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An indirect loss estimation methodology to account for regional earthquake damage to highway bridges

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AN INDIRECT LOSS ESTIMATION METHODOLOGY TO ACCOUNT FOR REGIONAL EARTHQUAKE DAMAGE TO HIGHWAY BRIDGES

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ABSTRACT

Earthquakes are one of the most serious natural disasters. They not only cause fatalities and injuries, but also result in infrastructure damage, social effects, and economic impacts. Without appropriate preventive action plans and mitigation policies, unforeseen natural catastrophes can cause tremendous losses, as evident for the 2005 Hurricane Katrina in the southern coastal United States (particular in New Orleans) and the 1994 Northridge Earthquake in Southern California. However, policymakers generally focus only on the losses directly caused by the earthquake, or more specifically the direct losses caused from the destruction of the infrastructure. They tend to overlook the consequences from these losses, such as business disruptions or reductions in final demand. This study proposes an integrated framework to estimate the indirect economic loss due to damaged bridges within the highway system from an earthquake event. The framework is designed to be general and convenient to apply to other study regions. In this dissertation, a simulated earthquake scenario centered in St. Louis Missouri with a magnitude 7.0 was used as a case study. The research results have clearly shown that the indirect losses are significant when compared to the direct loss. Policymakers can apply this study framework and the results as a guide and decision tool for developing an appropriate preventive action plan to reduce the risk and potential losses before the earthquake occurs.

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1. INTRODUCTION

1.1. STATEMENT OF THE PROBLEM

Due to the geological location of the United States - having fault lines across the country - earthquakes are an unavoidable occurrence. There are approximately 10,000 annual earthquakes in Southern California area alone, based on National Earthquake Information Center data (http://neic.usgs.gov). Most of these earthquakes are too small to detect, however, about 15-20 of them are larger than magnitude 4.0. Most recently, there have been two severe earthquakes in the West Coast; the Loma Prieta earthquake in 1989 and the Northridge earthquake in 1994. The Northridge earthquake caused damage estimated at $46 billion dollars, and was considered as the costliest disaster in US history (Rowshandel et al. 2000) before the recent flooding caused by Hurricane Katrina in 2005. Not only is the West Coast of the U.S. at risk, but the Midwest is also at risk of an earthquake hazard (Olshansky and Wu, 2004). Historical information regarding the severity of earthquakes in the state of Missouri has been recorded since 1811, with the most recent severe earthquake occurring in 1968. This 1968 earthquake was centered in southern Illinois and was the strongest in the central United States since 1895. It caused moderate damage to chimneys and walls in Hermann, St. Charles, St. Louis, and Sikeston, Missouri. Portions of 23 states felt the effects of the earthquake (http://neic.usgs.gov).

Severe earthquakes can cause tremendous damage to people and physical construction. Many important infrastructures can be damaged, such as residence, building, electrical facilities, water utilities, and the transportation network. In particular, roadways make up an important urban transportation network used by people for pleasure and business. Roadways consists of two types of structures, i.e., roads (paved and unpaved) and bridges (McCaskill, 2001). Bridges are the most vulnerable component in the roadway structure, in that the impact of damage to bridges can result in a reduction in traffic flow capacity, or even totally unusable routes (Werner et al. 1997). The cost to recover the capacity of road network from damages is an obvious loss. However, there also are indirect costs as a result of these damages. First, with road capacity reduced, people have to use more time to travel, have to travel along a farther redirected route, or might not be able to travel at all. Furthermore, this loss is not usually directly traced in terms of money, but rather in the form of increase travel time/distance, which should also be considered in terms of dollars. The question then becomes how to measure this increased travel time/distance in dollars since travel time and distance are not normal market goods. It will be necessary to develop a model to translate these measurements into a monetary value.

In addition to the initial hidden loss mentioned above, another loss that should be considered is the reaction from the increase in travel cost and how it can affect the entire economic system. As the result of the increased cost in transportation (the initial indirect loss), people might reduce the number of trips they normally make. However, there still are some trips that are unavoidable, such as trips between home and the work place, as well as freight trips to transport goods from industries to retail locations, among others. Addition travel cost will decrease the spending budget/allowance of the affected individuals, resulting in a reduction of consumer demand. For the producer, the cost of the product will increase, leading to an increase in the price of goods. This will cause even further reduction in consumer demand. In general, the loss in a producers' profit and the whole community's welfare level may be affected.

Therefore, a model that is only capable of estimation of the initial loss (increase in travel cost) is not sufficient to illustrate the overall loss to the economy. The development of a model to estimate the ripple effects of the initial loss onto the entire economic system is necessary. One benefit of a model that is capable of a total loss evaluation is that it will allow policy makers to become better aware of the estimated economic risk. Under this risk, policy makers can conduct a Cost-Benefit Analysis to develop a feasible prevention plan to alleviate potential future loss that might occur from a catastrophic event (CGER, 1999; King et al. 1997; Lindell and Prater, 2003).

1.2. SCOPE OF THE RESEARCH

In order to estimate the economic loss, the study area and the earthquake scenario have to be initially defined. For this research, the concerned study area focuses on the metropolitan St. Louis urban region under a simulated earthquake scenario with an epicenter located at St. Louis, Missouri. The earthquake scenario under study has had some preliminary findings made from previous research project (Cooperative Agreement DTFH61-02-X-00009) at the University of Missouri-Rolla, funded by the Federal Highway Administration (FHWA). The results from this scenario study will be used as the initial input for the research within this dissertation. Therefore, the objective of this research is to evaluate the total indirect economic loss from damaged bridges along the metropolitan highway network in the St. Louis region due to an earthquake.

The developed transportation network model (Chen et al. 2005) provides the increases in travel time and distance in the St. Louis metropolitan area due to the earthquake incident, and will be used as the initial input for the indirect loss estimation. The economic module and market value of travel time and distance need to be developed to translate these changes into a dollar figure. Once this is completed, the initial indirect loss can be evaluated. For the study, St. Louis metropolitan transportation information and demographic data for the year 2004 is utilized.

After the initial indirect loss is estimated, an additional economic model is needed to convert the loss into a more complete economic loss measure. The initial loss that occurs from the earthquake will affect the economic system and disrupt the initial economic pattern. Consequently, the economic system will adjust to the new equilibrium state. The Computable Generalized Equilibrium (CGE) model is selected as the framework for the total economic loss estimation model. Using the Social Accounting Matrix (SAM) as input, the CGE model contains information about price-dependent market interaction among industries and consumers, as well as the initial equilibrium state of the economic system. The CGE model can simultaneously explain the origin and spending of the agents' income, thereby making it possible to observe the effects on the entire economic system from change(s) in any particular portion of the economic system (Shoven and Whalley, 1992; Francois and Reinert, 1997). Moreover, the CGE model is capable of conducting a counterfactual scenario experiment. As a result, the effect of future preventive plan(s)/alternative(s) can be observed. Therefore, the CGE model can also be utilized as one of the tools to assist policy making.

1.3. OUTLINE OF THE FOLLOWING SECTIONS

This dissertation is organized into seven remaining sections. Section 2 provides a literature review regarding the losses that occur from an earthquake event, loss estimation methodologies, the value of time and distance estimation approach, and the input-output model and the CGE model for observing changes in the economic system. Section 3 describes the research framework and methodology of this study, as well as the study scenario selection and detail. Section 4 presents the initial indirect loss estimation module, which helps in translation of the increase in highway network travel time and distance to a dollar figure. Section 5 discusses the total indirect loss estimation module in terms of the data management to construct the CGE model, along with the development of the CGE model for the St. Louis metropolitan area. Finally, Section 6 concludes the dissertation with a discussion of the results, along with providing directions for future research.

2. LITERATURE REVIEW

2.1. EARTHQUAKE LOSS

An earthquake is one of the most serious natural disasters. From 1947 thru 1980, earthquakes produced 28 of the greatest disasters, causing about 450,000 deaths (Lindell and Prater, 2003). Earthquakes do not only cause fatalities and injuries, but also result in infrastructure damage, social effects, and socioeconomic impacts (Kawashima and Kanoh, 1990; Enke et al. 2007; Patek and Elahi, 2000). 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. (Chang, 2000; CGER, 1999). From an economic perspective, there are costs associated with the damage caused by an earthquake, such as the repair or replacement costs for the damaged structure, temporary unemployment, business interruption, etc. Generally, economic earthquake losses can be categorized into two groups: direct economic loss and indirect economic loss.

2.1.1. Direct Economic Loss. Direct economic loss is the economic damage generated directly by an earthquake, for example, the damage of buildings, roads, production facilities, the indoor property loss, etc. Basically, these losses can be measured by the repair or replacement costs of the damaged structure and properties, including building contents and business inventory (Brookshire et al. 1997; Lindell and prater, 2003; Enke et al. 2007; CGER 1999; An et al. 2004; Chen et al. 2005; Sohn et al. 2003; FEMA, 2001). Naturally, direct losses are easy to notice and observe since it is directly caused by the earthquake. However, it is only a part of the total losses that caused by the earthquake. Still, there are another costs associated with the earthquake effect, called indirect economic loss.

2.1.2. Indirect Economic Loss. The basic idea of the indirect economic loss is the loss that represents the consequences of earthquake destruction. Brookshire et al. (1997) gave the definition of indirect loss as any loss that are extensive than just the direct physical impact, such as income losses, business inventory loss, etc. Boisvert (1992) defined the indirect loss as the loss resulted from the multiplier or ripple effect through out the economy due to supply bottlenecks and reduced demand as a result of the direct loss. Burrus et al. (2002) referred to the indirect loss only as the decreases in economic output due to business disruption/interruption. From the studies mentioned earlier, along with other studies (Enke et al. 2007; Rowshandel, 2000; FEMA, 2001), it is obvious that there are variations in the definition detail and boundary of indirect economic loss. Thus far, CGER (1999) has provided possibly the most rigid definition and good boundary for the indirect economic loss. CGER defined and categorized the indirect economic loss into three groups: induced loss, linkage loss, and spending reduction.

2.1.2.1 Induced loss. Induced loss is the reduction in sales, wages, or profits due to the limited business operation capacity. This inability to fully operate is the result of direct damage. For example, the reduction in sale due to physical damage of production facility, or the increase of transportation cost as a result of transportation network destruction, among others.

2.1.2.2 Linkage loss. Linkage loss is the loss of the successive industrial sector due to the reduction of demand and production capacity in the immediate effected industrial sectors. There are two types of linkage loss, which are forward and backward linkage loss. This can be illustrated and explained by Figure 2.1. In this basic business relationship diagram, there are three industrial sectors with the relationship as sectors A and B are the suppliers of sectors B and C, respectively. Sector C delivers final product to consumers. Assume that the earthquake caused the direct damage to some of the sector B production facility, resulting in reduction of sector B producing capacity.

First, there is supply shortage for sector C due to the reduced availability of input from sector B. Eventhough sector C did not receive any direct damage from the earthquake, they still cannot operate at their full production capacity if they cannot find the alternative source for the input from sector B. Because there is not enough of output from sector B, which is the intermediate input for sector C. This loss is referred as forward linkage loss, meaning that the impact of direct damages has an effect on the next stage(s) of the production process.

Next, in the same earthquake situation, sector A will suffer from the demand shortage. This is the consequence from sector B not being able to operate at their usual capacity resulting in reduction of sector A output demand. Therefore, sector A has to reduce their production activity even if there is no damage in their sector. This loss is called the backward linkage loss, implying the impact of direct damages effect on the previous stage(s) of the production process.

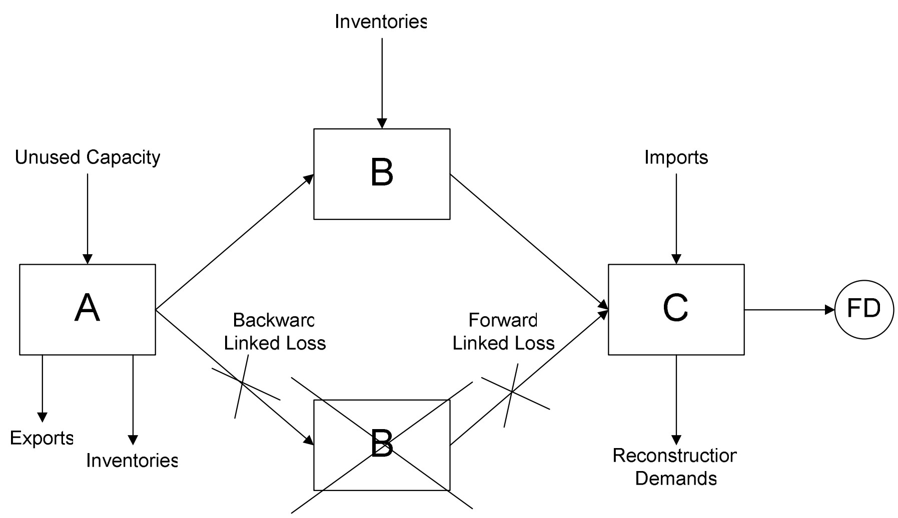


Figure 2.1. Business Diagram Explaining Linkage Losses (FEMA, 2001)

2.1.2.3 Spending reduction. When firms encounter direct physical damage or infrastructure failure or linkage loss, they have to reduce their production level, resulting in decrease in sales. In order to make their business feasible, they have to trim down their expenditure or even close their company. Consequently, employees of those firms will experience income losses and will be forced to reduce their consumption according to their lower allowance. This will initiate a new round of firm cutbacks.

2.1.3. Direct Economic Loss and Indirect Economic Loss Comparison. As discussed earlier, there are different types of losses that occurred from an earthquake, each having a wide ranging effect on society. The physical damage to structure, death and injury, and the collateral hazards are just the beginning of an economic damage assessment. Sometimes, policymakers focus only on the physical damages, or direct losses, and overlook their subsequence indirect losses. Those consequences are also important and significant.

Many earthquake loss estimation studies have been conducted for the 1994 Northridge earthquake incident since it is the costliest earthquake in US (OTA, 1995; Rowshandel et al. 2000). Gordon and Richardson (1995) estimated the Northridge structural loss at $20 billion and additional business interruption loss or indirect loss at $6 billion, almost one third of the direct loss. For the same incident, Petak and Elahi (2000) presented direct loss at $41.8 billion and $7.5 billion for indirect loss. Gordon et al. (1998) used the Southern California Planning Model (SCPM) with their survey method resulting in estimation of business interruptions at $6.5 billion, transportation interruptions at $1.5 billion, and total structure damage at more than $25 billion.

Other than the California region, there are also studies conducted for the regions that are geologically located in the area with high earthquake risk. For example, Chen et al. (2005) developed the model to estimate the St. Louis metropolitan earthquake loss due to the bridge damage in the highway network and found that the increases in highway network travel cost alone account for about 55% of direct loss to the highway network. Veneziano et al. (2002) studied the Memphis earthquake and its impact on transportation capacity, considering the loss at the national level. Venziano et al. presented that the indirect losses have a significant dollar figure compared to the direct loss, ranging about 30%. Chang et al. (2000) estimated the Memphis earthquake loss due to the water utility damage. Their result indicated that indirect loss magnitude is about one third of the direct loss. Brookshire et al. (1997) made the study for the Boston, Massachusetts region. Estimation from their model showed the ratio of direct to indirect loss was in the range of 12.4% to 14.3%.

Based on evidence, CGER (1999) concluded that in larger disasters there is a higher proportion of indirect impact. These studies confidently confirm that indirect loss has a significant magnitude compared to the direct loss. Thus, it is important for policymakers and researchers to extend their concern beyond the physical damage to also consider the consequence of these damages.

2.1.4. The Importance of Loss Estimation. Each earthquake can cause tremendous economic losses. Table 2.1 provides approximate dollar figure for the losses from multiple historical earthquake scenarios provided by various researchers and organizations. In addition to the loss figures for these historical incidents, some researchers and organizations also provide the annualized earthquake loss figure for current and potential future earthquakes. The annualized loss is the estimated loss of the potential earthquake scenario times by the probability of occurrence of that earthquake. Olshansky and Wu (2004) applied the ATC-21 (ATC, 1988) along with HAZUS model (a natural hazard loss estimation methodology developed by FEMA) and estimated the annualized direct economic losses to buildings at approximately $500,000 (2001 US Dollar) for the vicinity of the New Madrid fault. The Federal Emergency Management Agency (FEMA) estimates $17 million in annualized earthquake loss for the Memphis area and $34 million for St. Louis (Stein et al. 2003). Based on these loss figures alone, one can easily be convinced that it is valuable to know in advance estimates of the potential loss figures in order to be better prepared for an unexpected event, or take necessary precautions.

Table 2.1. Loss Estimation from Earlier Studies (Rowshandel et al. 2000)

Earthquake	Date	Magnitude	Total Loss[a]
San Fernando	February 9, 1971	6.7	2200[b]
Imperial Valley	October 15, 1979	6.5	70[b]
Coalinga	May 2, 1983	6.4	18[b]
Whitter Narrows	October 1, 1987	5.9	522[c]
Loma Prieta	October 17, 1989	7.0	10000[d]
Northridge	January 17, 1994	6.7	46000[e]
Petrolia	April 25, 1992	7.0	80[c]
landers	June 28, 1992	7.6	120[c]
Hector Mine	October 16, 1999	7.4	Minor

[a] Estimate are in millions dollar (Year 2000 dollar value)
[b] Estimate is from FEMA
[c] Estimate is from U.S. Office of Technology Assessment
[d] Estimate is from NRC
[e] Estimate is from California Governor's Office of Emergency Services

While the extreme geophysical events cannot be avoided, their impacts can be dramatically reduced by regional government policies or hazard mitigation initiatives, such as reinforcing structures to enable them to better withstand the shock of an earthquake, or land use planning to decrease structural exposures. Although these loss reduction mitigation plans might seem costly, they could result in damage prevention and eventual savings.

Previous studies provide evidence of the benefit from appropriate mitigation plans. In the Northridge earthquake study by Petak and Elahi (2000), it was found that all the failed transportation structures were not strengthened. On the other hand, all 122 strengthened structures were not damaged. Those strengthened investments proved to save damage and lives. King et al. (1997) made the analysis for Palo Alto, California scenario regarding the failure in lifeline utility (water service). King et al. proposed that by spending investment in the order of $500,000 can lead to over $6,000,000 in saving. Rose et al. (1997) presented that reallocation of electricity resources across industrial sectors and sub-regions in the aftermath of the Northridge earthquake scenario can reduce the loss from electricity utility disruption by more than 70%. Veneziano et al. (2002) showed that reinforcing the masonry buildings before the Memphis earthquake incident would reduce the potential direct and indirect losses by about 31% and 25%, respectively.

Therefore, developing a reliable loss estimation model will make a significant contribution toward the design of mitigation and development of preventive plans. Information regarding the estimated losses from past or potential hazard will be available for community leaders. At times, policy makers may not want to invest in preventive plans since the cost is immediate, while the benefit is uncertain. The model can provide a quantitative basis for national and local government to design the mitigation plan, which should help in optimizing any investment in a preventive policy, as well as dictate to the appropriate form and area where assistance should be provided. Moreover, planners can develop disaster impact projections before disasters strike to assess potential consequences of alternative hazard adjustment (CGER, 1999; Lindell and Prater, 2003). Other than the federal and local policy makers, individuals, businesses, and insurance companies would also like to know the potential loss that could occur. Thus, insurance companies can design the proper product to offer to their customers, while individuals and businesses will be able to acknowledge the risk they encounter and correctly decide how they should protect themselves, both physically and financially.

2.2. EARTHQUAKE LOSS ESTIMATION METHOD

2.2.1. Methods for Direct Loss Estimation. Direct economic loss, by its definition, can be estimated from the repair or replacement cost of the damaged structures. Brookshire et al. (1997) categorized the direct loss estimation methods into two large groups based on their source of information which are primary data collection efforts and secondary data collection efforts.

2.2.1.1 Primary data collection effort. The primary data collection method estimates the direct economic loss based on survey methods focusing on businesses and households in the impacted areas (Tierney and Nigg, 1996; Gordon and Richardson 1995). The information received from surveys describes the losses which businesses or individuals encounter. This method appears to be reasonably accurate and easy for validation since the source of the losses is directly from the suffered individuals or businesses (Boarnet, 1998; Brookshire et al. 1997). However, the survey process is costly and takes a long time to complete (CGER, 1999). It is also weak in its ability to pinpoint the direct cause of business slowdown (Boarnet, 1998; Brookshire, 1997).

2.2.1.2 Secondary data collection effort. Instead of collecting the data directly from the individuals or businesses, the secondary data collection effort method collects information mostly from creditable secondary sources, such as tabulations of insurance claims, small business loans, and other form of disaster relief (Lahr 1996). Brookshire et al. (1997) proposed that this method is reasonably accurate after cross-checked with other sources. This method requires fewer resources, in both money and time, than the primary data collection. However, it will be more difficult to clearly identify the cause of loss, as well as the victim involved.

Although both data collection methods can perform well for direct loss estimation, they lack the prediction power to estimate the loss of the future earthquake. If the method cannot approximate the potential loss, it usually is not very useful for design of preventive and mitigation plans. Hence, the adequate direct loss estimation model must not only be able to link the geographic event (earthquake) to physical damages and translate those losses into the economic terms, but it should contain the prediction ability as well.

Some efforts have been put into developing methods with predictive ability. For example, the Applied Technologies Council (ATC) applied the survey method to develop the direct loss estimation method with some predictive level, labeled as ATC-13 (ATC, 1985). ATC-13 is the direct earthquake loss estimation for the California area based on the expert opinion. The information was collected from experts about the construction damage level at given earthquake magnitudes, as well as the information regarding the recovery duration to a certain capacity level of those damaged construction. Based on this information, ATC-13 has an ability to estimate the direct losses for the potential earthquake scenario. Furthermore, time series analysis, statistical modeling, econometrics, and simulation techniques can be applied and make the direct loss estimation method more comprehensive (Brookshire et al. 1997; Guimaraes et al. 1993; Shinozuka et al. 1998)

2.2.2. Methods for Indirect Loss Estimation. Contrary to the direct losses, indirect losses are naturally characterized with more ambiguous causes and the uncertain amount of losses than direct losses (CGER, 1999; Enke et al. 2007; Chang et al. 2000). It is not possible to estimate the indirect losses based solely on survey methods. Additionally, there is still a lack of systematic data collection, both during normal situations and after the incident, in order to be properly used as the ingredient for indirect losses estimation/prediction model development (CGER, 1999).

