture sector only

|  |  |
| --- | --- |
| Economic Sector | **2%∆FDAgric** |
| Agriculture | -141995.6115 |
| Mine | 0 |
| Construction | 0 |
| Manufacturing | 0 |
| Transportation | 0 |
| Trade | 0 |
| Finance, Insurance and Real Estate | 0 |
| Service | 0 |
| Government | 0 |

4.3.2.1.2. Other Economic Sectors

The same calculations for all of the other economic sectors of Tehran considered I-O table have been done and for each economic sector technical coefficients matrix and Leontief inverse matrix reproduced as a result of estimated sectoral loss of function percentage for that special sector leaving other sectors with no change. Final demand value of each sector reduction also considered leaving the other sectors with no change.

Based on the results of these calculations, the total gross output of the economy stimulated by changes in final demand for each sector was specified by following procedure.

4.3.3. Specifying the total gross output of the economy stimulated by changes in final demand for each sector

The column sums of the Leontief Inverse are sectoral multipliers specifying the total gross output of the economy directly and indirectly stimulated by a unit change in final demand for each sector. Consequently, based on each sector computed final demand reduction percentage, the total gross output change of the economy will be as follows:

4.3.3.1. Agriculture

 Table 8- Total gross output reduction of the economy stimulated by 2% change in final demand for Agriculture sector only

|  |  |
| --- | --- |
|  | -145907.23 |
|  | -32.12 |
|  | -232.36 |
|  | -18741.41 |
| **∆XAgric=(I-A)-1\*∆FD** | -4715.87 |
|  | -7320.44 |
|  | -2271.99 |
|  | -297.97 |
|  | -26.87 |
| ***∆XAgric*** | ***-179546.26*** |

4.3.3.2. Other Economic Sectors

Total gross output reduction of the economy stimulated by calculated percentage change in final demand for the other economic sectors are shown in the below table:

Table 9- Total gross output reduction of the economy stimulated by reductive changes in final demand for different economic sectors

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Agriculture** | **Mine** | **Construction** | **Manufacturing** | **Transportation** | **Trade** | **Finance Insurance Real Estate** | **Services** | **Government** |
| **2%** **∆FD** | **2%** **∆FD** | **10%** **∆FD** | **20%** **∆FD** | **20%** **∆FD** | **20%** **∆FD** | **10%** **∆FD** | **20%** **∆FD** | **20%** **∆FD** |
| ***∆XAgric*** | ***∆XMine*** | ***∆XConst*** | ***∆XMfrng*** | ***∆XTrns*** | ***∆XTrade*** | ***∆XFIRE*** | ***∆Xserv*** | ***∆XGov*** |
| ***-179546.26*** | ***-12756.54*** | ***-2824793.81*** | ***-25539824.46*** | ***-5659347.84*** | ***-9416385.63*** | ***-5704825.32*** | ***-5596433.57*** | ***-4036940.21*** |

4.4. Model Outputs

By specifying total gross output reduction of the economy stimulated by definite change in final demand for each economic sector, it’s now time to calculate macroeconomic indices change such as GDP in order to see what will happen if all economic sectors affected simultaneously which is the real case that happens in an earthquake occurrence. There are 3 approaches which can be used for this purpose which are applied and the results are as follows:

4.4.1. Approach 1: linear relation

In order to calculate macroeconomic indices change such as GDP as a result of simultaneous reduction in final demand of all economic sectors, the simplest way is to collect total gross output reduction of the economy stimulated by definite change in final demand for each of them in a linear manner without any coefficients.

4.4.1.1. Total gross output reduction of the economy

By considering linear relation as mentioned above, the results will be as followings:

Table 10- Total gross output reduction of the economy as a result of simultaneous damage of all sectors using approach 1: linear manner

|  |  |
| --- | --- |
|  | **Sector** |
| **∆Xtotal=** | **∆XTrns+∆XMfrng+∆Xagric+∆Xmine+∆Xconst+∆Xtrade+∆XFIRE+∆Xserv+∆Xgov=** |
| **Trns** | **Mfg** | **Ag** | **Mine** | **Const** | **Trde** | **FIRE** | **Serv** | **Govt** |
| -5659347.84 | -25539824.46 | -179546.26 | -12756.54 | -2824793.81 | -9416385.63 | -5704825.32 | -5596433.57 | -4036940.21 |
| **∆Xtotal=-58970853.64** | Total gross output reduction of the economy as a result of simultaneous damage of all sectors |