The indirect economic losses could be influenced by various disruptions, for example, transportation difficulty due to damaged highway and transportation systems, water pipe damage, and electricity disruption, among others. Estimation of indirect losses from a specific cause is a complicated task. However, to perform a reliable estimation of total indirect losses is much more difficult. Simply summing up all the losses from each particular cause will result in an overestimate of the total indirect losses since some of the losses will be double counted (Boisvert, 1992). Due to their character, the creditable indirect losses estimation model must be data intensive, large scale, complex systems, and likely to require complicated computations (An et al. 2004).

Since there is often too much information to consider from a wide variety of sectors, it is practically impossible to capture every earthquake indirect loss by a single model, however, some effort has been put into developing a dependable indirect loss estimation model. In order to achieve the development of a model, the scope and boundary of the model must be specified. For example, the study for the Memphis area by Werner et al. (2000) considered the indirect loss from the highway damage only as the increased travel cost within the network. They developed an equation to translate the increase travel time and distance to increased travel cost. The increased cost was estimated only at a single point of time after the incident and did not expand to capture the loss to the entire economic impact. Gordon et al. (1998) conducted a survey and collected data to be applied with the Southern California Planning Model (SCPM). They were then able to estimate the economic impact and increased travel cost for the Northridge Earthquake. The estimated indirect loss covered all three types of indirect losses as previously discussed. However, there was still a limitation in their model due to the input data. It was not possible to conduct a survey to collect the data from every single individual or business that might be affected.

There are many different models that are utilized by researchers in order to estimate the indirect loss (An et al. 2004). Those models are different by their supplementary work regarding the scope and boundary of each model. However, there are only few computation approaches applied, such as econometric models, mathematical optimization techniques, the Input-Output model, and the Computation Generalized Equilibrium (CGE) model (Brookshire et al. 1997). Currently, there are three major computation approaches widely used in this field: the Input-Output Model, HAZUS, and the CGE model.

2.2.2.1 Input/Output model. Input-Output (I-O) techniques were first developed by Wassily Leontief and continuously refined by other economists over time (FEMA, 2001). The basic idea of this model is to consider the economy by divided it into a number of industrial sectors. Each sector uses input from itself and other sectors to produce a product. The model is linear and shows all purchases and sales among sectors according to the static technological relationships of production. Other than the business sectors, the model also includes household, governments, investment, and exports in the analysis. As a result, the model allows users to access the flow of goods and services among industrial sectors, as well as the flow of other input used in production, such as labor, capital, imported goods and services, and government services (FEMA, 2001; Boisvert, 1992; UN, 1999).

Table 2.2 illustrates a simple example of an I-O model. For this example, it is assumed that the economy consists of three industrial sectors: A, B, and C. Row V represents the values-added in each sector, i.e. labor, capital, government services, etc. Row M stands for imports to each producing sector from other regions. The assumption is made that the economy is in an equilibrium state, meaning that all markets are cleared. Furthermore, all of the produced products and services will be used up either for the intermediate goods or for final demand. This relationship for sector A can be shown in Equation 2.1.

Table 2.2. Input-Output Table (FEMA, 2001)

From \ To	A	B	C	Final Demand	Gross Output
A	X_{AA}	X_{AB}	X_{AC}	Y_A	X_A
B	X_{BA}	X_{BB}	X_{BC}	Y_B	X_B
C	X_{CA}	X_{CB}	X_{CC}	Y_C	X_C
V	V_A	V_B	V_C		
M	M_A	M_B	M_C		
Gross Outlay	X_A	X_B	X_C	Y	X

$$X_A = X_{AA} + X_{AB} + X_{AC} + Y_A \qquad \text{Eq 2.1}$$

The other crucial assumption of I-O model is that the producing technological requirement for all sectors is fixed. This means the ratio of input requirements from any particular sector and the total output from that sector is fixed, and defined as coefficient “a”. Equation 2.2 shows the “a” coefficients for sector A.

$$a_{AA} = \frac{X_{AA}}{X_A}; \quad a_{AB} = \frac{X_{AB}}{X_B}; \quad a_{AC} = \frac{X_{AC}}{X_C} \qquad \text{Eq. 2.2}$$

Employing the "a" value from Equation 2.2, the relationship of output from sector A with each sector's output and final demand can be written in Equation 2.3.

$$X_A = a_{AA}X_A + a_{AB}X_B + a_{AC}X_C + Y_A \qquad \text{Eq. 2.3}$$

The relationship of the economy in Table 2.2 can be expressed in matrix form as:

$$X = AX + Y \qquad \text{Eq. 2.4}$$

Rearranging Equation 2.4 shows that the gross output minus the intermediate usage equals the final demand. (Equation 2.5)

$$(I - A)X = Y \qquad \text{Eq. 2.5}$$

In order to examine the required gross output of each sector from the given set of final demand, Equation 2.5 is rearranged into Equation 2.6.

$$(I - A)^{-1}Y = X \qquad \text{Eq. 2.6}$$

The term $(I – A)^{-1}$ is called the Leontief Inverse. Equation 2.6 and the Leontief Inverse are crucial to the I-O model. Based on the assumption of fixed technological requirement, the Leontief Inverse needs to be calculated only once. Equation 2.6 and the Leontief Inverse serve researchers as a tool to estimate changes in gross output due to changes in final demand, as shown in Equation 2.7.

$$(I - A)^{-1}\Delta Y = \Delta X \qquad \text{Eq. 2.7}$$

Therefore, the I-O model is capable of capturing the backward linkage loss or the loss from demand shortage under the condition that the business pattern, defined by the flow of goods and services, does not significantly change from the initial conditions. The model also shows the ripple effect of change in one economic sector through successive chains of producers and/or consumers (Brookshire et al. 1997). Many studies have been applied this I-O technique to estimate the losses from earthquake damage (Ho, 2001; Gordon and Richardson, 1995; Cho et al. 2001; Gordon et al. 1998; Boisvert, 1992; Kawashima and Kanoh, 1990; Yamano et al. 2004).

Although the I-O model can provide a reasonable estimation of indirect loss, there are still some restrictions. First, the I-O approach emphasizes the backward linkages loss or demand shortage, but neglects forward linkages loss or supply shortage (Cho et al. 2001). Moreover, it also assumes the "a" values to be fixed at the initial stage before the disaster incident. This is somewhat unrealistic due to the reduction in production activities from the damages to the infrastructure (Boisvert, 1992).

2.2.2.2 HAZUS. Since the I-O approach has some crucial limitations, many researchers have put effort into improving the I-O approach and overcoming its limitations. Some studies considered households as an industrial sector, which make them endogenous in the I-O approach. This allows the I-O model to capture the loss from spending reductions (FEMA, 2001). For dealing with forward linkage loss or supply shortage, some researchers (Oosterhaven, 1988; Rose and Allison, 1989) have developed another set of coefficient from the I-O table called supply-side multiplier. Thus far, the most popular and current standard as a loss estimation model based on an improved I-O approach is HAZUS (An et al. 2004).

HAZUS is an integrated framework providing the capability to generate a multifaceted description of potential loss damages and losses from all types of natural hazards, and is not limited only to earthquakes (Brookshire et al. 1997). It was developed by FEMA under a contract with the National Institute of Building Sciences (NIBS). The purpose of FEMA for developing HAZUS was to provide loss estimation, which is essential to decision-making at all levels of government, as well as provide a basis for developing mitigation plans and policies, emergency preparedness, and response and recovery planning (FEMA, 2001). HAZUS utilizes various modules in order to estimate disaster loss. The direct loss module estimates damage in buildings and infrastructure. The direct loss damages are then converted into a loss of functionality measurement for each industrial sector, which then serves as the input for the indirect loss module. The algorithm used in the loss estimation of HAZUS approach is a dynamic input-output model (Sohn et al. 2003).

The core of the HAZUS computation algorithm is the I-O model. However, with some modification, HAZUS overcomes the crucial limitations of the conventional I-O model. First, HAZUS considers household as an endogenous sector, which then provides a calculation of loss estimation from spending reductions. HAZUS allows the technological requirement coefficient to be adjusted. This gives researchers the capability for capturing the forward linkage loss, adjusting the business pattern, and consequently rebalancing of the economic equilibrium. The conventional I-O model uses an extremely strict economy condition. Under this condition, the economy has neither slack in production factors i.e., labor, import replacement, inventories or substitute intermediate goods, nor additional outlet of the output in the form of additional exports. Therefore, the production technological coefficients, matrix A, are fixed for both before and after the disaster situation. HAZUS relaxes this assumption by allowing some tolerance level in those factors which will allow the business pattern, or flow of goods and services, to be readjusted according to the reduction of production capacity or supply shortage after the disaster, making the model more realistic. Therefore, the A matrix is not static and will adjust itself to be capable of estimating not only the backward linkage losses, but also the forward linkage losses (FEMA, 2001).

Additionally, HAZUS also considers the losses that will occur along the time line after the incident. In its integrated framework, there is a recovery module that will generate the recovery capacity level for each industrial sector, which allows the loss estimation at different points of time. While HAZUS can handle indirect loss estimation more realistically than the I-O model, there still are some limitations. HAZUS allows the production inputs to be readjusted by the slack in those same inputs. However, in a real situation, it is likely that some of intermediate goods can be substituted with others, as well as allowing for substitution between labor and capital. Moreover, the HAZUS does not consider the effects of relative price changes on final demand (FEMA, 2001). This is also a limitation for the I-O model. All the adjustments are only from quantity changes.

2.2.2.3 Computable General Equilibrium (CGE) model. The CGE model represents multi-market simulation models based on the simultaneous optimizing behavior of individual consumers and firms, subject to economic account balances and resource constraints (Shoven and Whalley, 1992). The CGE model is capable of detecting changes in the economy due to a system disturbance, the same as the I-O model and HAZUS, but without many of their limitations. While maintaining the links among business sectors, the CGE model overcomes some of the crucial limitations of the I-O model and HAZUS. CGE allows the price of output to adjust by introducing non-linear functions in production and consumption, as well as letting endogenous prices to be adjusted. Moreover, it also allows the possibility of input substitution, both intermediate goods and production factors, as well as the substitution of imported goods for regionally produced goods (Brookshire et al. 1997; Rose and Lim, 2002; Böhringer et al. 2003; Patridge and Rickman). The CGE has been used in the field of regional economic and policy analysis (Goodman, 2003; Hoffmann et al. 1996), as well as in the field of loss estimation from disasters (Rose and Lim, 2002; Chang et al. 2000).

The core theory of the CGE model is general equilibrium theory. Different from partial equilibrium, which considers the equilibrium of any single market, general equilibrium views the economy as a system consisting of many interconnected markets (Nicholson, 1994). The CGE economic model structure is based on the Arrow-Debreu model. This model considers the economy as a system consisting of a specific number of consumers and commodities. Each consumer comes into the market with an initial endowment of commodities and a set of preferences, resulting in demand functions for each commodity. Consumers maximize their utility based on their preferences, endowments, and incomes. Market demand is the sum of each consumer's demand. Commodity market demand depends on all prices. On the production side, producers maximize their profits. The production levels will be the function of commodity prices and demands (Shoven and Whalley, 1992; Partridge and Rickman).

However, in the equilibrium state of the CGE system, all markets have to satisfy Walrasian's Law (Francois and Reinert, 1997; Shoven and Whalley, 1992; Nicholson, 1994; Varian, 1993; Partridge and Rickman, 1998). This equilibrium state can be described as the state of equilibrium that will be reached as price falls below some condition (a set of prices such that each consumer is choosing his or her most preferred affordable bundle, and all consumer choices are compatible in the sense that demand equals supply in every market). In other words, to reach the equilibrium state, there are three conditions to be met. The first condition is market clearance. This implies that at equilibrium prices and levels of activity, the net supply of any commodity must balance or exceed excess demand by consumers. Second, the income balance condition means that the value of each agent's income must equal the value of endowments. The last condition regards zero net profit. This represents the condition that no producer earns an excess profit, or no activity does any better than breakeven at the equilibrium prices (Francois and Reinert, 1997; Shoven and Whalley, 1992; Nicholson, 1994; Varian, 1993; Partridge and Rickman, 1998).

The structure of functions in CGE model can be described as shown in Figure 2.2. The objective of the system is to maximize consumer utility, with constraints on consumer income, endowments, and commodity prices. There is not a fixed functional format for both demand and production. However, the selected function format must be reasonably easy to evaluate for any price vector and should allow key parameter values (income and price elasticity) to be incorporated while retaining tractability (Shoven and Whalley, 1992). For the demand part, there are two functions - consumer demand function and consumer preference. The consumer preference can be represented by the utility function. Utility is a quantitative measure of preference. Utility is an abstract concept and its units are arbitrary (Parkin, 1999). The absolute value of utility is meaningless such that only the relative value contains information - the higher the utility value, the higher preference level. The commonly applied utility function forms are Cobb-Douglas and Constant Elasticity of Substitution (CES) (Shoven and Whalley, 1992; Nicholson, 1994, Rutherford, 1995, Varian, 1993; Partridge and Rickman, 1998). On the production side, CES value-added functions are usually used to allow for substitution between primary factors. It also sometimes allows for substitution among intermediate goods (Shoven and Whalley, 1992). Currently there are computation tools that help relax some limitation of Cobb-Douglas and the CES function, making the analysis more realistic. This tool is a module within the Generalized Algebraic Modeling System (GAMS), called the Mathematical Programming System for General Equilibrium (MPSGE) analysis (Rutherford, 1999). This tool allows the researcher to utilize the hierarchical CES or nested CES function within the CGE system. Employing this approach, CES or Cobb-Douglas functions can be contained within CES functions, and several layers of chain can be managed (Shoven and Whalley, 1992). This will expand the number of elasticity parameters that can be used, allowing some commodities to be examined in more detail.

The benchmark equilibrium is constructed from the current base situation. The information used as the input for the CGE benchmark model is from the Social Accounting Matrices (SAM). SAM is a model describing the supply and demand system in an economy. It shows how income is derived from production activities and how it is distributed to the various socio-economic groups. The advantage of using SAM is in how it describes the flow of goods and payments between institutions in the economy. Within the policy simulations, single parameters or exogenous variables are changed and a new or counterfactual equilibrium is computed. Comparison of those two equilibrium states will be able to capture the changes in economic variables, such as employment, production activity level, welfare, relative prices, etc. (Böhringer et al. 2003; Francois and Reinert, 1997; Rutherford, 1999). Therefore, the important figure to be examined is the relative value of concerned variables, not their absolute values.

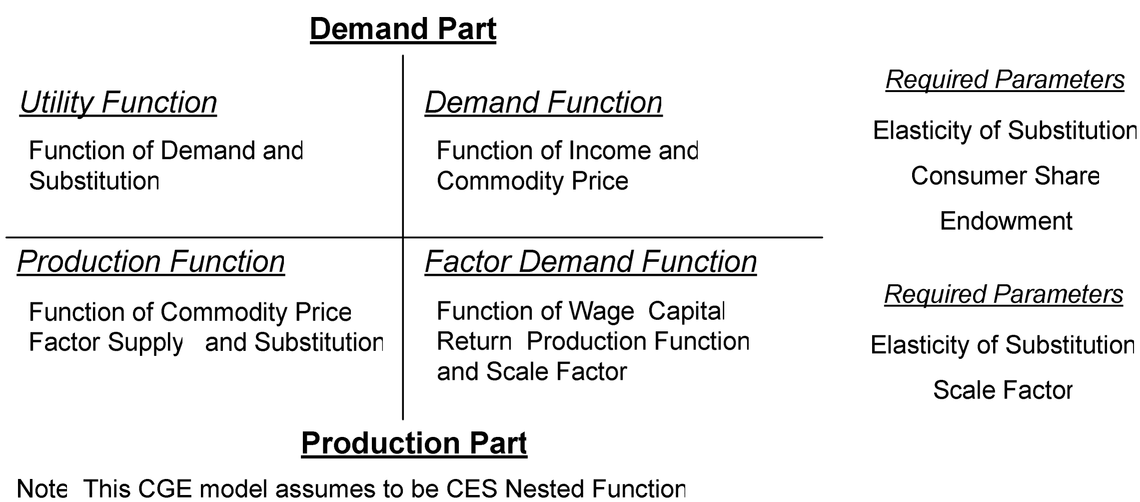


Figure 2.2. CGE Functions Structure

Although the CGE model applies a non-linear algorithm, which allows the model to analyze the problem more realistically, there is always a concern about the stability and uniqueness of the equilibrium. There are some prerequisites of the system to ensure the equilibrium uniqueness. However, in the case of system disturbance (ex. tax or price change), the system will not be confirmed for solution stability and uniqueness. This topic is still an on-going area of research (Wing, 2004). Another issue of concern in the CGE model regards to the elasticity values used endogenously within the model. These values are varied based on study region and current economic theories. Sensitivity analysis or validation should be conducted before the study result from the CGE model can be applied (Böhringer et al. 2003; An et al. 2004). Moreover, it is difficult to replicate the same CGE model and results from a previous study. Even if all the information is obtained, and a good computation tool, such as MATLAB, GAMS, etc., are used, modeling still requires good computer programming skills and a good understanding in economic theory (Böhringer et al. 2003, Shoven and Whalley, 1992).

2.3. VALUE OF TIME AND DISTANCE

To estimate the cost of travel within the transportation network, two factors that compose the travel cost and that need to be examined are the amount of time users spend in the network, and the distance they travel within the network. To estimate the cost of the trips the users made in the network requires modelers to translate the time and distance usages into a dollar value. In other words, the estimation of value of travel time and distance has to be conducted in order to estimate the travel cost. There are many studies that consider the estimation of the value of travel time and travel distance. Victoria Transportation Policy Institute (VTPI) made an excellent literature review for this field of study (VTPI, 2003). Most of these studies (U.S. DOT, 1997; Frye, 1973; Kawamura, 1999; Thomas, 1968; Thomas and Thompson, 1970) were looking at these values from the perspective of travel time and/or distance savings with the purpose of performing a cost benefit analysis of a new road project. Some studies (Erhardt et at., 2002; Ghosh, 2000; Nakamura and Kockelman, 1999; Vilain and Bhandari, 2001, Richardson, 2001) considered the value of time and distance as the users' willingness to pay in order to save a certain amount of travel time and distance, normally considering this additional cost as the toll fee. Among those researchers, there are only a few (Waters et al. 1995; Gunn 2001) which discussed these values from the perspective of loss due to increases in travel time and/or distance. From the perspective of loss, the value of time and distance were worth more than the travel time or distance that could be saved.

2.3.1. Value of Time. Time that is used to travel is valuable because people can either dedicate that time to earn more money, or use it toward their leisure activities. Travel time is a non-market intangible item, making it difficult to value. There are many factors believed to be related to travel time cost, such as trip purposes, income classes, time of day, length of trip, demographic data of the user, etc. (Gunn, 2001; Frye, 1973). However, there is still no precise and universally accepted value of time. Many approaches have been developed to estimate the value of travel time. Some studies (Thomas 1968; Thomas and Thompson, 1970) applied a survey method to find the relationship between the value of time and the demographic data. The survey was typically conducted to collect the value of time for each individual and their demographic data, such as income and trip length, among others. Then, an empirical model was developed based on this survey data. A behavioral study approach can also be applied (Erhardt et al. 2002; Richardson 2001). This approach infers the value of time from situations in which drivers face time and monetary tradeoffs. A logit model is then applied, along with a mode choice process, to develop the mode choice utility empirical model showing the relationship of mode utility decision with travel time and price variables. By finding the ratio of these two coefficients in the mode utility function, the value of time is then estimated (Kawamura, 1999).

Normally, the value of travel time is presented in proportion of the user's wage rate. Based on a literature review (Gunn, 2001; Frye, 1973; VTPI, 2003; U.S. DOT, 1997; Mackie et al. 2003), the figures vary from 20% to 120% of the hourly wage rate. These numbers are different when considering the region of study, trip purpose, trip length, and the time the trip was made. Based on the review of recent studies by U.S. Department of Transportation (DOT) (1997), DOT experts developed recommendations regarding the value of travel time to be used for various U.S. highway projects. Many factors, such as trip duration, trip purpose, wage rate, and travel modes are considered to be relevant along with the value of travel time. However, only a few of them are considered significantly related. The U.S. DOT concluded that only the single demographic data point of hourly wage rate is related to the value of travel time. The

U.S. DOT gave the recommendation to value travel time at 50% of the hourly wage rate for personal trips and 100% of the hourly wage rate for business trips.

2.3.2. Value of Distance. Not only is time an intangible cost that people need to spend during their travel, they also need to spend other cost during trips, such as bus fare, gasoline cost, vehicle maintenance cost, etc. Those costs are generally presented in terms of per travel distance and usually considered as travel distance cost (VTPI, 2003; AAA, 2003; Waters et al. 1995). For automobile travel, the vehicle operating cost is considered. This cost mainly consists of fuel cost, maintenance cost, repair cost, and insurance cost (AAA 2003; Curry 1972; Waters et al. 1995). By their nature, these costs are strongly related to the vehicle travel distance. However, these costs will vary by the region, size of the vehicle, and the vehicle travel distance. Therefore, to estimate the cost of travel distance, the estimation needs to be made at a regional level and the data used in the estimation must be creditable. There are respectable agencies that provide raw information about the vehicle operating cost, including the DOT, the Bureau of Transportation Statistics, and the Census Bureau, among others.

2.4. POINTS TAKEN FROM THE LITERATURE

- Earthquake can cause tremendous loss other than just physical damage. There are further losses as a consequence of the physical damage, called indirect losses. These losses are significant when compared to the physical damage losses. However, sometimes they are overlooked by policy makers.
- Unlike the direct loss, indirect loss is not easy to measure due to its ambiguous source(s) of loss. Summing the loss from all causes will result in double counting of some losses. It is practically impossible to capture all indirect losses with one single model. Therefore, a systematic loss estimation approach needs to be developed. Furthermore, the scope of indirect loss also needs to be defined.
- A loss estimation methodology is a necessary and important tool for policy makers. Being able to obtain information about the potential loss from a future disaster will assist policy decision making. Mitigation plans and preventive plans could also result in both life and financial saving.

- The CGE model is one of the most realistic approaches for indirect losses estimation. However, there are still problems with the model regarding the uniqueness and stability of the solved equilibrium value. Moreover, the endogenous parameters, in the form of the elasticity of substitution, should be validated before applying any recommendation from the CGE model.
- Values of travel time and distance are subjective and difficult to estimation. However, they are important parameters for estimating the cost of increased travel time and distance that result from the damage network.

3. STUDY FRAMEWORK/METHODOLOGY

This section discusses a proposed approach for estimating the indirect earthquake loss from damaged bridges in highway network for the St. Louis Metropolitan area. The approach consists of two connected modules: the initial indirect loss estimation and the expanded indirect loss estimation. However, this approach requires a preliminary methodology for estimation of the direct loss. Therefore, the complete earthquake loss estimation framework consists of two major parts. First, the direct loss estimation is used to transform the earthquake ground shake into physical damage, as well as estimate the damage into a dollar figure. Consequently, the second part of the framework estimates the indirect loss. Using the damage state estimated from the direct loss estimation as input, the initial indirect loss, or increased network travel cost, is estimated by utilizing the transportation network simulation model and value of travel time and distance as inputs. Next, the initial indirect loss will be allocated and expanded into the entire indirect economic impact by applying the CGE technique. Section 3.1 provides background on the loss estimation model framework and reviews some of the previous utilized frameworks. In Section 3.2, the proposed study framework is described, as well as the scope and objective of the study. Section 3.3 provides brief information about the direct loss estimation and its importance to the indirect loss estimation process. The detail of initial indirect loss estimation is discussed in Section 3.4. Finally, Section 3.5 presents an approach for how the CGE will be applied to calculate the expanded economic losses from the damaged bridges in the highway system.

3.1. INTRODUCTION TO THE EARTHQUAKE LOSS ESTIMATION FRAMEWORK

Many studies have been performed for developing a reliable framework and approach to estimate losses from a natural disaster (CGER, 1999; Boisvert, 1992; Brookshire et al. 1997; Cho et al. 2001; Chang et al. 2000; Chen et al. 2005). CGER (1999) recommended that the scope of study and modeling of indirect losses due to natural disasters should concentrate on those losses that occur in the region of impact near the time of the event. In other words, the geographic boundaries and the time period over which the study of indirect losses should be conducted must be defined and standardized.

Brookshire et al. (1997) analyzed the HAZUS approach and stated that the integrated framework with linked modules, starting from the specific direct damage to the physical environment and that are indirectly related to the damage state, are required for the earthquake loss estimation. They described the framework of HAZUS with three connected modules. First is the Direct Physical Damage Module (DPDM) that is used to facilitate changing the ground shake motion into structural damages. The second module, called Direct Economic Loss Module (DELM), is then used to translate the resulting structural damages into a dollar figure in terms of the replacement and repair cost. The DELM provides the input for the Indirect Economic Loss Module (IDELM). The IDELM determines the effects of both supply shortage and business disruptions based on those inputs. Moreover, the recovery and losses along the time line after the incident are also determined using both DELM and IDELM. Chang et al. (2000) proposed that a good loss estimation model should start with the spatial model that transmits the earthquake shake to the physical damage. From the physical damage, another module will estimate the direct loss. Using that direct loss (which will disrupt/change the business/economic pattern) as input, another module will estimate the ripple effect of that loss, resulting in the indirect loss. Following the same idea, Cho et al. (2001) developed a second version of SCPM called SCPM2. This SCPM2 framework consists of different small linked modules handling different tasks. These modules include the integration of seismic, transportation network, spatial allocation, and input-output models. Combining the result from all modules permits the study of how the economic impacts of industrial and transportation structure loss are distributed over the metropolitan space.

In terms of model assessment and performance of the loss estimation model, An et al. (2004) made a review and comparison of different models in the field of disaster loss estimation. They recommended several important key criteria to assess the loss estimation model, such as policy relevance, spatial dimension, time dynamic analysis, degree of endogeneity, etc. After the comparison and assessment of the models, they concluded that there is no single model that can fully satisfy all the key criteria. However, there are two models that outperform the others (model by Rose et al. (1997) and SCPM2 by Cho et al. (2001)). Both models form an integrated framework that starts from the direct physical damage estimation. Other than these two models, the researchers commented that HAZUS is also doing well. However, it is a closed source model in which the user has limited accessibility and adjustability. Therefore, it could be concluded that a reliable loss estimation model should utilize an integrated framework that starts from the physical damage and then converts this information into a direct loss. Then, the indirect loss will be able to be examined from the direct loss estimation result. To accomplish the modeling, the scope of the model, geological boundary, study scenario, and time period of study need to be initially defined.

3.2. PROPOSED STUDY SCOPE AND FRAMEWORK

3.2.1. Study Scope and Definition. According to the previous studies and their recommendation, restrictions must be initially defined in order to design a reliable framework for estimating indirect economic loss due to earthquake situation. First, since there are many sources that can cause the indirect loss, the scope of study must be specified to some particular source of loss. For this study, the scope and definition of the indirect loss are limited to the indirect loss due to the damaged bridges in the highway network. Second, the study scenario for this research is a simulated earthquake incident of magnitude 7.0 with the epicenter located at St. Louis, Missouri. The geological boundary of this study is limited to an eight county region in the St. Louis metropolitan area. Finally, the time frame for the study begins the first day after the earthquake incident thru the 500th day after the incident.

3.2.2. Study Framework. Following the same approach as previous studies, the proposed framework for this research is designed and illustrated in Figure 3.1. The framework consists of three connected modules handling different tasks in order to achieve the estimation of the indirect loss from earthquake scenario. The first module of the framework is the direct loss estimation module, which determines the direct loss resulting from the damaged bridges in highway network. This module provides input for the second module, the initial indirect loss module, which considers the loss that is a direct consequence from the lower capacity highway network. Finally, the expanded indirect loss module determines the ripple effect to the entire economic system from the initial indirect loss and estimates this loss into a dollar figure. The following sections discuss these modules in more detail.

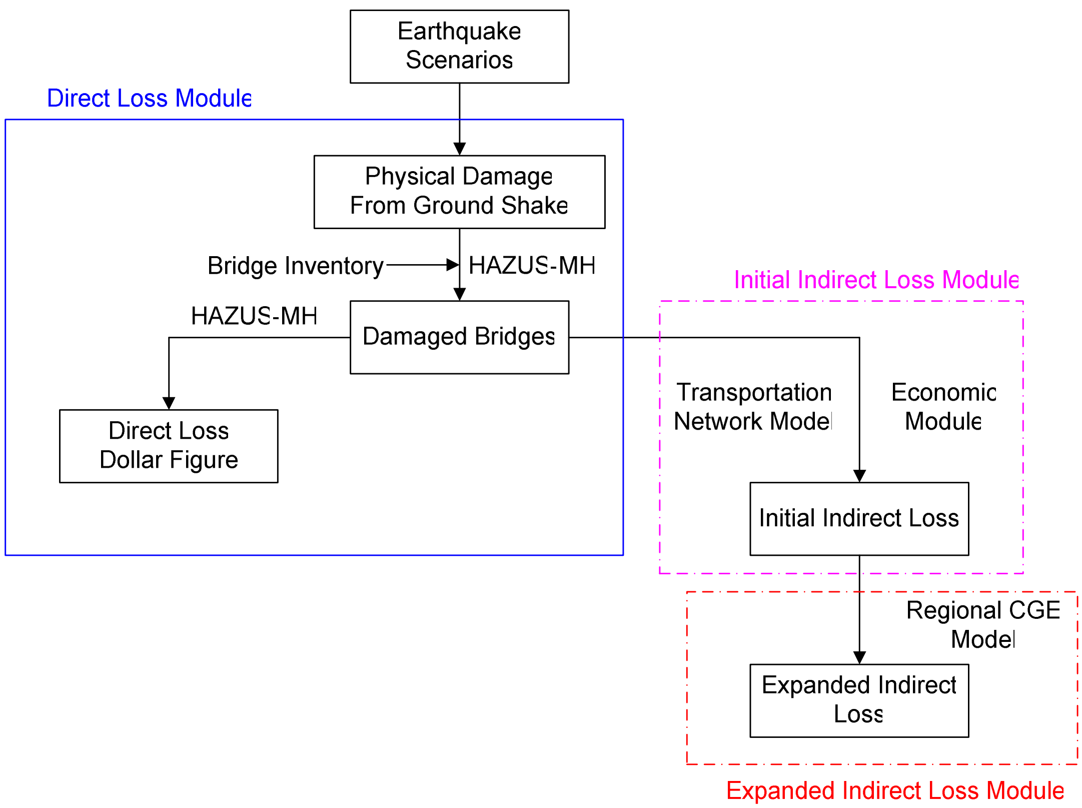


Figure 3.1. Loss Estimation Framework

3.3. DIRECT LOSS ESTIMATION MODULE

The definition of direct economic loss for this study is defined as the repair or replacement cost of the damaged bridges due to the earthquake incident. In this direct loss module, the HAZUS-MH (Multi Hazard) software is applied as the tool to estimate the direct loss. First, the St. Louis earthquake scenario is simulated, allowing the ground shake motion information to be collected. Next, this information is used as input to the HAZUS-MH software to generate the physical infrastructure damage, which is damage to the bridges for this study. The analysis is conducted dynamically along the time line since the bridges are recovered over time after the incident. The ATC-13 report (ATC, 1985) is applied as the guideline for the bridge recovery rate. Based on the ATC-13 bridge recovery chart for all damage states, the bridges will be fully recovered within 500 days after the incident. The time frame of this study, from days 1 to 500 after the incident, was selected based on the ATC-13 recovery chart. There are total of five points of time within the study timeframe selected as the study time points, including day 1, 30, 90, 250, and 500 after the incident. These points were selected to best represent the whole ATC-13 recovery chart. The information about the damage state of bridges in the highway network will be used as input for the initial indirect economic loss module. The direct economic loss module was conducted by Chen et al. (2005) as the part of a research project (Cooperative Agreement DTFH61-02-X-00009) at the University of Missouri-Rolla, funded by FHWA. This study applies the outcome from this project as the input. More detail about the direct loss estimation module can be found in the report (Chen et al. 2005).

3.4. INITIAL INDIRECT LOSS ESTIMATION MODULE

The total indirect economic loss for this study is the loss that occurs from the damage bridges, other than the repair or replacement cost. Other than the physical damage, the damage bridges will reduce the highway transportation capacity or even completely close some of the route in the network. This will obviously increase the transportation time and distance in the highway network, as well as the transportation cost. The definition of initial indirect loss is defined as the expected financial loss that occurs from increased transportation costs in the highway network due to the increased travel time and distance. These costs also play an important part when the cost benefit analysis of the road project is conducted.

This initial indirect loss module starts with information about which bridges are damaged and what damage state they are in. This bridge information will be used as input to the transportation planning model to estimate the increase in travel time and travel distance in the highway network. The regional highway transportation network model with the adjustable link capacity is required. With the adjustable model, the capacity of the link for the damaged bridges is adjusted to the actual status after the earthquake event.

Once the data is updated, the impact of the damaged bridges is introduced into a transportation model to evaluate the loss in transportation performance or traffic flow following the earthquake damage. The transportation model will then be run for each selected point of time after the earthquake incident and the result from each run will be compared with the baseline situation. The changes in travel time and distance for each point of time after the earthquake will then be observed.

The transportation network applied in this study is provided by the Metropolitan Planning Organization (MPO) in St. Louis, East-West Gateway (EWG) Council of Governments (http://www.ewgateway.org). EWG allowed for transportation highway network modeling runs on their computer hardware and software. In this transportation model, the entire study area is divided into a series of zones with different demographic characteristics (total of 1109 zones for the St. Louis metropolitan area). This EWG road network model covers all of the interstates, freeways, expressways, and other principal arterials in the study region. The model output gives the traffic data in detail of traffic from zone to zone, for each type of trip and time period of trip made.

The travel trip of this study can be classified by the trip purpose: work trip, non-work trip, or commercial trip. Work trip is a trip made from/to home to/from the work place, while a non-work trip is a trip made during non-business hours and not related with the individual's work. Work trips and non-work trips are arranged into the same group as the commuting trip. The commuting trip is a trip made by a person during his/her non-working hours, whereas the commercial trip is a trip where travel time is "on the clock" from the employer's point of view. In this study, it was assumed that all commercial trips are made only by freight companies.

For the time period of trips made, the traffic data output from the model is considered on an hourly basis. The 24 hours of a day are divided into 2 groups, peak time and off-peak time. The peak time period is 5 hours for each day, covering 3 rush hours in the morning and another 2 rush hours in the evening, while the remaining 19 hours of the day is considered as the off-peak time. The daily value of the initial indirect loss can be calculated from a weighted average of peak and off-peak periods of any single day.

The baseline scenario (year 2004 regular situation without an earthquake occurrence) and its associated dataset were provided by EWG. The land use data, housing units, household, and employment information are used by EWG as input data to generate the travel demand model for the St. Louis metropolitan area. This baseline scenario will be used later as the benchmark model for examining the changes in travel time and distance after the earthquake occurs. In order to introduce the damage from the earthquake into the highway system, the EWG transportation network had to be modified from the original 2004 baseline network. The damaged bridge information from HAZUS-MH was used as the input to modify the network. The damaged bridges were located on the EWG highway link and reduced the capacity in those links based on the damage state of the bridges. Then, a series of EWG transportation model runs had to be developed to determine the changes in travel time and distance for the study area. This part of the framework is also taken from the outcome of the Chen et al. (2005) study. Once again, more detail on the transportation model can be found in their report (Chen et al. 2005).

After the increased travel time and distance information is obtained, it will be used as the input for the economic module, which will transmit those changes into a dollar figure considered as increased transportation cost or initial indirect loss. This economic module is shown in Figure 3.2. In order to give a dollar value to the increased travel time and distance, the value of travel time and value of travel distance are required. They work as a medium to translate those changes from a time unit and distance unit into a dollar figure.

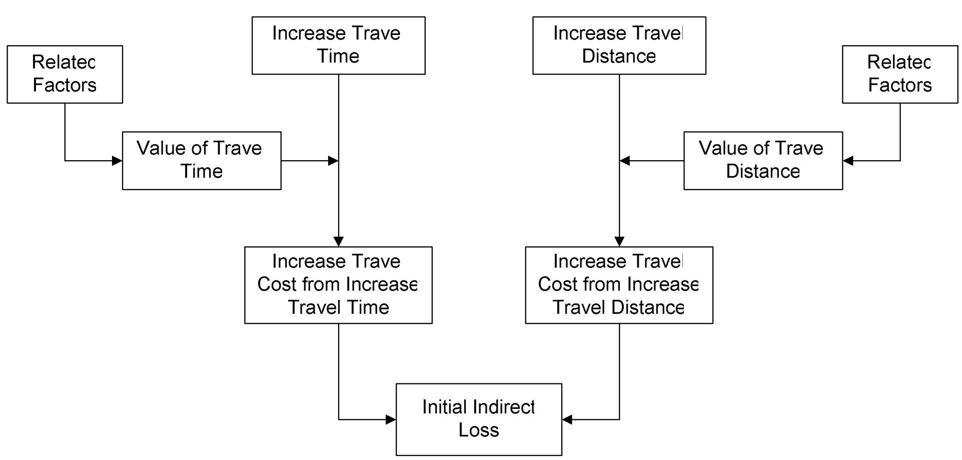


Figure 3.2. The Initial Indirect Loss Estimation Economic Module

The values of time and distance for the St. Louis regional need to be developed since these values are geologically varied based on related factors and the demographic data as discussed in Section 2.3.1 and 2.3.2. Most of the studies commonly refer to the value of travel time and distance in the perspective of savings. However, in this study these values need to be considered as the value of travel time delayed and the value of increased travel distance. Since there are two types of trips (commuting trips and commercial trips) in this study, the value of travel time and distance for each type of trip needs to be estimated separately. These values of travel time and distance estimations will be mainly developed based on the result from earlier studies due to the limitation of time and resources.

First, when considering the value of travel time for commuting trips, many international studies (Mackie et al. 2003; Gunn, 2001; VTPI, 2003) have showed that the value of time has a significant relationship with some of the demographic data, i.e., income and trip length. Collecting the demographic data from the study zones and combining it with the results of earlier studies, can develop an empirical model for the value of travel time. However, the results from these studies are varied based on the characteristics of the sample used in the studies. Thus, it might not be appropriated to apply these international study results with this domestic study. Fortunately, there is one recent domestic study conducted by the U.S. DOT. This study (U.S. DOT, 1997) is recommended as the guideline for applying the value of travel time for highway projects in the U.S. Therefore, for this study, the estimated value of travel time for both types of trip will be based mainly on the recommendation from U.S. DOT study (U.S. DOT, 1997), in combination with other studies' recommendations as additional supplements.

For the travel distance value of the commuting trip, there are different types of cost which are highly relevant to the vehicle owner doing the traveling. These costs are basically insurance costs, repair and maintenance costs, depreciation in value of the vehicle, and fuel cost. These costs are often called the cost of ownership. All of these costs are varied based on the travel distance made by the vehicle owner. They are also geologically varied. One recognized study in the estimation of cost of ownership per distance unit is the "Your Driving Cost" study conducted by Runheimizer Consulting

(AAA, 2003). The approach for estimation of the value of increased travel distance for commuting trips will be modified from this study.

Based on its definition, the commercial trips in this study refer to the trips made by freight companies only. It is obvious that some of the company resources have to be used to cover the increased travel cost due to the increase in travel time and distance. Usually, these are either the costs of more trucks and drivers or the cost of overtime and greater operating expenses of the company. Therefore, the value of the commercial trip travel time and distance should be valued from the consumer point of view, or at a price the consumer has to pay for the freight service. An earlier study by Waters et al. (1995) proposed a respectable approach to estimate the value of travel time of the commercial vehicle in this perspective. They considered all the operating expense costs of the freight company and related those costs to the time unit, achieving an estimated value of travel time. The Waters et al. (1995) study presented a framework that only estimated for the value of commercial trip travel time. For this study, estimation of both commercial trip travel time and distance will be developed by modifying this approach.

As shown in Figure 3.2, by applying the value of travel time and distance, the increased travel time and distance will be translated into a dollar value. Combining the increased travel cost from increased travel time with the increased cost from increased travel distance, the initial indirect loss, or the increased travel cost for one point of time, will be obtained. This process will be done for each point of time (day 1, 30, 90, 250, and 500) along the study time frame. The total initial indirect loss within the 500 days study timeframe can be approximated as the area under the graph between the initial indirect loss and time after the incident. The full detail about the value of travel time and distance estimation, along with the calculation process for the initial indirect loss, will be discussed later in Section 4.

3.5. EXPANDED INDIRECT LOSS ESTIMATION MODULE

The increased transportation cost can only be considered as the initial indirect loss. In addition to this increased travel cost, there will also be a ripple effect on the economy resulting from these costs. In a normal situation, the economy is in a particular equilibrium state. However, when an earthquake occurs, there will be the initial indirect loss introduced to the economy which will disturb the current economic equilibrium. Considering the economy as the system that consists of a group of different industrial sectors, the initial indirect loss must be allocated to the impacted sectors. For the producing sector, this additional cost will cause an increase in the production cost of the sector's output, and consequently the price of commodity. On the other hand, for the consuming sector this additional cost will reduce the spending allowance and eventually reduce the final demand of the commodity. The increased price for some of the commodities, along with spending reductions on some commodities, will cause more ripple effects. The economic system will then readjust itself until it reaches a new equilibrium state. The loss to the entire economic system can be labeled as the expanded indirect loss.

In order to estimate this expanded loss, the CGE model is selected as the tool based on a review of its capability as discussed in Section 2.2.2.3. First, the St. Louis regional CGE model of the current situation has to be developed as a benchmark model. Applying the initial indirect loss as an input, the effect from the earthquake can be introduced to the economic system by allocating the increased travel cost to impacted sectors via the CGE model. Then, the modified CGE model will be run to find the new equilibrium state after the earthquake event. Next, the benchmark equilibrium state will be compared with the new equilibrium state to examine changes in industrial sector outputs, commodity price, household income, and welfare levels. Finally, the expanded indirect loss will be estimated.

The benchmark CGE model for the St. Louis metropolitan area can be developed by using the SAM of the same area as input. The SAM will focus on the inter-industry relationship within the St. Louis area while considering the remaining areas as the rest of the world. The model will consider the transfer of goods and services between the St. Louis area and the rest of the world as import/export. The SAM can be developed from the input-output table information. This information is developed from many data sources, such as the Bureau of Economic Analysis, the Census Bureau, and the Bureau of Labor Statistic, among others. The CGE model will be developed by using the MPSGE module in the GAMS software as the programming language. The structure of the model will include a nested CES model in order to realistically deal with the problem and give more flexibility to the economic system.

For the nested CES model there are endogenous parameters that have to be specified before the model is run. These parameters are the elasticity of substitution for both the demand and production side. There are no specific values for these parameters. They are subjective values and regionally vary from product to product. The result from a literature review in this field of study will be used as the guideline to select these values. Additionally, in order to give some level of model validation, the simulation will be used to generate sets of elasticity values to be used for each run of the model.

In addition to the initial parameter values of concern, there is the issue in the method to introduce the initial loss into the model. With the limitation in the transportation model from the initial loss estimation, the increased travel cost will be considered from two types of trips: commuting trips and commercial trips. Based on their definitions provided earlier, commuting trips and commercial trips are made by the household sector and freight service sector, respectively. Therefore, for this study the initial indirect loss, or increased travel cost, is distributed to only two sectors in the economic system, defined as the decreased spending allowance for the household sector and the increase operating cost for the freight sector. To introduce the loss to the economic system, the production efficiency of the freight sector will be reduced and the production factor endowment from the domestic household will be changed.