4.4.1.2. Gross Output before earthquake occurrence

The last column sum of studied Tehran Input-Output table is its gross output before earthquake occurrence which is equal to:

Table 11- Total gross output of the economy before earthquake occurrence

|  |  |
| --- | --- |
| Economic Sector | Gross Output (Million Rials) |
| Agriculture | 8379134 |
| Mine | 658353 |
| Construction | 25697155 |
| Manufacturing | 132504765 |
| Transportation | 30515262 |
| Trade | 50537291 |
| Finance, Insurance and Real Estate | 58829794 |
| Service | 26833947 |
| Government | 18896150 |
| Sum | 352851851 |

4.4.1.3. GDP

As discussed earlier for each Input-Output table GDP can be calculated as the summation of sectors values-added or subtracting total import from the summation of final demand in the table.

Table 12- GDP amount before Earthquake Occurrence

|  |  |
| --- | --- |
| Economic Sector | Values-added |
| Agriculture | 4000384 |
| Mine | 425601 |
| Construction | 10618587 |
| Manufacturing | 34307876 |
| Transportation | 19026044 |
| Trade | 37410314 |
| Finance, Insurance and Real Estate | 51038406 |
| Service | 19644936 |
| Government | 14830307 |
| GDP | 191302455 |

4.4.1.4. GDP Reduction and Post Earthquake GDP using approach 1

The amount of GDP Reduction Percentage is equal to total gross output reduction of the economy as a result of simultaneous damage of all sectors which is calculated in section 4.4.1.1 divided by total gross output of the economy before earthquake occurrence shown in Table 29.

Table 13- GDP Reduction and Post Earthquake GDP using approach 1

|  |  |
| --- | --- |
| Total gross output reduction | **-58970853.64** |
| Pre-earthquake Total gross output of the economy | 352851851 |
| GDP reduction percentage | -0.167126383 |
| GDP reduction amount | 31971687.39 |
| Pre earthquake GDP | 191302455.067157 |
| GDP reduction amount | 31971687.387974 |
| Post earthquake GDP | 159330767.679183 |

4.4.2. Approach 2: Considering direct indirect backward links and forward links

Another approach to find out macroeconomic effects of simultaneous reduction in final demand of all economic sectors is to consider direct indirect backward links and forward links of each economic sector.

4.4.2.1. Direct indirect backward links

For each economic sector the related direct indirect backward link determines the effects of one unit change in that sector final demand on the production of total economy. This will be achieved through column sums of Leontief Inverse Matrix for each sector. The results are as follows:

Table 14- Direct and Indirect backward links

|  |
| --- |
| Direct indirect backward link (DIBLj) |
| **Agriculture** | **Mine** | **Construction** | **Manufacturing** | **Transportation** | **Trade** | **Finance Insurance Real Estate** | **Services** | **Government** |
| 1.27002472 | 1.064258 | 1.181217699 | 1.15890924 | 1.128512238 | 1.067369027 | 1.060670207 | 1.088342472 | 1.082852222 |

4.4.2.2. Direct indirect forward links

Direct indirect forward links show how each economic sector sells its products and services to the others. It is calculated by row sums of Gosh Matrix as follows:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ag | Mine | Cnst | Mfg | Trns | Trde | FIRE | Serv | Govt |
| 1.02814705 | 0.000197 | 0.001905458 | 0.138609754 | 0.001132459 | 0.001577549 | 0.001091138 | 0.003383825 | 0.00138648 |
| 0.00293989 | 1.000157 | 0.017838992 | 0.073336112 | 0.000737543 | 0.00104068 | 0.003047963 | 0.001130066 | 0.000765694 |
| 0.00054479 | 8.54E-05 | 1.012379797 | 0.00232357 | 0.000820072 | 0.002144892 | 0.0378825 | 0.002132782 | 0.000941709 |
| 0.00852162 | 0.000141 | 0.013673065 | 1.103994902 | 0.008139352 | 0.009458631 | 0.005040429 | 0.008574634 | 0.005127154 |
| 0.00931099 | 0.000199 | 0.027160225 | 0.042273799 | 1.048757632 | 0.032249466 | 0.008894351 | 0.007173453 | 0.003582053 |
| 0.00872724 | 7.36E-05 | 0.017923619 | 0.063420524 | 0.018297072 | 1.009035254 | 0.004137311 | 0.005849432 | 0.004127215 |
| 0.00232681 | 0.000125 | 0.012217444 | 0.021824867 | 0.005190858 | 0.00942206 | 1.022895517 | 0.006684709 | 0.007763971 |
| 0.00066902 | 8E-05 | 0.000795957 | 0.007284788 | 0.00309145 | 0.002876381 | 0.002668438 | 1.008578778 | 0.002336815 |
| 8.5665E-05 | 2.33E-05 | 0.001295295 | 0.001717916 | 0.00059082 | 0.000535165 | 0.00093499 | 0.000662394 | 1.000664181 |