As discussed earlier, the economic system in the benchmark model starts out at a particular equilibrium stage. Then, the initial indirect loss is introduced into the system and disturbs the initial equilibrium stage. Consequently, the system will adjust itself to the new equilibrium stage. At this point, the expanded indirect loss will be examined. However, the loss must be considered at a different timeframe from the initial indirect loss estimation. This is due to the fact that the CGE is an annual model. All the information used in developing the model are given as yearly values. Therefore, in the expanded indirect loss analysis, the estimated loss will only be for the year 2004. The introduction of the loss to the CGE model will be the accumulated initial indirect loss from the first day after the earthquake thru the 365th day after the incident.

Other than the capability in capturing the expanded indirect loss, the CGE model also provides the opportunity to measure the benefit of the preventive policy or the mitigation plan for the future earthquake. Assuming the preventive plan can reduce some amount of initial indirect loss, the magnitude of loss introduced onto the CGE model is different from the non-preventive situation. Then, the level of expanded indirect loss can be observed by running the series of CGE models. The reduced magnitude of total indirect loss compared with the non-preventive situation can be considered as a benefit from the preventive plan. The CGE model will become a tool for cost benefit analysis and will provide valuable information for policy markers in order to make the decision for future disaster planning. Full details of the CGE model development will be discussed later in Section 5.

4. INITIAL INDIRECT LOSS MODULE

This section presents the detailed work for each element in the initial indirect loss estimation module. The overall module can be divided into three connected parts as shown in Figure 4.1. The module begins with the transportation model, which provides the information about the changes in travel time and travel distance within the highway network. Next, these changes are translated into a dollar figure by the second part that applies the value of time and distance as the medium. Finally, these dollar figures will be summed up in the third part by another economic module, resulting in the initial indirect loss figure. This initial indirect loss module has been developed to estimate only the expected or average initial indirect loss that would occur without considering variation. It is also purposely designed to be easy to understand and update. To obtain the most accurate estimation, all information employed for developing the model regards the St. Louis/Midwest region with the information is obtained from reliable public sources, such as the Census Bureau, the Department of Transportation (DOT), Bureau of Transportation Statistics, etc. Section 4.1 provides the details of the applied transportation network model, the obtained output from this model, as well as its restrictions. Consequently, Section 4.2 describes the approach for developing the value of travel time and distance. Next, the economic model used to calculate the initial indirect loss figure is presented in Section 4.3. Finally, the results from this initial indirect loss module are shown, analyzed, and discussed in Section 4.4. This initial indirect loss result will later be used as the input for the expanded indirect loss module.

4.1. EWG TRANSPORTATION NETWORK MODEL

This transportation network model, as discussed earlier in Section 3.4, is originally provided by the Metropolitan Planning Organization (MPO) in St. Louis, East-West Gateway (EWG) Council of Governments (http://www.ewgateway.org). EWG provided the year 2004 base model which will be used as the benchmark and also will be modified in order to study the changes in the travel pattern within the highway network due to the earthquake incident. Those changes are part of the outcome of the project conducted by Chen et al. (2005) and will be taken as the input for this study.

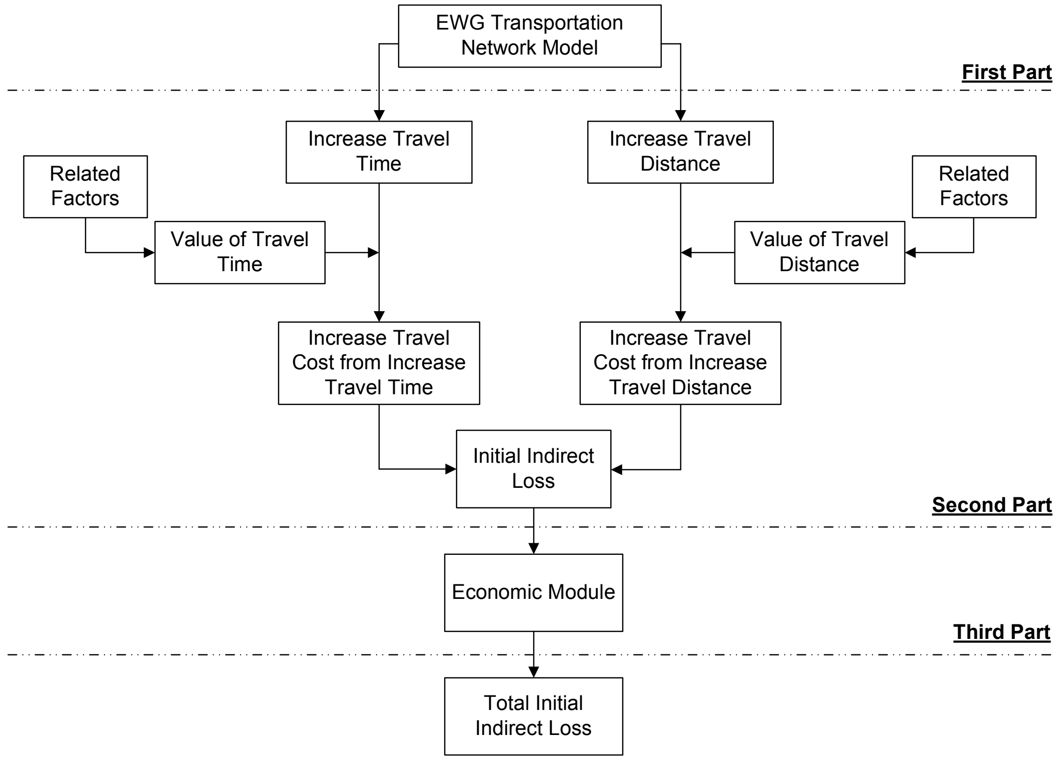


Figure 4.1. Diagram of the Overall Initial Indirect Loss Estimation Module

The EWG transportation model is an Urban Transportation Planning System (UTPS). The UTPS is the model used to predict the number of trips made within an urban area by trip type (work, non-work, etc.), time of day (peak period, daily, etc.), zonal origin-destination pair, mode of travel (bus, car, etc.), and routes taken through the transportation network by these trips (Enke et al. 2007; Chen et al. 2005). To produce the output, UTPS have to go through four traditional major stages which are trip generation, trip distribution, modal split, and trip assignment. There are various commercially calculation software packages to support UTPS-based modeling. MINUTP software is utilized by EWG as the core calculation package. The output of UTPS is a predicted set of modal flows on links in a transportation network. EWG model divides the entire geological study area into a series of zones with different demographic characteristics (total of 1109 zones for the St. Louis metropolitan area). The model output gives the traffic information (travel time and travel distance) in detail of flow from one zone to the others, as well as the traffic within the same zone. Although the EWG model can provide important information, it also has limitations that create some restrictions on the initial indirect loss estimation module.

First, each EWG model run considers the network condition within a single day. However, the output from each run (the traffic information) is on hourly basis for two time periods during the day (peak time and off-peak time). Therefore, the output is not actually a daily result. The weight average technique must be applied to approximate the traffic information in terms of a daily result. Next, the EWG model categorizes the trip within the network into three types, i.e., work trip, non-work trip, and commercial trip. However, the initial indirect loss estimation module will put these three types of trip into only two groups, i.e., commuting trips and commercial trips, as discussed earlier in Section 3.4. This is performed due to the vague definition of the work trip and in order to simplify the calculation process. The definition of the work trip is a trip made from/to home to/from the work place. Sometimes, this work trip can also be related to the business and has to be made during the business hours, however, it is impossible to justify and account for this type of trip. Thus, it is conservatively reasonable to put both work trips and non-work trips into the same group as the commuting trip and assume that these trips are made by the person from/to home to/from any other place and that the trips are made only during non-business hours. On the other hand, the commercial trip consider by the EWG model can also consider trips other than the trips made by the freight company, such as sales trips, business meeting trips outside the company ground, and utility workers trips, among others. However, it is again impossible to justify this type of trip. Therefore, as a conservative estimate, the commercial trips referred to in this study will be limited only to the trips made by the freight company.

The outputs of the transportation model are the matrices of travel time and travel distance, showing the traffic flow from/to each zone to/from the other, and within the same zone. The outputs from each run are four matrices of traffic information, two for the travel time during peak and off-peak time and the other two for travel distance during peak and off-peak time. In order to observe the changes in the network due to the earthquake, the run result from the counterfactual situation needs to be compared to the baseline scenario traffic information (year 2004 normal situation without an earthquake incident). These changes, which simply are the differences of traffic information between the modified situation and the baseline, will also be done in a matrix format. The resulting change matrices, along with the demographic data for the region, can then be utilized in the second and third part of the initial indirect loss module.

4.2. VALUE OF TRAVEL TIME AND TRAVEL DISTANCE

The output obtained from the transportation network includes the changes in traffic information due to the earthquake incident. Therefore, it is necessary to translate these numbers into a dollar figure. To perform the translation, the value of travel time and travel distance are necessary to transform the changes that are the values in time units and distance units into a dollar figure. The additional cost of travel or the initial indirect loss can simply be estimated by multiplying these values with the increased travel time and distance.

In order to estimate the value of travel time and travel distance, significant information needs to be gathered. This information will be gathered from reliable sources, such as the Bureau of Labor Statistic and Bureau of Transportation Statistics. All the detail regarding the description, the sources, the conversion approach, and the year of raw information used in developing the value of travel time and travel distance are listed in Appendix A. All of the calculations in this study will be performed on the same 2004 base year. Since the information comes from different sources, and some of data is from a different year base, the data update process is needed in order to bring the data to year 2004 base. The gathered information can be divided into two groups, i.e., the non-monetary information and the monetary information. Non-monetary information is information that is not in a dollar number, for example, the fuel consumption rate and annually vehicle travel mileage. This group of information will be updated by using the historical average value and regression analysis. On the other hand, the monetary information will be transformed using the Consumer Price Index (CPI) and Producer Price Index (PPI). The numbers from a consumer point of view, such as car price, insurance cost, repair cost, and fuel cost for commuting trip are updated using an average percentage increase in CPI from the year 1991 to the newest available year 2003. In a similar manner, the numbers related to the producer position, such as commercial vehicle price, maintenance and repair cost, insurance cost, fuel cost, and the driver's hourly wage are updated using the latest 10-year average percentage increase in PPI. The detail of CPI and PPI values are shown in Appendix B.

As discussed earlier in Section 2.3.1 and 2.3.2, the travel time and travel distance values are different from one type of trip to another, as well as the demographic information of the traveler. Thus, each type of trip will have different component factors and approaches to determine the value of travel time and travel distance. The following will discuss the two types of trips being considered, i.e. commuting trips and commercial trips.

4.2.1. Commuting Trips. In this study, commercial trips refer to the trips made by individual who live within study region, such as the trip from home to work place, from work place to shopping place, from shopping place back to home, etc.

4.2.1.1 Value of travel time. There are many existing studies in the field of travel time value. As previously mentioned in Section 2.3.1 and 3.4, different approaches have been developed for estimating the value of travel time, such as the survey approach (Ghosh, 2001) and the logit model approach (Nakamura and Kockelman, 2000). For this study, the empirical model of travel time value will be developed based on earlier studies by U.S. DOT (U.S. DOT, 1997). The U.S. DOT (1997) concluded that there is only a single demographic data point, the hourly wage rate, related to the value of time. The U.S. DOT suggested the plausible ranges of the travel time value at 35 – 60% of the hourly wage rate, with the recommended value at 50% of the hourly wage rate. The U.S. DOT stated that the valuation of increases in travel time is equal to the value of travel time savings. However, other studies (Waters et al. 1995; Gunn, 2001) stated that people typically value the delay time more than the savings time. Moreover, the U.S. DOT stated that there is no significantly difference in the value of time between work trips and non-work trips as long as they both are for personal travel. Thus, the conclusion is made that the value of time for all commuting trips is set at 60% of the hourly wage rate, which is in the upper range as defined by the U.S. DOT. In order to update this value, the U.S. DOT recommended updating only the hourly wage rate, but not the percentage of wage rate.

Therefore, the travel time value will be different from zone to zone due to the differences in income data of each zone in the study area. The income information was provided by EWG. The EWG data file included the land use information from the census which shows the number of households in each income level for each zone in the study area. A weighted average of zone income is used to represent the income for every person in that zone. The value of travel time for a person in a zone can be estimate by multiplying the weight average income of that zone by 60%.

4.2.1.2 Value of travel distance. There are different types of travel distance costs, all of which are highly relevant to the travel distance made by the vehicle owner. These components are different based on the utilization purpose of the travel distance costs. The two main purposes for developing the distance costs are for tax deduction reasons and for estimating the cost of ownership. Since the study's purpose is to find the costs that occur from the additional travel distance, the value of travel distance calculation for this study will be the approach modified from the AAA study (AAA, 2003). This AAA (2003) study was conducted by Runheimizer Consulting Company with the objective of estimating the vehicle ownership cost per travel distance unit. The components of the travel distance cost in the estimation process are insurance costs, repair and maintenance costs, depreciation, and fuel costs. Some initial assumptions (listed in Appendix C) must also be made in addition to the required information (listed in Appendix D and E). The template showing the estimation approach in detail is presented in Table 4.1. By using the regional values for all required information, the travel distance costs for the commuting trip for the St. Louis metropolitan area is estimated at $0.28 per kilometer in 2004 US dollars. This number will be applied for every commuting trip made in the study area.

4.2.2. Commercial Trips. As mentioned earlier in Sections 3.4 and 4.1, the business/commercial trips in this study are defined as the trips made only by freight companies. The commercial travel time and travel distance value estimation approach is developed based on the commercial vehicle travel time value study made by Waters, Wongs and Megale (Waters et al. 1995). The scope of that study was extended from only the estimation of the value of travel time, to also cover the estimation of the value of travel distance as well.

Table 4.1. Commuting Travel Distance Value Estimation Template

Commuting Trip Travel Distance Value				
	Information			
a)	Value of personal travel time		60%	of hourly wage
b)	Hourly wage		Varie by zone	
c)	Annual car insurance cost		$ 856.62	
d)	Annual car repair and maintenance cost		$ 667.80	
e)	Price of vehicle		$ 27,214.55	
	General Assumption			
f)	Depreciation per year of vehicle		12.00%	
g)	Assumed annual hour		2,000	hours
h)	Annual highway mileage		20775	kilometers
i)	Fuel consumption per mile		$ 0.05	per kilometer
j)	Number of person per car		1.316	people
	Cost of Distance Ownership			
1)	Distance repair cost	(d / h)	$ 0.03	
2)	Distance depreciation	(e x f) / h	$ 0.16	
3)	Distance insurance cost	(c / h)	$ 0.04	
4)	Cost of ownership by distance	(1 + 2 + 3)	$ 0.23	
5)	Fuel consumption per mile	(i)	$ 0.05	
	Value of Increased Distance	(4 + 5)	$ 0.28	per kilometer

Note: All figures are in year 2004 Dollar value

4.2.2.1 Value of travel time. Although commercial trips are made during the working time, the value of this time savings might not be valued at the wage rate of employees depending on how they spend this time (Waters et al. 1995). If the saving time is utilized as the employee leisure time, it should be valued as only a fraction of the employee wage rate. Conversely, since every commercial trip is made on the working time, the increase in travel time will result in a decrease in productivity. It is also inappropriate to value this delay time only at the employees' wage rate. This delay time should be valued at the employees' wage rate plus the relevant time based costs for operating the business. Since the estimation will be considered at the level of consumer price, the travel time value will also include the cost of money, company profit mark-up, and sales tax.

4.2.2.2 Value of travel distance. Following the same approach as for the travel time value, the components of travel distance value will include the costs that are relevant to travel distance. The main component of the travel distance cost is fuel consumption. The other costs, such as insurance costs, repair costs, and depreciation are partly relevant to both travel time and travel distance. As such, they are also taken into the consideration. In addition to these costs, company profit mark-up and sales tax are also considered. This will result in the cost of travel distance in the perspective of what consumers have to pay for the service, or the market price of the service.

Due to the availability of information and the simplification of the calculation, commercial vehicles are grouped into only two categories, i.e., truck and tractor plus trailer unit. There are some initial assumptions that need to be determined before the calculations. These assumptions, along with the predetermined values of the components used in the estimation, are listed and described in Appendix B, C, D, and F. The calculation approaches for both commercial travel time and distance are presented in Table 4.2. Part of the data employed in the analysis is from a nationwide survey conducted by the Bureau of Transportation Statistic (Annual Report: Motor Carrier Financial & Operation Information Database). Initially, the database was noisy, as it included missing values and outliners. To overcome these data issues, samples with missing values were dropped out from the analysis, whereas only the middle 80 percentile of data were used in order to eliminate the outliners. The number used to represent the truck and tractor information value from this survey database is the weighted average of the middle 80th percentile of data after eliminating the high and low 10 percentile outliers. The details are provided in Appendix F. Since there are two types of commercial vehicle considered in this study, the resulting numbers representing the commercial trip travel time and travel distance values will be determined by the weight average values of these two vehicle types. The estimated values, in year 2004 US dollars, are shown in Table 4.3.

Table 4.2. Commercial Travel Time and Distance Value Estimation

Commercial Trip Travel Time and Distance Value				
	Information		**Tractor + Trailer**	**Truck**
a)	Average cost of tractor/truck		$58,778.54	$42,357.28
b)	Average cost of trailer		$23,548.07	n/a
c)	Annual repair cost of truck/tractor/trailer		$4,662.73	$4,662.73
d)	Annual Insurance cost truck/tractor/trailer		$3,495.90	$3,495.90
	General Assumption			
e)	Average age of tractor/truck (year)		2.5	2.5
	Average age of trailer (year)		4	4
f)	Depreciation per year of tractor/truck		16%	16%
	Depreciation per year of trailer		12%	12%
g)	Depreciation due to time		40%	40%
h)	Repair/Maintenance due to time		20%	20%
i)	Cost of money		12%	12%
j)	Insurance due to time		15%	15%
k)	Assumed annual hour (hours)		2,000	2,000
l)	Annual highway mileage (kilometers)		48,383	48,383
m)	Fuel consumption per mile		$0.25	$0.25
n)	Profit markup		3.41%	3.41%
o)	Sales tax		6.95%	6.95%
p)	Driver hourly wage		$16.07	$16.07
q)	Driver wage burden		26%	26%
	Cost of Hourly Ownership			
	Tractor/truck			
1)	Hourly repair cost	(c x h) / k	$0.47	$0.47
2)	Hourly depreciation	(a x f x g) / k	$1.88	$1.88
3)	Hourly interest cost	(a - [a x e x f]) x i / k	$2.12	$1.52
	Trailer			
4)	Hourly repair cost	(c x h) / k	$0.47	n/a
5)	Hourly depreciation	(b x f x g) / k	$0.57	n/a
6)	Hourly interest cost	(b - [b x e x f]) x i / k	$0.73	n/a
7)	Hourly tractor/truck insurance cost	(d x j) / k	$0.26	$0.26
8)	Hourly trailer insurance cost	(d x j) / k	$0.26	n/a
9)	Hourly cost of ownership	sum of 1) thru 9)	$6.75	$4.13
10)	Profit markup	(9 x n)	$0.23	$0.14
11)	Sales tax	(9 + 10) x o	$0.49	$0.30
12)	Hourly value of vehicle time	(9 +10 + 11)	$7.47	$4.57
	Cost of Driver			
13)	Driver hourly wage	(p)	$16.07	$16.07
14)	Driver wage burden	(q)	26%	26%
15)	Driver hourly wage burden	(13 x 14)	$4.18	$4.18
16)	Hourly cost of driver	(13 + 15)	$20.25	$20.25
17)	Profit markup	(16 x n)	$0.69	$0.69
18)	Sales tax	(16 + 17) x o	$1.46	$1.46
19)	Hourly value of driver time	(16 + 17 + 18)	$22.39	$22.39
20)	**Value of Time Delayed** (per hour)	(12 + 19)	$29.86	$26.97

Table 4.2. Commercial Travel Time and Distance Value Estimation (continued)

Commercial Trip Travel Time and Distance Value (continued)

	Cost of Distance Ownership		**Tractor + Trailer**	**Truck**
	Truck/tractor			
21)	Distance repair cost	(c x [1 - h]) / l	$0.08	$0.08
22)	Distance depreciation	(a x f x [1 - g]) / l	$0.12	$0.08
	Trailer			
23)	Distance repair cost	(c x [1 - h]) / l	$0.08	n/a
24)	Distance depreciation	(b x f x [1 - g]) / l	$0.05	n/a
25)	Distance tractor/truck insurance cost	(d x [1 - j]) / l	$0.06	$0.06
26)	Distance trailer insurance cost	(d x [1 - j]) / l	$0.06	n/a
27)	Cost of ownership by distance	sum of 21 thru 26	$0.44	$0.22
28)	Fuel consumption per mile	(m)	$0.25	$0.25
29)	Cost of operating by distance	(27 + 28)	$0.69	$0.47
30)	Profit markup	(29 x n)	$0.02	$0.02
31)	Sales tax	(29 + 30) x o	$0.05	$0.03
32)	**Value of Increased Distance**	(29 + 30 + 31)	$0.76	$0.52

Table 4.3. Value of Commercial Vehicle Travel Time and Distance

	Tractor & Trailer	Truck	Weighted average
Value of Time Delayed (per hour)	$29.86	$26.97	**$29.06**
Value of Increased Distance (per kilometer)	$0.76	$0.52	**$0.70**

Note: The values in table are in year 2004 dollar values

4.3. ECONOMIC MODULE FOR INITIAL INDIRECT LOSS CALCULATION

The third part of the model is the economic module and resulting calculations. For this part, all information obtained from the previous parts, including the changes in traffic information (between the baseline and the counterfactual scenario) and the values of travel time and travel distance, will be put through the calculation process in order to achieve the total initial indirect loss for the St. Louis area. Basically, the initial indirect loss is the integration of the increased travel cost of each route within the study area. In other words, it could be stated that the calculation process for the third part is the summation process of the initial indirect loss due to the earthquake from each traffic route within the study area. This calculation can be expressed as in the following equation:

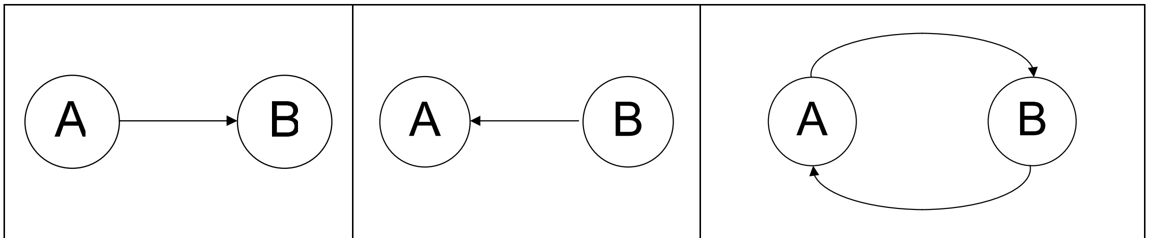
$$\text{Total Initial Indirect Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} \text{Loss from increase travel time of route ij} + \sum_{i=1}^{n}\sum_{j=1}^{n} \text{Loss from increase travel distance of route ij} \qquad \text{Eq. 4.1}$$

i = Route origin zone number

j = Route destination zone number

n = Total number of zones in the study area

Equation 4.1 shows that the loss is calculated separately for each travel route instead of for each study zone. The reason why the loss must be calculated on the travel route level is due to the travel time value issue is explained as follows. The travel time information output from the EWG highway network is in the matrix format showing the total amount of travel time from zone to zone during a certain period of time. For example, one value in the output matrix will present the total amount of time consumed by all trips from zone A to zone B during the peak hours. The caution that has to be stated is that the time value for each zone can not be applied to all the trips from that zone to the others. This can be explained by Figure 4.2. Consider the trips that occur between zone A and zone B. The time value for a person in zone B could be used when the trip is made by a person who originally lives in zone B. However, all trips made from zone B to zone A are not only made by individuals who live in zone B, but also by the returning travelers who originally live in zone A. Therefore, assumptions have to be made. First, the time value of each zone will be used only for the trips made within that zone. Second, for the trips between each pair of zones, the average time value of that pair will be applied as the time value for those trips. This results in a loss calculation for each travel route instead of for each zone. All the calculations will be done in a matrix form with the matrix represented as the number of study zones by the number of study zone. Finally, to obtain the loss figure of the whole study area, all of the elements in the matrix will be summed up as shown in Equation 4.1.



Trip of person in zone A from zone A to zone B	Trip of person in zone B from zone B to zone A	Trip of person in zone A from zone A to zone B and then his/her return trip from zone B to zone A

Figure 4.2. Travel Route Illustration

From Equation 4.1 it can be seen that the initial indirect loss consisted of two types of loss, which are the loss from increased travel time and loss from increased travel distance. These two types of loss for each travel route can be presented in more detail by describing it based on different types of trip. The detail of loss from increased travel time for each travel route ij in Equation 4.1 can be expressed as the following series of equations:

Loss from increase travel time for route ij = Loss from increased commuting trip travel time for route ij + Loss from increased commercial travel time for route ij   Eq. 4.2

Loss from increased commuting trip travel time for route ij = (percentage of work trip traffic + percentage of non-work trip traffic) × (number of passenger per vehicle) × (value of commuting trip travel time) × (personal income for people who make route ij trip) × (increased travel time for route ij)   Eq. 4.3

Loss from increased commercial trip travel time for route ij	=	(percentage of commercial trip traffic) × (value of commercial trip travel time) × (increased travel time for route ij)	Eq. 4.4

In the same way, the loss from increased travel distance can be expressed in the following equations:

Loss from increased travel distance for route ij	=	Loss from increased commuting trip travel distance for route ij + Loss from increased commercial travel distance for route ij	Eq. 4.5
Loss from increased commuting trip travel distance for route ij	=	(percentage of work trip traffic + percentage of non-work trip traffic) × (value of commuting travel distance) × (increased travel distance for route ij)	Eq. 4.6
Loss from increased commercial trip travel distance for route ij	=	(percentage of commercial trip traffic) × (value of commercial travel distance) × (increased travel distance for route ij)	Eq. 4.7

For the sake of simplicity, there are some assumptions that have to be made in the initial indirect loss estimation before the actual calculation can be made. First, the percentages of different types of trip (work trip, non-work trip, and commercial trip) are the same for every zone throughout the study area. The number of passengers per vehicle is also assumed to be the same for every zone, and all passengers in the vehicle are adults. The number of passenger per vehicle for the commuting trips is represented by the weighted average of different types of commuting trips. It is assumed that there is only the driver in the vehicle for the commercial trip. Moreover, some assumptions from the calculation of time and distance value are vital to the indirect loss estimation results. Those assumptions include the vehicle highway mileage travel per year and the number of annual working hours. The assumptions for all calculation are presented in Appendix C.

In addition to these assumptions, a data preparation process is required. It can be seen from Equation 4.3 that the income data is required to estimate the loss from increased commuting travel time. This value will be different for each trip since it depends on the origin and destination of the trip, as discussed earlier. The data used to develop the income matrix is the land use data from census data applied during the trip generation process of the EWG transportation model. The data are projected onto year 2004 and are in the form of the number of households in different income groups for each study zone. Using the median value of each income group, the number used to represent the income value for each zone is the weighted average income value based on the number of households in each income group.

Some of the zones have a missing data problem due to the land use characteristic for those zones. Thus, assumptions need to be made. First, for the trips within that zone, the weighted average income for all zones will be used to estimate the value of time for those trips. Second, the weighted average income for all zones will again be used to estimate the value of time for the trips between the zones which have no data. Third, for the trips between a zone without data and a zone that has data, the income data for the zone with data will be used to estimate the value of time for those trips.

The study area of this initial indirect loss estimation covers both internal and border zones of the St. Louis metropolitan, for a total of 1109 zones. Since the people who live in the border zone are spending time and consuming the network capacity while they are traveling into the inner zones, the border zones are also included in the analysis. However, the data is available for the inner 1066 zones only. The last assumption is that the income of the inner zone will be used to estimate the travel time value for the trips between the inner zone and the border zone, whereas the weighted average income for all zones will be used for the trips between and within the border zones themselves. Combining these assumptions with the previous assumptions discussed for the commuting travel time, the income matrix can then be developed. The MatLab® coding for preparing this income matrix is shown in Appendix G.

With all the initial assumptions, information gathering, and preparation, the actual calculation process can proceed using Equation 4.1. The input of the calculation is the changes in travel time and travel distance on hourly basis during peak and off-peak periods of the day. Therefore, the initial indirect loss will also be initially estimated on an hourly basis during peak and off-peak periods. The peak and off-peak period values will be calculated separately. Consequently, the daily initial loss figure is attained by finding the 24-hour weighted average of the hourly loss number during both the peak and off-peak periods. The most affected route for each scenario is also pointed out during the calculation. During the calculation process, the MatLab® software package was used as the calculation tool due to its capability in handling large matrix/array calculations. MatLab® coding script is available in Appendix H. The calculation will be conducted for a series of specific points of time along the time horizon after the earthquake event.

4.4. INITIAL INDIRECT LOSS MODULE RESULTS AND DISCUSSION

4.4.1. The Module Result. Depending on the input matrix, the output for each calculation from the third part of the initial indirect loss module is the hourly initial indirect loss during the either peak or off-peak period. This peak or off-peak hourly loss number is the loss number at only one specific time after the incident. The time horizon considered in this study starts from day 1 through day 500 after the earthquake incident with specific observation points at days 1, 30, 90, 250, and 500 after the incident. This timeframe was selected based on the recovery curve from the Applied Technology Council document ATC-13, "Earthquake Damage Evaluation Data for California" (ATC, 1985). The ATC-13 recovery chart presented that with any level of damage, the bridge will be fully recovery within 500 days after the earthquake incident. In the same way, the specific points of observation time were selected with regard to the ATC-13 chart. These points were selected in order to create the best representative points for the whole ATC-13 recovery curve.

The obtained output from the calculation is in an hourly basis. However, the desired output is the daily initial indirect loss for each specific time after the incident. Thus, the daily value will be estimated from the 24-hour weighted average of the hourly loss during peak and off-peak period, as mentioned in Section 3.4. The peak period is 5 hours for each day (3 rush hours in the morning and another 2 hours in the evening), while the off-peak period is the remaining 19 hours in the day. The initial indirect loss results can be properly illustrated as a graph between the daily initial indirect losses versus the day after the incident, as shown in Figure 4.3. The details for the calculated initial indirect loss number can be found in Tables 4.4 and 4.5, along with the most effected travel route in the study area. By examining these numbers it can be seen that a large portion of the loss comes from the loss due to the increased travel time. This had also been stated in other studies (VTPI, 2003). The cost in travel is mostly from the travel time.

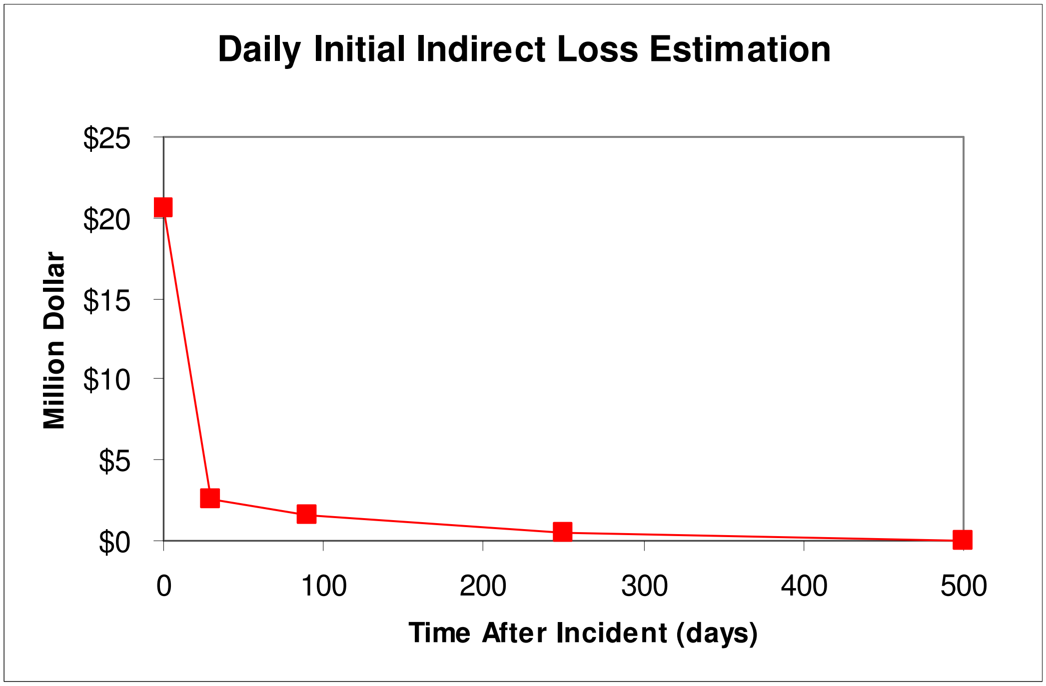


Figure 4.3. Daily Initial Indirect Loss

Table 4.4. The Detail Initial Indirect Loss Number and the Most Affected Route Detail

		Hourly Initial Indirect loss (2004 USD)			**Most Affected Route**		
@ Day	**Period**	**Distance Cost**	**Time Cost**	**Total Cost**	**From Zone**	**To Zone**	**Cost**
1	**Peak**	$610,506.97	$1,006,611.97	**$1,617,118.94**	864	597	$27.14
	Off-Peak	$135,969.80	$521,944.34	**$657,914.14**	1107	1047	$9.44
30	**Peak**	$5,149.38	$102,124.00	$107,273.38	820	266	$8.22
	Off-Peak	-$7,706.05	$116,208.74	$108,502.69	1107	1043	$9.44
90	**Peak**	-$30,956.78	$149,301.50	$118,344.72	338	763	$8.19
	Off-Peak	-$37,733.92	$87,231.79	$49,497.87	363	780	$7.16
250	**Peak**	-$31,747.64	$63,050.70	$31,303.06	1071	431	$7.11
	Off-Peak	-$13,832.72	$33,739.87	$19,907.14	159	899	$6.77
500	**Peak**	$0.00	$0.00	$0.00	n/a	n/a	n/a
	Off-Peak	$0.00	$0.00	$0.00	n/a	n/a	n/a

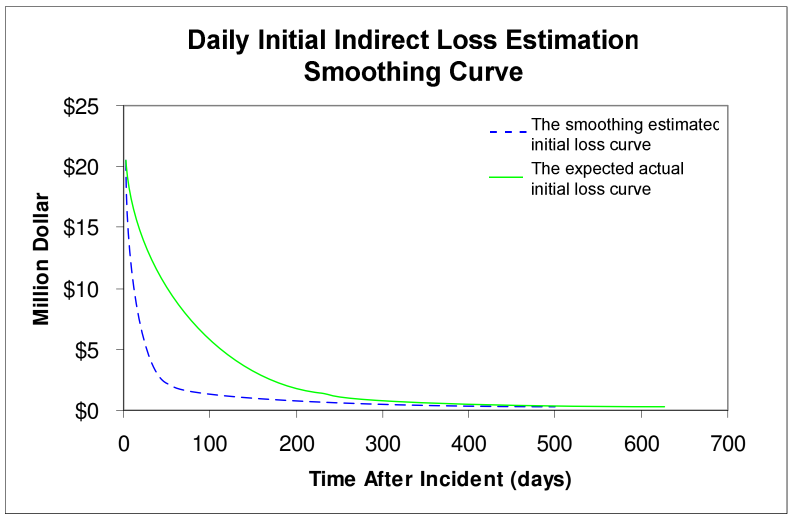
Table 4.5. The Daily Initial Indirect Loss Number

	Study Scenario (Million Dollar)		
@ Day	**Peak**	**Off-Peak**	**Daily Loss**
1	**$4.23**	**$1.55**	**$20.59**
30	$2.90	$0.67	**$2.60**
90	$2.90	$0.68	**$1.53**
250	$2.93	$0.62	**$0.53**
500	$0.00	$0.00	$0.00

In order to report the loss or to compare the result with other studies, a single figure of loss is needed. The total initial loss for the incident is the integration of the daily initial loss from the incident day through the day when the system is fully recovered, such that the overall initial indirect loss can be approximated by the area under the graph of daily initial indirect loss from day 1 through day 500 after the incident. Following this approach, the initial indirect loss for study scenario is estimated at $703.86 million. Utilizing the HAZUS software package, the direct loss for the same scenario was estimated at $1.3 billion (Chen et al. 2005). Considering the magnitude of the initial indirect loss, it is a significant amount when compared to the direct loss figure, at about 55%.

This estimated initial indirect loss is difficult to justify. The number estimated by other studies (Boarnet, 1996; Gordon and Richardson, 1995; Ho, 2001; OTA, 1995; Petak and Elahi, 2000) for the previous earthquake incidences vary even for the same incidence. For example, the damage of Northridge earthquake in 1994 was estimated to range from $25.5 billion to $53.3 billion (2004 US dollar) for the direct loss and from $7.6 billion to $9.56 billion (2004 US dollar) for indirect loss. The direct loss in those studies included the loss in infrastructure, including highways, buildings, and residences, whereas the indirect loss included all business interruptions. Since the study scope focus was only on the damaged bridges within the highway network, the direct loss is just the cost to recover those damaged bridges. In a similar manner, the initial indirect loss is the increased transportation cost resulting from those damaged bridges. Therefore, the indirect loss numbers from earlier studies are much larger than the initial indirect loss number estimated here. Nonetheless, the estimated numbers are in the general range.

Moreover, the estimated initial indirect loss number is based on the ATC-13 recovery curve. The ATC-13 curves were developed from the survey of expert opinion in the California area. The construction companies and related organizations in California have much more experience than in the Midwest. Therefore, the actual loss for the study scenario is likely to have a longer effect and a larger total magnitude than the estimated figures. The actual loss for the study scenario should be as shown in Figure 4.4.



Note: the expected loss curve is just an assumption curve and not to scale

Figure 4.4. Estimated and Expected Initial Indirect Loss Smoothing Curves

4.4.2. Sensitivity Analysis. The initial indirect loss estimation is constructed from many variables, such as value of travel time, value of travel distance, and the personal annual income in the study area, among others. Although these values are taken from the literature or developed based on reliable information sources, they are still somewhat difficult to justify. Furthermore, there are some crucial assumptions made during the value of travel time and travel distance estimations, as shown in Appendix C. Among the variables and assumptions, three are likely to have a significant influence on the total initial indirect loss estimation result, including the annual working hours, the value of commuting travel time, and the annual highway mileage travel. Therefore, it is worth conducting a sensitivity analysis between the estimated total initial indirect loss and these three factors in order to give some justification for the estimation.

The sensitivity analysis is conducted by varying the value of one factor from -20% thru +20% of the standard value, while holding the other two constant at their standard values. The results from the analysis are shown as follows in Figure 4.5. Two of the three factors in this analysis are associated with the additional cost that occurs from the increased travel time. These two factors, annual working hours and the value of commuting time, are found to be important factors when estimating the initial indirect loss. Value of commuting time has a strong positive linear relationship with the initial indirect loss value, whereas the annual working hours has a strong negative nonlinear relationship with the initial indirect loss figure. On the other hand, annual mileage travel, which accounts for the additional cost resulting from increased travel distance, shows a weak relationship with the initial indirect loss number. By changing the annual mileage travel by 20%, the estimated initial indirect loss will change only about 3%. The details of the sensitivity analysis can be found in Table 4.6.

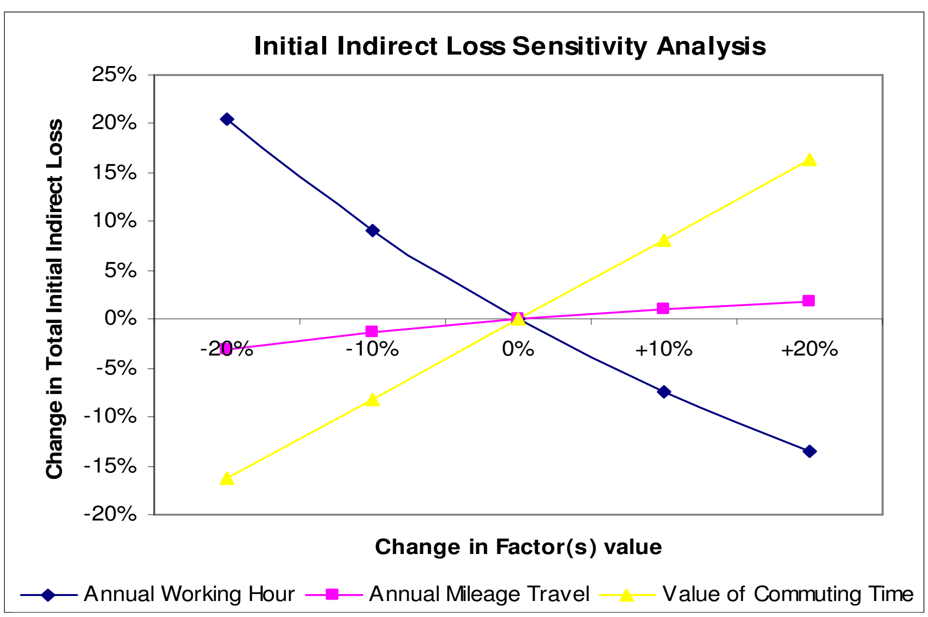


Figure 4.5. Sensitivity Analysis Chart

Table 4.6. The Detail Figure of Sensitivity Analysis

	Total Loss Partial Indirect Loss (Million Dollar)		
Change by	Annual working hour	Annual mileage	Value of time
-20%	$847.49	$682.03	$588.96
-10%	$767.69	$694.81	$646.41
0%	$703.86	$703.86	$703.86
+10%	$651.63	$710.65	$761.31
+20%	$608.11	$717.17	$818.76

According to the results, it can be concluded that the assumptions made relating to the travel time calculations have more of an impact on the partial indirect loss estimation result than the assumptions made for the travel distance. This conclusion seems reasonable since the increased travel time cost accounts for a large portion of the total initial indirect loss. Thus, it is important to make a rational justification for the high influence of these assumptions in order to achieve reliable initial indirect loss estimation.

5. EXPANDED INDIRECT LOSS ESTIMATION MODULE

This section describes the details of expanded indirect loss estimation module. This module takes the results from the initial indirect loss estimation module as inputs. The key theory applied in this module is the Computable Generalized Equilibrium (CGE) model. First, the economic system is modeled as a system consisting of several industrial sectors, households, and the government. It is assumed that initially the economic system is in the equilibrium stage. Introduction of the initial loss from the earthquake scenario into the impacted industrial sectors will disturb the equilibrium of the system. Consequently, the system will adjust itself until the new equilibrium stage is achieved. By comparing the new equilibrium stage with the initial stage, the indirect economic loss of the entire economic system can be examined and estimated. Section 5.1 introduces the elements of the modeled economic system in this module and explains the relationship among each element. Section 5.2 provides detailed information of the CGE model in terms of both an analytical and numerical perspective. The data and information used to build the CGE model and the process for developing the SAM are explained in Section 5.3. The discussion about the tool utilized for solving the problem, along with the process to develop the CGE model, is presented in Section 5.4. Finally, the results of the module are discussed and analyzed in Section 5.5.