Table 15- Direct and Indirect forward links

|  |
| --- |
| Direct indirect Forward link (DIFLi) |
| **Agriculture** | **Mine** | **Construction** | **Manufacturing** | **Transportation** | **Trade** | **Finance Insurance Real Estate** | **Services** | **Government** |
| 1.177431132 | 1.100993747 | 1.05925555 | 1.162670479 | 1.179600491 | 1.131591218 | 1.088451117 | 1.028381626 | 1.006509756 |

4.4.2.3. Total gross output reduction of the economy considering direct indirect backward links and forward links

By applying direct indirect backward links and forward links coefficients of each sector to gross output reduction calculations the results can be shown as following:

Table 16- Total gross output reduction of the economy as a result of simultaneous damage of all sectors using approach 2: considering direct and indirect backward links and forward links

|  |  |
| --- | --- |
|  | **Sector** |
| **∆Xtotal=** | **(∆XTrns\*DIBLTrnsd \*DIFLTrnss)+(∆XMfrng\*DIBLMfrngd \*DIFLMfrngs)+ (∆XAgric\*DIBLAgricd \*DIFLAgrics)+(∆XMine\*DIBLMined \*DIFLMines)+ (∆XConst\*DIBLConstd \*DIFLConsts)+(∆XTrade\*DIBLTraded \*DIFLTrades)+ (∆XFIRE\*DIBLFIREd \*DIFLFIREs)+(∆XServ\*DIBLServd \*DIFLServs)+ (∆XGov\*DIBLGovd \*DIFLGovs)=** |
| **Trns** | **Mfg** | **Ag** | **Mine** | **Const** | **Trde** | **FIRE** | **Serv** | **Govt** |
| -7533687.567 | -34413114.47 | -268487.49 | -14947.3726 | -3534414.23 | -11373350 | -6586150.5 | -6263704.183 | -4399866.487 |
| **∆Xtotal=-74387722.21** | Total gross output reduction of the economy as a result of simultaneous damage of all sectors considering direct and indirect backward links and forward links |

4.4.2.4. GDP Reduction and Post Earthquake GDP using approach 2

As explained earlier, the amount of GDP Reduction Percentage is equal to total gross output reduction of the economy as a result of simultaneous damage of all sectors divided by total gross output of the economy before earthquake occurrence. Following this procedure, considering sectoral direct and indirect backward links and forward links will be resulted in following figures:

Table 17- GDP Reduction and Post Earthquake GDP using approach 2

|  |  |
| --- | --- |
| Total gross output reduction | **-74387722.21** |
| Pre-earthquake Total gross output of the economy  | 352851851 |
| GDP reduction percentage | -0.210818569 |
| GDP reduction amount | 40330109.76  |
| Pre earthquake GDP | 191302455.067157 |
| GDP reduction amount | 40330109.759147 |
| Post earthquake GDP | 150972345.308010 |

4.4.3. Approach 3: Normalized direct indirect backward links and forward links

In order to have economic interpretation of sectors performance one should normalize their direct indirect backward links and forward links. This is done by dividing average performance of each sector to the average performance of total economy. The results contain some coefficients whose numerical values are around one. As the average performance of total economy is equal to one, each sector whose index is greater than one has more average performance than the total economy and vice versa.

4.4.3.1. Normalized direct indirect backward links

Following above mentioned procedure produce below results for normalized direct indirect backward links of each economic sector:

Table 18- Normalized direct and indirect backward links

|  |
| --- |
| Normalized direct indirect backward link (DIBLjnd) |
| **Agriculture** | **Mine** | **Construction** | **Manufacturing** | **Transportation** | **Trade** | **Finance Insurance Real Estate** | **Services** | **Government** |
| 1.13146363 | 0.948147 | 1.052345557 | 1.032470975 | 1.00539032 | 0.9509179 | 0.944949928 | 0.969603118 | 0.964711861 |