5.1. THE MODELED ECONOMIC SYSTEM

The general equilibrium theory by itself involves the study of simultaneous equilibrium in all markets of the entire economy (Nicholson, 1994; Shoven and Whalley, 1992). The prices and production of all goods are interrelated. A change in the price of one good, say fuel, may affect another price, such as transportation service. If the price of fuel goes up, the price of transportation service might go up as well. The demand for fuel might be affected by a change in transportation service demand, with a consequent effect on the price of fuel. Calculating the equilibrium price of just one good, in theory, requires an analysis that accounts for all of the millions of different goods that are available. Therefore, it is practically impossible to find the equilibrium state freely without some restrictions. In order to make the general equilibrium state as a computable problem or

CGE model, it is necessary to apply some conditions to the modeled economic system. First, the modeled economic system must follow the Arrow-Debreu model. Second, the conditions of equilibrium state are the same as the conditions of Walrasian equilibrium. (Shoven and Whalley, 1992; Partridge and Rickman, 1998)

As discussed earlier in Section 2.2.2.3, the Arrow-Debreu model considers the economic system as a system consisting of a series of commodities (industrial sectors) and consumers (domestic households and foreign households). In this study, those elements can be grouped into three large groups with different roles: Producer, Households, and Government. There are relationships between each element in the form of monetary and non-monetary transfers between themselves, as shown in Figures 5.1 and 5.2, respectively.

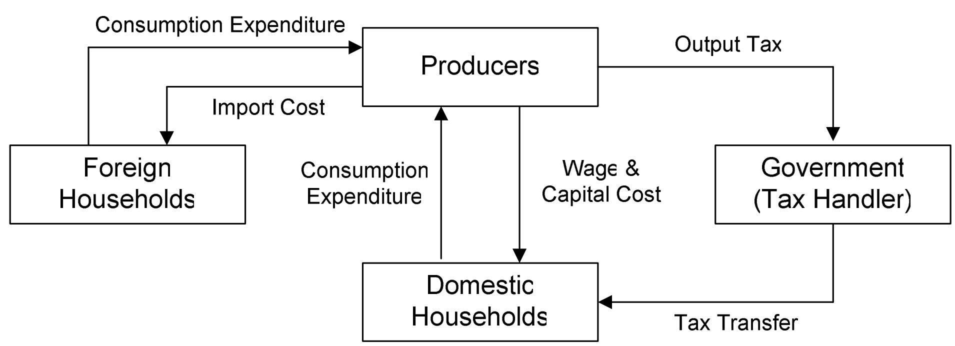


Figure 5.1. Monetary Transfer Within the System

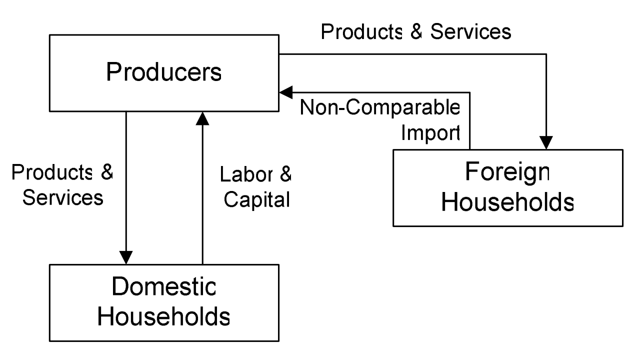


Figure 5.2. Non-Monetary Transfer Within the System

5.1.1. Producers. Producers are the ones who produce goods and services and sell them to the market. Producers employ the primary factors, labor, and capital provided by the domestic households, intermediate commodities from their own sector and other industrial sectors, and imported intermediate provided by the foreign households as input in the production processes. The behavior of Producers and the relationship among the output and required inputs in production can be mathematically explained by a production function or production technology. The production technology can be expressed in a certain function format, such as Cobb-Douglas, Constant Elasticity of Substitution (CES), etc. (Varian, 1993; Shoven and Whalley, 1992). Producers pay wages and capital cost to Domestic Households and the non-comparable imported intermediate cost to Foreign Households, both as compensation. Producers are also required to pay output tax to the government. Producers generate their incomes from selling their goods and services to the market, as intermediate input and final demand commodities. In this study government organizations and enterprises are included as Producers and treated as the industrial sector. A nested production function of the CES function, the Cobb-Douglas function, and the Leontief function are selected to express the production technology for this study. The detailed structure of the nested production function will be discussed later in Section 5.2.1.

5.1.2. Households. Households have the role as the consumers and the primary factors supplier, as well as the imported intermediate provider. There are two groups of households in this study: Domestic Households and Foreign Household. Domestic Households come into the market with primary factor endowments, labor supply and capital. However, not all of the labor endowment will go toward Producers, since part will also be consumed as leisure time. Their income comes from the wage and return of capital received from Producers, as well as the transferred tax from the Government. Domestic Households spend their income consuming products and services from Producers based on their preference. Domestic Households also choose between providing for the labor supply and capital, and/or consuming commodities and leisure time based on their preferences. The preference can be expressed by a utility function in the certain format, such as Cobb-Douglas, CES, etc. (Shoven and Whalley, 1992). Again, for this study, the nested function between CES function and Cobb-Douglas function is selected to express the utility function for Domestic Households. On the other hand, Foreign Households come into the market as the provider of non-comparable imported intermediate commodities, or the required intermediate input that is not available domestically. Their income is basically the price of these imported intermediate commodities paid by Producers. At the same time, Foreign Households spend their income consuming products and services from Producers based on their preference. The utility function for Foreign Household in this study is expressed by Cobb-Douglas function. The detail of the utility function for both Domestic Households and Foreign Households is discussed in Section 5.2.2.

5.1.3. Government. In this study, the government plays only the role of tax handler. The government collects output taxes from Producers and distributes all of that money back to Households as wealth distribution. Government organizations and enterprises which produce and consume some goods and services in the economic system are treated as an industrial sector in Producers as discussed above.

5.2. THE CGE MODEL STRUCTURE AND EQUILIBRIUM STATE

Since the modeled economic system is in the form of the Arrow-Debreu model, the system is considered as a competitive market. In a competitive market, it is assumed that there are many suppliers in the system, each with an insignificant share of the market. In the same industrial sector, each firm produces an identical product and has same level of access to resources and production technology. Moreover, consumers are assumed to have perfect information about the prices all sellers in the market charge (Varian, 1993). Therefore, all transfers within the system are purely price driven transfers. For example, if the price of one product goes up, consumers will substitute that product with others based on their preference, and vice versa. By changing prices of products and factors in the system, these transfers will continue until the system reaches equilibrium, which is when the supply of all producers and the demand of all consumers are in balance in all markets (Partridge and Rickman, 1998).

The behavior of each agent in the system along with their constraints and the conditions at which the system will reach the equilibrium state can be expressed in a mathematical equation. In this section, the analytical and numerical models for the supply side (or Producers) and for the demand side (or Households) are discussed in detail, as well as the equilibrium condition and the objective of the model.

5.2.1. Producers Behavior. The Producer behavior of the CGE model in this study is represented by a multi-layered CES production function for each sector. The CES function is used to exhibit substitution possibilities available to Producers. The CES function has a constant elasticity value within the same layer but the nested function allows for the use of different substitution elasticity values for different inputs. In other words, the nested CES function allows different elasticity across the layer. There are two special cases for CES function – when the elasticity value equal to 0 or 1 (Shoven and Whalley, 1992). For the case where the elasticity is equal to 1, the production technology is explained in the format of Cobb-Douglas. On the other hand, when the elasticity is equal to 0, the production technology is basically the Leontief function.

In this study, the input required in production of any particular commodity is categorized into two large aggregated groups, i.e., aggregated material and value added input. Aggregated material is the composite of all intermediate commodities required in the production process of a particular commodity, as well as the non-comparable import material. On the other hand, value added input basically consists of labor supply and capital. The diagram in Figure 5.3 demonstrates the characterization of the production function for any particular commodity X_i. It is assumed that there are total of N commodities in the system.

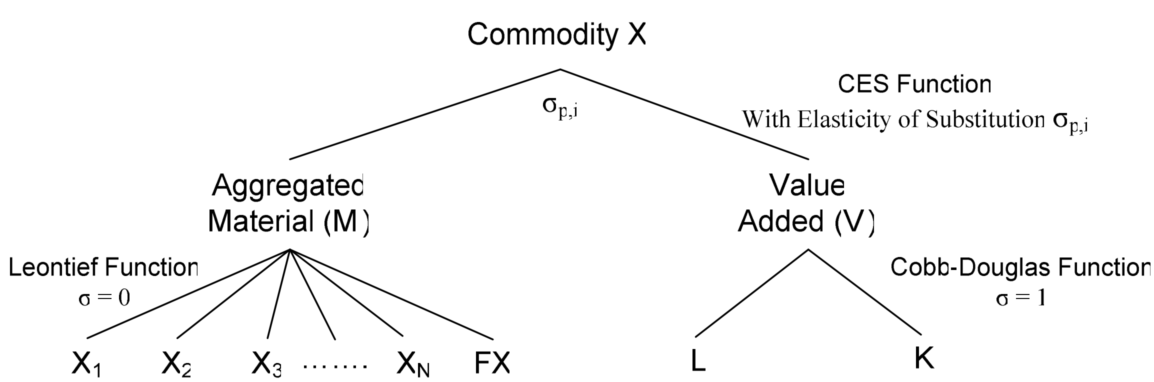


Figure 5.3. The Production Technology Diagram

Equation 5.1 describes the top layer of the production function. It states that the industrial sector X_i has the CES function of aggregated material and value added.

$$X_i = (1+T_i)\left[\beta_{m,i} M_i^{\rho_{p,i}} + \beta_{v,i} V_i^{\rho_{p,i}}\right]^{\frac{1}{\rho_{p,i}}} \qquad \text{Eq. 5.1}$$

X_i = Output of commodity from industrial sector i

M_i = Aggregated material required to produce commodity X_i

V_i = Combination of value added required to produce commodity X_i

$\beta_{m,i}$ = Aggregated material share factor in production of X_i

$\beta_{v,i}$ = Value added share factor in production of X_i

T_i = Output tax of commodity X_i

$\rho_{p,j}$ = Degree of substitutability between the aggregated material and value added for the production of commodity X_i

$\sigma_{p,i}$ = Constant elasticity of substitution for the production of commodity X_i

where

$$\sigma_{p,i} = 1 - \rho_{p,i} \qquad \text{Eq. 5.2}$$

Equation 5.3 expresses the left branches at the lower layer of the nesting diagram in Figure 5.3. It describes that the aggregated material is a Leontief function which is a linear function consisting of intermediate commodities and non-comparable import.

$$M_i = (\beta_{1,i} X_1 + \beta_{2,i} X_2 + ... + \beta_{N,i} X_N + \beta_{FX,i} FX_i) = (\sum_{j=1}^{N} \beta_{j,i} X_j + \beta_{FX,i} FX_i) \qquad \text{Eq. 5.3}$$

M_i = Aggregated material required to produce commodity X_i

X_j = Commodity from industrial sector j used as intermediate input in aggregated material M_i

FX_i = Non-comparable import intermediate required in aggregated material M_i

$\beta_{j,i}$ = Intermediate commodity X_j share factor in aggregated material M_i

$\beta_{FX,i}$ = Non-comparable import intermediate share factor in aggregated material M_i

The other branch in the lower layer of production function can be expressed as in Equation 5.4. This branch represents the aggregated value added V_i which consists of labor and capital. It exhibits the value added as the Cobb-Douglas function between labor and capital.

$$V_i = (L_i^{\alpha_{v,i}} K_i^{1-\alpha_{v,i}}) \qquad \text{Eq. 5.4}$$

V_i = Combination of value added required to produce commodity X_i

L_i = Labor supply required as input for value added V_i

K_i = Capital required as input for value added V_i

$\alpha_{v,i}$ = Labor supply share factor in value added V_i

In the economic system, Producers attempt to maximize their profit basically by minimizing their production cost. The production cost and price of commodity X_i are expressed in Equation 5.5 and 5.6.

$$c_{X_i} = \sum_{j=1}^{N} \left(p_{X_j} b_{j,i} + p_{FX} b_{FX,i} \right) + p_L l_i + p_K k_i \qquad \text{Eq. 5.5}$$

c_{X_i} = Cost of commodity X_i

$b_{j,i}$ = Number of unit of commodity X_j required to produce one unit of commodity X_i

$b_{FX,i}$ = Number of unit of non-comparable import required to produce one unit of commodity X_i

l_i = Number of unit of labor supply required to produce one unit of commodity X_i

k_i = Number of unit of capital required to produce one unit of commodity X_i

p_{X_j} = Price of commodity X_j

p_L = Wage rate per unit of labor supply

p_K = Capital cost per unit of capital

p_{FX} = Price per unit of non-comparable import

$$p_{X_i} = (1+T_i)c_{X_i} \quad \text{Eq. 5.6}$$

p_{X_i} = Price of commodity X_i

c_{X_i} = Cost of commodity X_i

T_i = Output tax of commodity X_i

5.2.2. Households Behavior. For this study, Households are divided into two groups: Domestic Households and Foreign Households. The nested CES function is selected to represent Domestic Households behavior and the Foreign Households behavior is expressed in Cobb-Douglas function.

5.2.2.1 Domestic Households behavior. The structure of Domestic Households welfare function is shown in Figure 5.4. The upper layer of the diagram represents that Domestic households select between the aggregated consumption (C_d) and leisure time (Leis) based on the CES function as described in Equation 5.7.

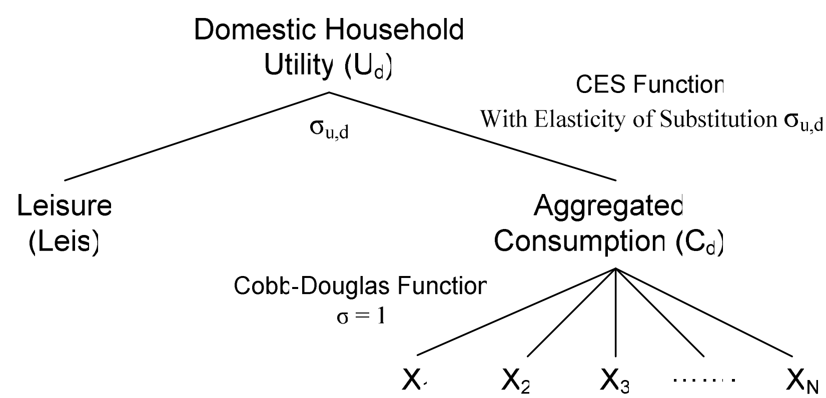


Figure 5.4. The Utility Function Diagram for Domestic Households

$$U_d = (\beta_{Leis} Leis^{\rho_{u,d}} + \beta_{c,d} C_d^{\rho_{u,d}})^{\frac{1}{\rho_{u,d}}} \quad \text{Eq. 5.7}$$

U_d = Utility function/Welfare of Domestic Households

Leis = Leisure time consumed by Domestic Households

C_d = Aggregated consumption consumed by Domestic Households

β_{leis} = Leisure time share factor in Domestic Households utility U_d

$\beta_{c,d}$ = Aggregated consumption share factor in Domestic Households utility U_d

$\rho_{u,d}$ = Degree of substitutability of the consumption between leisure time and aggregated consumption for the Domestic Households utility U_d

$\sigma_{u,d}$ = Constant elasticity of substitution for the Domestic Households utility U_d

where

$$\sigma_{u,d} = 1 - \rho_{u,d} \qquad \text{Eq. 5.8}$$

Equation 5.9 exhibits the lower branch of the Domestic Household demand function. It denotes that the aggregated consumption C_d has a Cobb-Douglas relationship.

$$C_d = \prod X_{i,d}^{\alpha_{cd,i}} \qquad \text{Eq. 5.9}$$

C_d = Aggregated consumption consumed by Domestic Households

$X_{i,d}$ = Commodity from industrial sector i consumed by Domestic Households as final demand

$\alpha_{cd,i}$ = Commodity X_i share factor in aggregated consumption C_d

where

$$\sum_{i=1}^{N} \alpha_{cd,i} = 1 \qquad \text{Eq. 5.10}$$

Domestic Households maximize their utility or welfare subject to their income. Domestic Households enter the market with some level of primary factor endowment that generates their revenues. In addition to these, they also receive part of their income in the form of fund transfers from the Government or tax handler. Domestic Households income is expressed in Equation 5.11.

$$I_d = \sum_{i=1}^{N}\left(p_L L_i + p_K K_i + \frac{T_i}{1+T_i} X_i \right) \qquad \text{Eq. 5.11}$$

I_d = Domestic Households income

X_i = Output of commodity from industrial sector i

L_i = Labor supply required as input to produce commodity X_i

K_i = Capital required as input to produce commodity X_i

p_L = Wage rate per unit of labor supply

p_K = Capital cost per unit of capital

T_i = Output tax of commodity X_i

5.2.2.2 Foreign Households behavior. For the Foreign Households, the Cobb-Douglas function is selected to describe their welfare or utility function. The diagram of Foreign Households utility is illustrated in Figure 5.5. Equation 5.12 expresses this utility function.

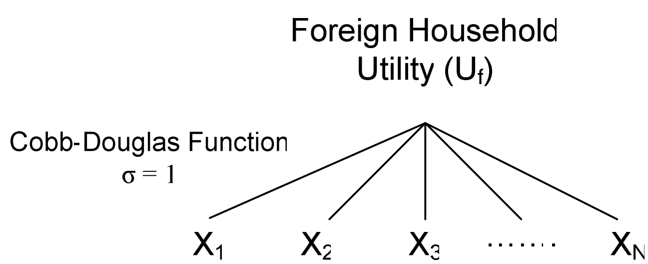


Figure 5.5. The Utility Function Diagram for Foreign Households

$$U_f = \prod X_{i,f}^{\alpha_{f,i}} \qquad \text{Eq. 5.12}$$

U_f = Utility function of Foreign Households

$X_{i,f}$ = Commodity from industrial sector i consumed by Foreign Households as final demand

$\alpha_{f,i}$ = Commodity X_i share factor in Foreign Households utility function where

$$\sum_{i=1}^{N} \alpha_{f,i} = 1 \qquad \text{Eq. 5.13}$$

Foreign household maximize their utility or welfare subjected to their income from selling their endowments, which is the non-comparable import. Their income is represented as given in Equation 5.14.

$$I_f = \sum_{i=1}^{N} p_{FX} FX_i \qquad \text{Eq. 5.14}$$

I_f = Foreign Households income

p_{FX} = Price per unit of non-comparable import

FX_i = Non-comparable import intermediate required as input to produce Commodity X_i

5.2.3. CGE Model Equilibrium Condition. From the above equations showing relationships between each element in the economic system, one can see that the CGE model is a model of simultaneous market clearing. A number of products and factors are identified and modeled. Households and Producers enter the market with different objectives. Producers are assumed to maximize their profits. This means minimizing the production cost, with factor demand generally responsive to factor prices. Households are assumed to maximize their welfare levels in their consumption decision, responding to price differences across goods and services. Households also have expenditure limitations due to their income constraint. Prices in each market are continuously adjusted to ensure that demand equals supply. This means that interactions between markets lead to the need for a simultaneous solution of the entire economic system (Partridge and Rickman, 1998; Rutherford, 1999; Shoven and Whalley, 1992).

In the CGE model, the system can be stated as being in equilibrium when it meets the conditions of the Walrasian Equilibrium (Francois and Reinert, 1997; Shoven and Whalley, 1992; Nicholson, 1994; Varian, 1993; Partridge and Rickman, 1998). There are three conditions to be met, which include Zero Net Profit, Income Balance, and Market

Clearance. These conditions will be discussed in terms of their meanings and mathematical presentations.

5.2.3.1 Zero net profit. The first condition refers to the cost in production and the selling price of the commodity. In the real world market, Producers generally try to maximize their profit. However, in the competitive market, there is no producer that makes excess or abnormal profit in long run equilibrium (Rutherford, 1999). For example, if one producer raises the price to make abnormal profit, there will be firms enter the market due to the profit possibility. Consequently, the mechanism of supply and demand will drive the price back down to the level of no excess profit. The cost of production, which consists of intermediate goods and the primary factor with taxes on output value, must be no less than the market price of the output. For this study, unit profit can be expressed as follow:

$$-\Pi_i = (1+T_i)\left[\beta_{M,i}\left(\sum_{j=1}^{N} p_{X_j} b_{j,i} + p_{FX} b_{FX,i}\right)^{\rho_{p,i}} + \beta_{V,i}\left(p_L^{\alpha_{v,i}} p_K^{(1-\alpha_{v,i})}\right)^{\rho_{p,i}}\right]^{\frac{1}{\rho_{p,i}}} - p_{X_i} = 0 \quad \text{Eq. 5.15}$$

Π_i = Unit profit of commodity X_i

p_{X_i} = Unit price of the commodities X_i

p_{X_j} = Unit price of the commodities X_j

p_L = Wage rate per unit of labor supply

p_K = Capital cost per unit of capital

p_{FX} = Price per unit of non-comparable import

$b_{j,i}$ = Number of unit of commodity X_j required to produce one unit of commodity X_i

$b_{FX,i}$ = Number of unit of non-comparable import required to produce one unit of commodity X_i

$\alpha_{v,i}$ = Labor supply share in value added V_i which is required in production of commodity X_i

$\beta_{m,i}$ = Aggregated material share factor in production of X_i

$\beta_{v,i}$ = Value added share factor in production of X_i

T_i = Output tax of commodity X_i

$\rho_{p,j}$ = Degree of substitutability between aggregated material and value added for the production of commodity X_i

5.2.3.2 Market clearance. At equilibrium price and activity levels, the supply of any commodity and factor must balance or exceed excess demand (Partridge and Rickman, 1998). This means all demands in the system need to be fulfilled. On the other hand, all the supplies in the system are completely consumed, either in form of final product, or intermediate input, for both the goods market and production factors market.

5.2.3.2.1 Market clearance for goods. For this study, all of the produced goods are consumed either as intermediate input or final product. The amount of goods consumed in each way depends on production technology and consumption preferences. At the equilibrium state, the commodity output from each industrial sector must be equal to the consumed goods. This can be expressed in mathematical terms as given in Equation 5.16.

$$X_i = \sum_{j=1}^{N} \beta_{i,j} X_i + X_{i,d} + X_{i,f} \qquad \text{Eq. 5.16}$$

X_i = Output of commodity from industrial sector i

$X_{i,d}$ = Commodity from industrial sector i consumed by Domestic Households as final demand

$X_{i,f}$ = Commodity from industrial sector i consumed by Foreign Households as final demand

$\beta_{i,j}$ = Intermediate commodity X_i share factor in aggregated material M_j

5.2.3.2.2 Market clearance for factors. All factor endowments must be completely used either in the production process by Producers or consumed by Households to fulfill their preferences. In this study, there are three types of endowments from Domestic and Foreign Households, including labor time, capital, and non-comparable import. The market clearance condition for labor time and capital are described in Equation 5.17 and 5.18.

$$Total\ Labor\ Time\ (LT) = Leis + \sum_{i=1}^{N} L_i \qquad \text{Eq. 5.17}$$

LT = Domestic Households total available labor time

Leis = Leisure time consumed by Domestic Households

L_i = Labor supply required as input to produce commodity X_i

$$K = \sum_{i=1}^{N} K_i \qquad \text{Eq. 5.18}$$

K = Total capital endowments from Domestic Households

K_i = Capital required as input to produce commodity X_i

In this study, the non-comparable import intermediate is assumed to be slack of the system. The slack means that at the equilibrium state, the system allows this factor or commodity to have some left over inventory, instead of having perfect clearance. However, the amount of the slack factor or commodity must be at least adequate for fulfilling the demand within the system. Equation 5.19 shows the equilibrium condition for non-comparable import.

$$FX = \sum_{i=1}^{N} FX_i + Left \qquad \text{Eq. 5.19}$$

FX = Total non-comparable import intermediate endowments from Foreign Households

FX_i = Non-comparable import intermediate required as input to produce Commodity X_i

Left = Left over of the non-comparable import intermediate

5.2.3.3 Income balance. The third condition regards the incomes of agents in the systems. In this study, these agents refer to Domestic and Foreign Households. The value of each agent's income must equal the value of factor endowments plus other sources of revenue, such as the transfer from Government to Domestic Households. At the equilibrium state, all the income of agents must be spent to maximize their preferences.

This equilibrium condition for Domestic and Foreign Households is presented in Equations 5.20 and 5.21.

$$I_d - \sum_{i=1}^{N} X_{i,d} = 0 \qquad \text{Eq. 5.20}$$

I_d = Domestic Households income

$X_{i,d}$ = Commodity from industrial sector i consumed by Domestic Households as final demand

$$I_f - \sum_{i=1}^{N} X_{i,f} = 0 \qquad \text{Eq. 5.21}$$

I_f = Foreign Households income

$X_{i,f}$ = Commodity from industrial sector i consumed by Foreign Households as final demand

5.2.4. The Objective and CGE Problem Setup. Households and Producers optimize their objective based on their constraints and the three equilibrium conditions. This optimization process is done by simultaneously changing variable values in all the above equations for all markets in the entire economic system. In each equation, there are both variables and parameters. In the above equations, price of commodities, value of factors/endowments, and quantity in production and consumption are variables. These variables will be simultaneously adjusted until the equilibrium state is achieved.

In the above equations, CES share factors, Cobb-Douglas shares factors, Leontief share factors, output tax rates, and the CES elasticity values are parameters. These values need to be identified to represent and model the economic system characteristics. These values are obtained from the literature or from the calibration methodology. Share factors and output tax rates are obtained by calibrating the model with benchmark data. The CES elasticity can be estimated by an econometric approach or taken from the literature based on the judgment of the modeler. Given the elasticity of substitution and information from the benchmark data, the model is solved to reproduce the benchmark data in order to calibrate all other parameters. The solution obtained with the benchmark data is referred to as the "replication" equilibrium (Partridge and Rickman, 1998; Rutherford, 1999; Shoven and Whalley, 1992).

5.3. DATA CONSTRUCTION

CGE model is developed based on the information from SAM as discussed earlier in Section 2.2.2.3. In this study, the year 2004 SAM for the study region of the St. Louis Metropolitan Area (MPA) is required for the development of the expanded indirect loss estimation module. Figure 5.6 illustrates the approach employed to build the regional SAM for this study.

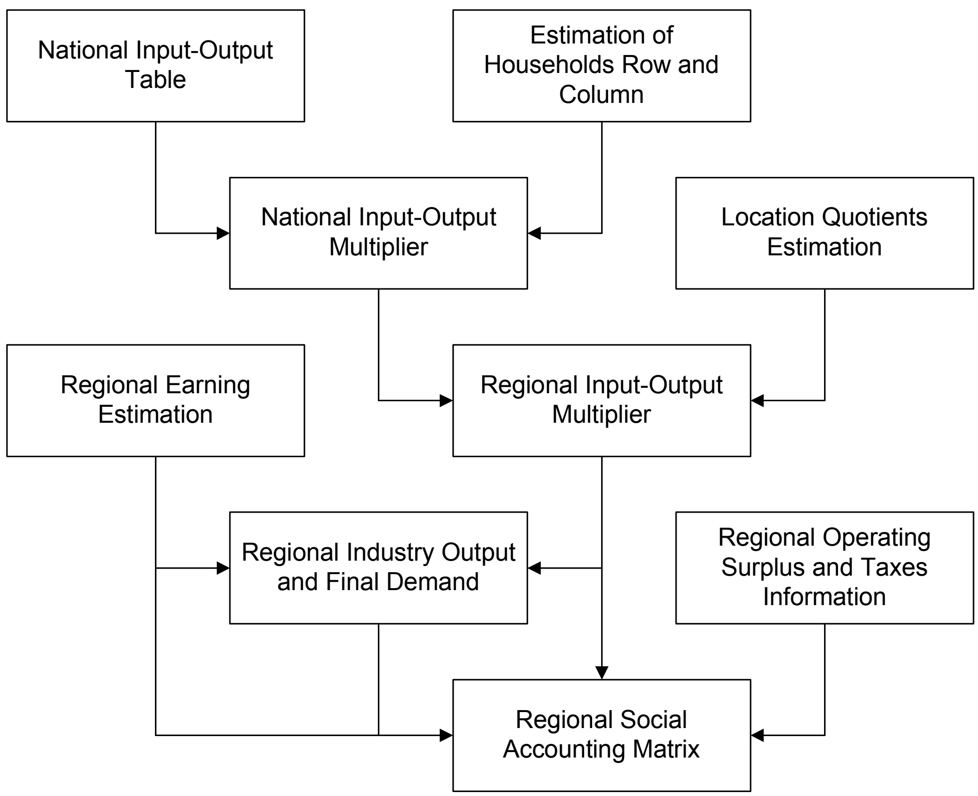


Figure 5.6. Data Development Diagram

SAM is an expanded version of the traditional I-O table. Therefore, I-O information can be used as the starting point of SAM development. In this study, the national level I-O table data provided by Bureau of Economic Analysis (BEA) is selected as the starting point. The BEA national I-O information is commodity and industry based. The commodity refers to the product or goods available to the market. A particular industry can produce more than single commodity. BEA provides the national direct requirement table in the format of commodity by industry and the make table in the format of industry by commodity. In order to simplify the model in this study, the calculation will be made only as industry based. Thus, the direct requirement table from BEA needs to be transformed into an industry-by-industry format in order to estimate the A matrix in I-O model, as discuss in Section 2.2.2.1. This transformation can be done by applying the industry share matrix (D). The industry share matrix can be estimated by following Equations 5.23 and 5.24. By multiplying the industry share matrix with the direct requirement table, the A matrix will be obtain as shown in Equation 5.26.

$$M = \begin{bmatrix} m_{11} & m_{12} & .. & m_{1j} \\ m_{21} & .. & .. & : \\ : & .. & .. & : \\ m_{i1} & .. & .. & m_{ij} \end{bmatrix} \qquad \text{Eq. 5.22}$$

M = Make table matrix in industry by commodity format

m_{ij} = Commodity j output produced by industrial sector i

$$D = \begin{bmatrix} d_{11} & d_{12} & .. & d_{1j} \\ d_{21} & .. & .. & : \\ : & .. & .. & : \\ d_{i1} & .. & .. & d_{ij} \end{bmatrix} \qquad \text{Eq. 5.23}$$

D = Industry share matrix in industry by commodity format

d_{ij} = Ratio of commodity j produced by industrial sector i to the total commodity j available

where

$$d_{ij} = \frac{m_{ij}}{\sum_{i=1}^{n} m_{ij}} \qquad \text{Eq. 5.24}$$

$$U = \begin{bmatrix} u_{11} & u_{12} & .. & u_{1i} \\ u_{21} & .. & .. & : \\ : & .. & .. & : \\ u_{j1} & .. & .. & u_{ji} \end{bmatrix} \qquad \text{Eq. 5.25}$$

U = Use table ratio matrix or direct requirement matrix in commodity by industry format

u_{ji} = Commodity j output used as intermediate input by industrial sector i

$$A = DU \qquad \text{Eq. 5.26}$$

A = Direct requirement matrix in industry by industry format

D = Industry share matrix in industry by commodity format

U = Use table ratio matrix or direct requirement matrix in commodity by industry format

In order to estimate the I-O multiplier defined by the BEA Regional Input-Output Multipliers Modeling System (RIMS II), households need to be treated as another industrial sector in the I-O table (BEA, 1997). Adding the estimation of households' row or the households' earning, and households' column or households' expenditure into the national I-O multiplier, the national level I-O multiplier based on RIMS II approach will be obtained as illustrated in Figure 5.6. The household direct requirement row can be estimated following the RIM II approach (BEA, 1997) in Equation 5.27.

$$HSHR_j = (W \& S_j + PRP_j + DF_j + ECHI_j - PCSI_j) / TIO_j \qquad \text{Eq. 5.27}$$

$HSHR_j$ = Households row for industry j column

$W\&S_j$ = Wages and salaries of households received from industry j

PRP_j = Proprietors' income of households received from industry j

DF_j = Directors' fees of households received from industry j

$ECHI_j$ = Employer contributions for health insurance of households received from industry j

$PCSI_j$ = Personal contributions for social insurance pay by households who work in industry j

TIO_j = Total industry output of industry j

j = Subscript represents the column industry sector j

Households' column represents ratio of the expenditures per dollar to total household earnings spent toward the commodity from the corresponding industry row. The estimation of households' column starts from the personal consumption expenditures (PCE). The PCE spending toward imported commodities must be removed, such that only the PCE in the domestically produced commodities is considered. The ratio of the PCE for each commodity to the total PCE is calculated for all commodities. At this point, the PCE ratio calculated from the national I-O table is in a commodity-based format. Therefore, it must be transformed into an industry-based format by applying the industry share matrix as mentioned earlier. Finally, the households' column will be obtained by multiplying these PCE share ratios with the ratio of personal income less tax and saving to the personal income in order to remove the dampening effect of taxes and savings on expenditures (BEA, 1997).

With the complete national I-O multiplier in the RIMS II standard, the RIMS II regional I-O multiplier can be estimated by utilizing the mixed Location Quotients (LQ) method recommended by Cartweight et al. (1981). The LQ is basically a technique that compares the local economy to a reference economy in order to identify specializations in the local economy. The mixed LQ based on the selection of different types of Simple Location Quotient (SLQ) values for different industrial sectors. The SLQ value can be expressed in mathematical terms as given in Equation 5.28. The national level data can be transformed into regional level data by applying the SLQ value as shown in Equation 5.29.

$$SLQ_i = \frac{Q_i^r / T^r}{Q_i^n / T^n} \qquad \text{Eq. 5.28}$$

SLQ_i = Simple location quotient of industry i

Q_i^r = Measure of the regional output of industry i

Q_i^n = Measure of the national output of industry i

T^r = Measure of aggregate regional economy activity

T^n = Measure of aggregate national economy activity

$$a_{ij}^r = a_{ij}^n \bullet SLQ_i^{/} \qquad \text{Eq. 5.29}$$

a_{ij}^r = Proportion of total output industry j that is accounted for by purchase of input from industry i at regional level

a_{ij}^n = Proportion of total output industry j that is accounted for by purchase of input from industry i at national level

$SLQ_i^{/}$ = SLQ_i if $SLQ_i < 1$ and

1 if $SLQ_i \geq 1$

The earnings are usually selected as the measure during the calculation of SLQ. Either the earnings or personal incomes can be selected for the calculation. In this study, the mixed LQ will be the selection between earnings-based SLQ and personal income-based SLQ for each industry sector. The selection criteria for whether to apply the earnings-based SLQ or personal income based SLQ for any particular industrial sector is based on that industry's output usage. If most of the output from a particular sector is used as the intermediate, the earnings-based SLQ will be applied. On the other hand, if most of the output from a particular sector is used as the final demand, the personal income-based SLQ will be employed (Cartwright, 1981). The earnings-based and personal income-based SLQ can be calculated as in the following equations (Detailed information regarding to SLQ number and type of SLQ applied to each industrial sector for this study can be found in Appendix J):

$$SLQ_{Ei} = \frac{E_i^r/TE^r}{E_i^n/TE^n} \qquad \text{Eq. 5.30}$$

SLQ_{Ei} = Earnings-based simple location quotient of industry i

E_i^r = Regional earning in industry i

E_i^n	=	National earning in industry i
TE^r	=	Regional total earning
TE^n	=	National total earning

$$SLQ_{Pi} = \frac{E_i^r / PY^r}{E_i^n / PY^n} \qquad \text{Eq. 5.31}$$

SLQ_{Pi}	=	Personal income-based simple location quotient of industry i
E_i^r	=	Regional earning in industry i
E_i^n	=	National earning in industry i
PY^r	=	Regional total personal income
PY^n	=	National total personal income

At this step, the regional RIMS II multiplier is estimated and ready to use. By applying the regional earning information with the direct requirement multiplier, the regional industry output for each industry sector can be estimated. Then, the regional final demand can be achieved by applying the industry output information with the regional total requirement multiplier (BEA, 1997). With the industry relationship information, the regional output and final demand, and the regional earning, SAM for the study region can be developed with the additional information regarding to the regional taxes and operating surplus. The basic structure of SAM for this study is shown in Table 5.1. The table shows the flow of product, factor, and money within the economy system.

The intermediate inputs and the gross outputs in Table 5.1 are estimated from the RIMS II multiplier. The capital usage in production is estimated from the operating surplus and the total of the surplus represents the total capital endowments from the Domestic Households. Labor supply is estimated from the regional earning information. It is assumed that there is only one type of tax in the economic system, which is the output tax. Therefore, the regional tax information can be assumed as the output tax paid by the Producers. All of the output taxes will later be transferred from Government to Domestic Households. With this, the non-comparable import is estimated from the total industry output less the sum of the intermediate input, primary factors usage, and output taxes. The aggregated final demand consumed by both Domestic and Foreign Households can be estimated from the RIMS II multiplier. However, these aggregate final demand needs to be divided for different households. As discuss earlier in Section 5.2.2.2, non-comparable import is the source of income for Foreign Households and they will spend all of their income toward final demand consumption. Therefore, the final demand for each household will be estimated as the weight average of the household's income with the assumption of the same consumption preference for both Domestic and Foreign Households. The last part of SAM left is the leisure time consumed by Domestic Households. This information is taken from the year 2004 American Time Use Survey (ATUS) conducted by the Bureau of Labor Statistics (BLS, 2005). This survey shows that in year 2004 each person normally takes 4.24 hours per day as leisure time while the average working time per day is 7.63 hours. This means that the leisure time consumption is approximately 55.57% of the labor supply value.

Table 5.1. SAM Structure

	Expenditure						
	1	2	3	4	5	6	7
Receipts	Activities	Commodities	Factors	Domestic Households	Foreign Households	Government (Tax Handler)	Total
1. Activities		Gross Outputs					Total Sales
2. Commodities	Intermediate Inputs			Final Demand Consumption	Final Demand Consumption		Aggregate Demand
3. Factors	Labor Supply and Capital			Leisure Time Consumption			Primary Factor Endowments
4. Domestic Households			Wages and Capital Return			Tax Transfers	Domestic Households Income
5. Foreign Households	Non-Comparable Import						Foreign Households Income
6. Government (Tax Handler)		Output Taxes					Collected Output Tax
7. Total	Total Production Costs	Aggregate Supply	Primary Factor Expenditures	Domestic Household expenditure	Foreign Household expenditure	Government Tax Transfers	

Using the aforementioned processes, the SAM for the study region is completed. However, another issue to be concerned with is the aggregate level of the industrial sector. From the beginning of the data development process, the industrial sector follows the 3-digit North American Industry Classification System (NAICS), which has a total of

66 sectors, including households. For the simplicity of the calculation process, it is decided to aggregate the industrial sector from 3-digit NAICS to 2-digit NAICS. This will result in a total of 20 industrial sectors and another separate small industrial sector. This separate sector is the focus study sector, which in this study is the truck transportation sector. Therefore, SAM in this study contains 21 sectors with total industry output of $186.2 billion. Additional information regarding the data development process, along with the data sources, can be found in Appendix I to Appendix L.

5.4. MODEL CONSTRUCTION

Based on the model structure discussed in Section 5.2 and SAM obtained from the process in Section 5.3, the CGE model for the expanded indirect loss module can be constructed. The CGE model is developed utilizing the GAMS/MPSGE software package as discussed earlier in Section 2.2.2.3. GAMS performs as the front end and final end to handle the data and present the output. It also provides the solver module (MILES and PATH) for the general equilibrium problem. For the model, the MPSGE is the language that handles the writing of the mathematical relationship among each element within the CGE model, as well as the equilibrium condition of the system. More detail regarding to the MPSGE syntax and example of CGE models can be found in Rutherford (1999) and manuscripts written by James Markusen at University of Colorado, Boulder.

During the early step of the CGE model construction by MPSGE, there are some issues of concern. First is the confliction of problem solving in the case of the slack commodity or factor. As mention earlier in Section 5.2.3.2, non-comparable import is allowed to be slack in the model. An assumption needs to be made as the P_{FX}, or the price of the non-comparable import, is constant before and after the earthquake situation. This is due to the fact that the MPSGE will consider the commodity or factor which is slack having a price of zero. At the benchmark scenario, all of the non-comparable import will be used up. However, the after-incident will result in reduction of industry output which will reduce the usage amount of non-comparable import. Consequently, there will be an excess amount of the non-comparable import intermediate in the economic system. This assumption of constant price for non-comparable import is reasonable because of the size of our study region. The price of non-comparable import, which comes from the rest of the world, should not be affected by the reduced import amount from our study region because our study region is much smaller when compared to the rest of the world.

Another issue to be considered is the selection of the numéraire. The CGE result has meaning only in relative terms. The absolute value by itself has no meaning (Markusen, 2005). Therefore, the reference or numéraire needs to be identified at the beginning of the calculation. In this study, the price index or the purchasing power is select as the reference. Therefore, the relative meaning of the result will be in terms of real money. With all of these points taken care of, the main structure of CGE model is developed. However, to complete the analysis of the CGE model for the interested scenario, two other important tasks need to be fulfilled, which are the model parameter calibration and counterfactual scenario adjustment.

5.4.1. Model Parameter Calibration. As mention in Section 5.2.4, parameters in the model need to be identified in order to exhibit the model characteristics. Most of the parameters in the CGE model can be estimated using the model calibration process, except for the elasticity value. The CGE model requires the elasticity values in order to calibrate other parameters. With a given set of elasticity values, the CGE model will be able to calibrate and identify all other parameters by replicating the benchmark scenario. All parameters are successfully calibrated when the model can perfectly reproduce the benchmark scenario.

First of all, the value in the CES production function ($\sigma_{p,i}$) and demand elasticity in the Domestic Households utility function ($\sigma_{u,d}$) needs to be identified externally. In this study, these elasticity values are selected based on extensive literature review on earlier CGE model studies which have similar model structure. The CES production function elasticity value typically ranges from 0.10 to 1.13 (Parry et al. 1999; Rotemberg and Woodford, 1996, Klenow, 1998; Leith and Mally, 2005, Perroni and Whalley, 1998, Bovenberg and Goulder, 1996; Dotsey and King, 2006). Many studies valued the production elasticity at 0.7. The elasticity of substitution between leisure time and aggregated consumption is found to range from 0.5 to 1.2 (Parry et al. 1999; Bovenberg and Goulder, 1996; Balistreri and Rutherford, 2001; Fullerton and Rogers, 1993; RTI, 2005).

The elasticity values are varied depending on the study region as well as time of study. It could be stated that there is no particular value that can be used perfectly for this study. Therefore, it is decided to iterate the model with random elasticity values and use the average output value to represent the expanded indirect loss estimated by this study. The center value for CES production function elasticity is selected at 0.7. The model will uniformly set random values of the production elasticity for each iteration. These production elasticity will be uniformly random from the values ranging from 0.35 to 1.05 (which is the range of ±50% from the center value). For the demand elasticity, the value of 0.85 is select as the center case. However, the model will uniformly randomize the demand elasticity value ranging from 0.5 to 1.2 for each iteration. The total of 100,000 iterations will be made.

5.4.2. Counterfactual Scenario Adjustment. After the benchmark scenario is successfully replicated, which means all parameter values are determined, the model is ready to be used for scenario analysis. In the study scenario, when the economic system equilibrium state is disturbed, the model will adjust itself by simultaneously changing the variable values within the system until the new equilibrium is reached. The changes in the system can be observed by comparing the variable values at the new equilibrium with the values in the benchmark scenario. In this study, these changes or the expanded indirect loss is defined as the reduced industry output value from Producers combined with the decrease in welfare level of Domestic and Foreign Households. This means the system output and welfare that result from the counterfactual scenario will be used to compare with the benchmark level to estimate the expanded indirect loss. Therefore, it is crucial to properly construct the counterfactual scenario (which correctly interprets the study scenario) into the CGE model.

The study scenario for this study refers to the incident which the benchmark equilibrium is disturbed by the increased travel cost, estimated in the initial indirect loss module. As discussed earlier in Section 3.4 and 3.5, the analysis of increased travel cost divides all travel trips into two types: commuting trips and commercial trips. Therefore, based on travel trip definition, it is assumed that the increased travel cost will be allocated only onto two sectors within the CGE model, i.e., the Domestic Households and truck transportation sector. Based on this idea, however, there are two important issues that arise, which are the different timeframe and approach to introduce the initial indirect loss to the CGE system.