4.4.3.2. Normalized direct indirect forward links

Following above mentioned procedure produce below results for normalized direct indirect forward links of each economic sector using Gosh supplier pattern:

Table 19-Normalized direct indirect forward links

|  |
| --- |
| Normalized direct indirect Forward link (DIFLins) |
| **Agriculture** | **Mine** | **Construction** | **Manufacturing** | **Transportation** | **Trade** | **Finance Insurance Real Estate** | **Services** | **Government** |
| 1.0666334 | 0.9973889 | 0.9595783 | 1.0532617 | 1.0685986 | 1.0251071 | 0.9860265 | 0.9316096 | 0.9117959 |

4.4.3.3. Total gross output reduction of the economy considering normalized direct indirect backward links and forward links

By applying normalized direct indirect backward links and forward links coefficients of each sector to gross output reduction calculations the results can be shown as following:

Table 20- Total gross output reduction of the economy as a result of simultaneous damage of all sectors using approach 3: considering normalized direct and indirect backward links and forward links

|  |  |
| --- | --- |
|  | **Sector** |
| **∆Xtotal=** | **(∆XTrns\*DIBLTrnsnd \*DIFLTrnsns)+(∆XMfrng\*DIBLMfrngnd \*DIFLMfrngns)+ (∆XAgric\*DIBLAgricnd \*DIFLAgricns)+(∆XMine\*DIBLMinend \*DIFLMinens)+ (∆XConst\*DIBLConstnd \*DIFLConstns)+(∆XTrade\*DIBLTradend \*DIFLTradens)+ (∆XFIRE\*DIBLFIREnd \*DIFLFIREns)+(∆XServ\*DIBLServnd \*DIFLServns)+ (∆XGov\*DIBLGovnd \*DIFLGovns)=** |
| **Trns** | **Mfg** | **Ag** | **Mine** | **Const** | **Trde** | **FIRE** | **Serv** | **Govt** |
| -6830022.919 | -24152270.43 | -181307.24 | -13872.25455 | -3034841.8 | -9179023.6 | -5315446.3 | -5055211.44 | -3550974.751 |
| **∆Xtotal=-57312970.76** | Total gross output reduction of the economy as a result of simultaneous damage of all sectors considering normalized direct and indirect backward links and forward links |

4.4.3.4. GDP Reduction and Post Earthquake GDP using approach 3

Following approach 3, the amount of GDP Reduction can be shown as:

Table 21- GDP Reduction and Post Earthquake GDP using approach 3

|  |  |
| --- | --- |
| Total gross output reduction | **-57312970.76** |
| Pre-earthquake Total gross output of the economy  | 352851851 |
| GDP reduction percentage | -0.162427859 |
| GDP reduction amount | 31072848.22 |
| Pre earthquake GDP | 191302455.067157 |
| GDP reduction amount | 31072848.217691 |
| Post earthquake GDP | 160229606.849466 |

**5. Conclusion**

Although most of the required sound conceptual bases for the accurate empirical estimation of losses from natural hazards are well known to economists, they are not necessarily familiar to those in other disciplines. On the other hand, conceptual refinements do not always readily translate into real world counterparts, but are an important first step in comprehensive and accurate natural hazard loss estimation. Many economic losses, especially direct and indirect business interruption, are not as readily apparent as property damage, and their validity is met by the skepticism of many engineers, some policy-makers, and even some economists. Perhaps most important is the collection of more empirical data and improvements in formulating and testing hypothesis about direct and higher-order losses, especially the offsetting effects of resiliency.

In this paper following description of theoretical background regarding definitions and prevalent methodologies currently use in natural hazard loss estimation studies, an integrated operational methodology which allows a more holistic accounting for the macroeconomic impacts of earthquake considering physical damage, the dynamics of recovery, sectoral vulnerability of first-order losses, and higher-order effects which take into account the system-wide impact of flow losses through interindustry relationships was developed.

Based on high concentration rate of economic capitals in an earthquake-prone region like Tehran and its rapid urban development progress without proper disaster prevention systems against potential earthquakes, it was considered as a case study for running the model. The results showed catastrophic macroeconomic effects reducing GDP up to 21 percent using different approaches for estimation. The results of Tehran case point out the emergence of a comprehensive planning process by means of spatial reorganization and administrative adjustment. Moreover, achievement of these attempts requires a well organized control and feedback system, mitigation private decisions and public policies, reallocation of scarce utility lifeline services in order to minimize regional employment or output losses by way of central administration or market mechanisms as well.

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