The timeframes in the analysis of initial indirect loss and the expanded indirect loss or CGE model are different. During the initial indirect loss estimation, the highway system is fully recovered in 500 days after the incident. The initial indirect losses or the increased travel cost are accumulating day-by-day until the system is back to normal. However, the CGE model that is developed based on SAM is defined on a yearly, or 365-day basis. Therefore, the initial indirect loss estimated earlier cannot be entirely transferred into the CGE model study scenario. The increased travel cost needs to be limited to the same timeframe as of CGE model, or only 365 days instead of 500 days. The increased travel cost for 365 days timeframe can be estimated as the area under the graph of daily initial indirect loss (Figure 4.3) from day 1 through day 365 after the incident. Tables 5.2 and 5.3 show these 365-day timeframe values in detail.

Table 5.2. The Detail Initial Indirect Loss Number for 365-Day Timeframe

Initial Indirect Loss	Day 1 - 30	Day 30 - 90	Day 90 - 250	Day 250 - 365	Day 1 - 365
Commercial Trip	$ 97,342,877.10	$ 37,134,351.00	$ 51,563,477.60	$ 14,950,500.41	$ 200,991,206.11
Commuting Trip	$ 250,415,343.45	$ 86,768,683.20	$ 113,791,264.80	$ 32,401,713.92	$ 483,377,005.37
Total	$ 347,758,220.55	$ 123,903,034.20	$ 165,354,742.40	$ 47,352,214.33	**$ 684,368,211.48**

Table 5.3. The Detail Commuting Trip Loss Number for 365-Day Timeframe

Commuting Trip Loss	Day 1 - 30	Day 30 - 90	Day 90 - 250	Day 250 - 365	Day 1 - 365
Travel Distance Loss	$ 62,359,083.75	$ (22,441,214.40)	$ (77,987,556.80)	$ (28,137,655.08)	$ (66,207,342.53)
Travel Time Loss	$ 188,056,259.70	$ 109,209,891.90	$ 191,778,791.20	$ 60,539,352.18	$ 549,584,294.98
Total	$ 250,415,343.45	$ 86,768,677.50	$ 113,791,234.40	$ 32,401,697.10	**$ 483,376,952.45**

From SAM, the total industry output value of truck transportation sector is $2.717 billion. In the study scenario, $200.99 million increased travel cost has to be introduced into this sector. The increased travel cost means the additional expenditures are required after the earthquake incident in order to make the same number of trips as in the benchmark situation. Therefore, this increased travel cost for the truck transportation can be interpreted in terms of increase production cost or lower production efficiency. In other words, in order to achieve the same level of output in study scenario, another $200.99 million worth of input is required. This will result in an approximately 7.7% increase in production cost or 92.9% production efficiency for the truck transportation sector when compared with benchmark. The additional required input will be a weighted average among all required input, i.e., intermediate inputs, non-comparable import, labor supply, and capital. The detail number of this increased input required is shown in Appendix M.

Another portion of initial indirect loss or the commuting trip loss will be absorbed by Domestic Households who enter the market with the endowments of labor supply and capital. The commuting trip loss consists of the loss from increased travel distance and increased travel time. Based on their definition, the loss from increased travel time is comparable with decrease in labor supply endowment. The loss from increased travel distance can be referred as the decrease in capital endowment. The number for commuting trip loss in Table 5.3 exhibits that the loss from increased travel distance is actually negative. This means that after the earthquake incident, the commuting trip travelers choose the shorter distance travel routes, but with longer travel time. Therefore, in the study scenario, Domestic Households actually have an additional $66.21 million worth of capital while losing $549.58 million worth of labor supply when compared to the benchmark scenario.

With the complete interpretation of the study scenario, GAMS/MPSGE coding of the expanded indirect loss module with the study scenario is developed and presented in Appendix N. The model will be run for a total of 100,000 iterations, with 10,000 iterations in each batch to estimate the expanded indirect loss. Moreover, the sensitivity analysis will be conducted to observe the effect of the different elasticity values on the model result.

5.5. EXPANDED INDIRECT LOSS MODULE RESULTS AND DISCUSSION

5.5.1. The Module Result. The expanded indirect losses estimated from the CGE model are different for each iteration depending on the set of random elasticity values. Therefore, it was decided to make 100,000 iterations and use the average of the estimated loss as the expanded indirect loss for this study. The model will be run in 10 batches with 10,000 runs in each batch. The histogram of the estimated indirect loss value is shown in Figure 5.7 and the average value along with standard deviation of the result for each batch is presented in Table 5.4.

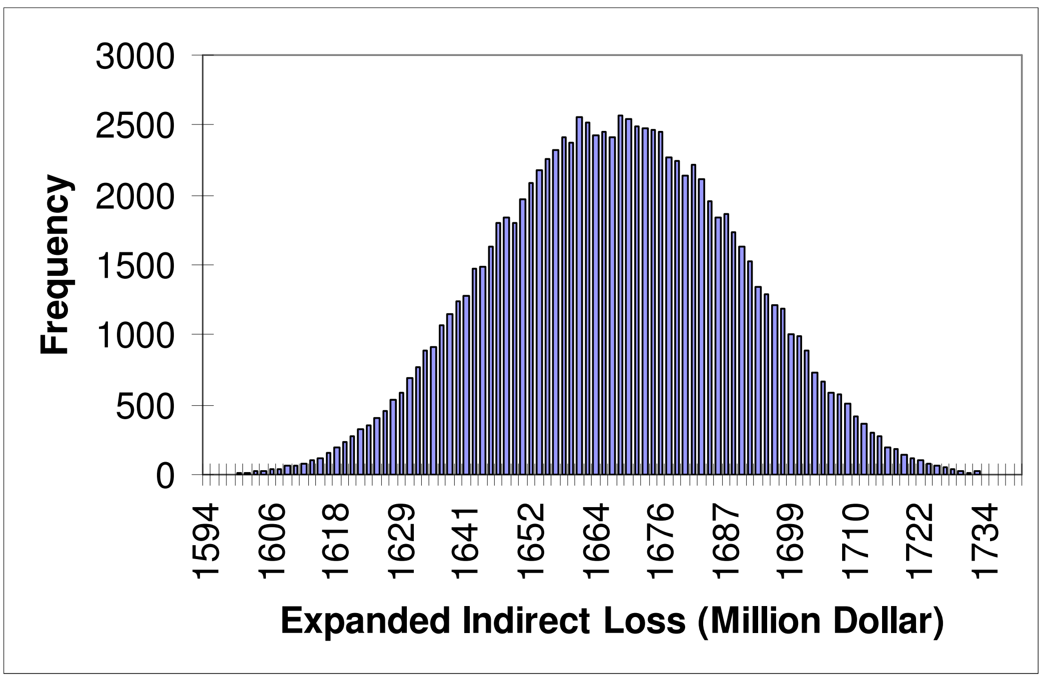


Figure 5.7. The Histogram of the Estimated Expanded Indirect Losses

Figure 5.7 illustrates the estimated expanded indirect losses as an almost perfectly normal distribution. Moreover, the result in Table 5.4 shows that the number of iterations at 100,000 is adequate. The average numbers of each batch are not significantly different, with the largest difference at $0.52 million or 0.03% compared to the total average. This

Table 5.4. The Detail Number of Average Indirect Losses and Standard Deviation

Batch #	Average	SD
1	$ 1,666.81	$ 21.81
2	$ 1,666.79	$ 21.99
3	$ 1,666.73	$ 21.84
4	$ 1,666.48	$ 21.80
5	$ 1,666.78	$ 21.47
6	$ 1,666.99	$ 21.68
7	$ 1,666.89	$ 21.84
8	$ 1,666.60	$ 21.75
9	$ 1,666.75	$ 21.72
10	$ 1,666.95	$ 21.76
Total	**$ 1,666.78**	**$ 21.77**

Note: The number is in millions of dollar

is also true for the standard deviation, which has the largest difference at $0.51 million or 2% compared to the total standard deviation. The standard deviation of the estimated value is also small when compared to the average value at approximately 1.3%. Therefore, the decision to select the average value of the estimated indirect loss to represent the expanded indirect loss is reasonable. As a result, the expanded indirect loss estimated by the module is concluded to be at $1,666.78 million for the 365-day time period in year 2004.

Although, the number of the expanded indirect loss seems to be at large magnitude, it actually is quite small when compared with the total size of the economy – it is only about 0.49% of the total economic output. The detail number of changes within the economic system is shown in Table 5.5. All of the industrial sectors' activity levels are decreased. The most impact sector is truck transportation sector in which the activity level is decreased by about 4%. The sector with the most price movement is also the truck transportation service sector. The price of transportation service is increased by 8.46%, while the initial indirect loss introduced to the sector initially increases the production cost by 7.7%, as mentioned in Section 5.4.2.

Table 5.5. The Detail Number of Average Changes from 100,000 Iterations

Sector	Description	Output Change	Price Change
11	Agriculture, Forestry, Fishing and Hunting	-0.511%	-0.242%
21	Mining	-0.605%	0.036%
22	Utilities	-0.393%	-0.198%
23	Construction	-0.492%	-0.014%
31-33	Manufacturing	-0.556%	0.051%
42	Wholesale Trade	-0.395%	-0.166%
44	Retail Trade	-0.387%	-0.135%
48-49	Transportation and Warehousing except Truck Transportation	-0.316%	-0.104%
484	Truck Transportation	-4.025%	8.460%
51	Information	-0.354%	-0.226%
52	Finance and Insurance	-0.338%	-0.238%
53	Real Estate and Rental and Leasing	-0.142%	-0.490%
54	Professional, Scientific, and Technical Services	-0.430%	-0.152%
55	Management of Companies and Enterprises	-0.391%	-0.146%
56	Administrative and Support and Waste Management and Remediation Services	-0.440%	-0.105%
61	Educational Services	-0.476%	-0.034%
62	Health Care and Social Assistance	-0.435%	-0.075%
71	Arts, Entertainment, and Recreation	-0.360%	-0.169%
72	Accommodation and Food Services	-0.454%	-0.057%
81	Other Services (except Public Administration)	-0.432%	-0.055%
92	Public Administration	-0.515%	0.011%

The direct loss estimated by Chen et al. (2005) is approximately at $1.3 billion. The direct loss refers to the repair or replacement cost of the damaged bridge and can be considered as a one-time cost. Therefore, it can directly be compared to the expanded indirect loss that is considered over a 365-day timeframe and does not produce any time conflict. The expanded indirect loss is 128% compared to the estimated direct loss.

On the other hand, the expanded indirect loss is the total loss on the entire economic system due to the increased travel cost. The estimated number from the CGE model is the number that already includes the initial indirect loss. From Table 5.2, the initial indirect loss for 365-day timeframe is estimated at $684.37 million. Therefore, it can be said that with $684.37 million initial indirect loss, there are actually additional losses on the entire economic system of $982.41 million for a 365-day time frame, resulting in the total effect on the entire economic system at $1.667 billion.

The value of expanded indirect loss is reasonably high compared to the direct and initial indirect losses, however, it is acceptable. This is due to the nature of direct and initial indirect loss estimation defined in this study. The direct loss estimation covers only the cost of repair or replacement of the damaged bridge. It does not include the loss that would occur on the households' side. For the initial indirect loss estimation, the estimated value is the increased travel cost which is used as the trigger of economic system equilibrium imbalance. Although, the increased travel cost is allocated into both industrial sectors and households, this estimation does not cover the effect of those losses on the entire economic system. On the other hand, the expanded indirect loss estimation is capable of observing the effect on the entire economic system caused by change(s) in part(s) of the system. It also takes the household losses into account in terms of reduced welfare. Moreover, the expanded indirect loss estimation already includes the initial indirect loss into itself. Therefore, it is logical that the expanded indirect loss in this study is larger than both the direct and the initial indirect losses.

5.5.2. Sensitivity Analysis. As discussed in Section 5.4.1, the CGE model of the expanded indirect loss module requires pre-defined values for the production elasticity ($\sigma_{p,i}$) and demand elasticity ($\sigma_{u,d}$) in order to calibrate all other parameters and, later on, analyze the study scenario. From an economic point of view, there are absolutely no correct values for these elasticity values. Although these elasticity values are selected randomly within the specific range based on the extensive literature review, it is still important to conduct a sensitivity analysis to observe the effect of different elasticity values on the estimated expanded indirect loss. The sensitivity analysis is conducted at three different demand elasticity values, which are 0.5, 0.85, and 1.2. At each demand elasticity value, the model will be run with a total of 9 different production elasticity values, i.e., 0, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0, with the assumption that the production elasticity is the same for all industries. Based on these selected values, there will be two special cases for the production function, which occur when the elasticity values are equal to 0 and 1. This will make the CES production function behave as the Leontief function and Cobb-Douglas function, respectively. The result of the sensitivity analysis is shown in Figures 5.8 and 5.9. The expanded indirect loss result for each sensitivity analysis case is provided in Appendix O.

Figure 5.8 shows the effect of the value of production function elasticity on the indirect loss in terms of dollars. It shows the linear relationship between expanded indirect loss and the production function elasticity. The magnitude of the difference between the lowest estimated figure and the highest estimated figure is approximately $271 million. The difference seems to be significant. However, if the expanded indirect loss is considered in terms of a percentage of total economic value, as in Figure 5.9, this difference will be approximately 0.08% of total economic value. The difference actually becomes insignificant. Therefore, it can be concluded that the influence of elasticity value on the expanded indirect loss estimation module is weak.

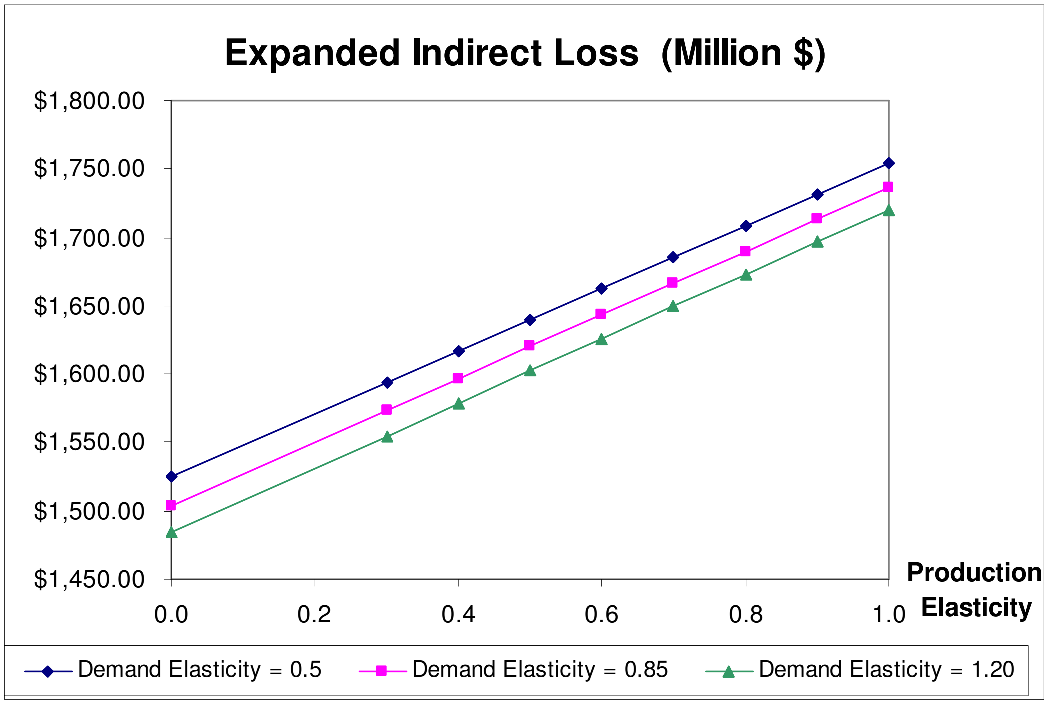


Figure 5.8. Sensitivity Analysis Graph in Total Indirect Loss

Other than observing the influence of parameters on the model result, sensitivity analysis can also be applied to verify the model behavior. First, consider the demand elasticity. This value indicates the flexibility of exchange between labor supply and leisure time. With higher demand function elasticity value, Households are more willing to change their leisure time into labor supply, and vice versa. In the study scenario, the system suffers a lower level of labor supply. This means the estimated indirect loss should be lower in the case where the demand elasticity is higher. Figures 5.8 and 5.9 illustrate that at any particular production elasticity value, the estimated indirect loss will

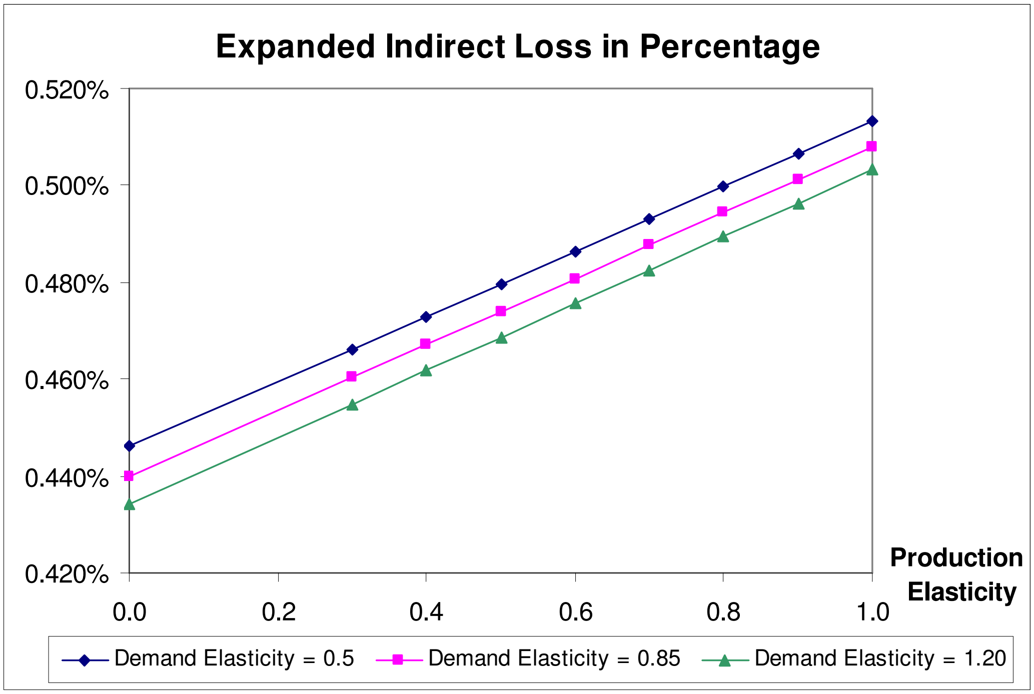


Figure 5.9. Sensitivity Analysis Graph in Percentage of Total Economic Value

be lower when the demand elasticity is higher. This confirms that the expanded indirect loss estimation module behaves according to the concept of the demand function elasticity.

On the other hand, the model behaves against the principle when observing the estimated indirect loss that results with different production elasticity values. Theoretically, when the system has a higher value of production elasticity, it will allow more flexibility in the production technology. This means Producers are more relaxed in exchanging from aggregated intermediate to aggregated value added, and vice versa. Consequently, the expanded indirect loss estimated within the system should decrease. Conversely, it is not the case for this study. Figure 5.8 and 5.9 clearly illustrate that with the same demand elasticity value, the estimated indirect loss increases when the production elasticity value increases. However, this unusual behavior can be logically explained by understanding the general idea of the model mechanism, the study scenario, and the definition of the expanded indirect loss.

First, the benchmark scenario equilibrium is initially disturbed by the lower labor supply, higher capital supply, and lower efficiency in truck transportation production technology. This means at the beginning of the study scenario, there will be an excess amount of capital, lack of labor supply, and higher cost of the truck transportation service. The CGE model is a price driving model. The model will adjust to equilibrium by avoiding the higher price commodities and production factors, with the condition that all the produced output and the supplied factors must be cleared (Shoven and Whalley, 1992). In this study, there is an exception in the case of non-comparable import intermediate, which is assumed to be a slack commodity with fixed price. Moreover, the numerical meaning of the expanded indirect loss for this study is defined as the reduced output value for all industrial sectors combined with the reduced welfare value for both Domestic and Foreign Households.

With further observation of the price and output value of each case during the sensitivity analysis (Appendix P), the system is actually more flexible when the production elasticity is higher. This can be examined in the output price changes in all industry sectors as well as the production factor price changes. They are lower for the system with higher elasticity. With this detail investigation, the output loss for the lower elasticity value case is less than the loss for the higher elasticity value case, as well as the welfare loss. Domestic Households' welfare consists of capital income, labor supply income, tax transfer income, and a leisure consumption component. The losses in labor supply income, tax transfer, and leisure time consumption loss are higher in the case with higher production elasticity value. However, the capital income loss is lower in the case with higher production elasticity. This means that the system attempts to avoid the commodities and factors with higher price. Initially, in the lower branch of the production function, where the system can exchange between capital and labor supply with Cobb-Douglas relationship, the system will try to change the required labor supply, which is scarce and pricy, to capital, which is in excess and cheaper. Then, in the upper level of production technology, the system can also exchange between aggregated intermediate and value-added. It will attempt to exchange between the required intermediate and the value added, whichever is cheaper. The exchanges are more likely to happen with higher production elasticity values. This will result in a reduction in industry output and lower loss in capital income for Domestic Households. The price of labor supply and labor supply level are also lower in the case of higher elasticity. This is due to the fact that the system attempts to avoid the pricy factor.

Another reason behind this odd behavior is that with the higher flexibility, the system can adjust itself to equilibrium faster than the lower flexibility case. For example, consider the case where the production function is the Leontief function. In this instance, a fixed ratio amount of input is required to produce the commodity. Thus, the system needs to produce a sufficient output for the intermediate. When the system can exchange between aggregated intermediate and value added with more flexibility, it will not need to produce large amount of output to achieve the equilibrium. Therefore, the total industry output value for the case with higher production elasticity can be smaller than the case with lower elasticity value.

Another important point to be made is that the expanded indirect loss estimation module is developed from the information contained in SAM, i.e., business patterns, flow of production factor within system, final demand consumption pattern, etc. This information varies depending on the study region and time of study. Even for the same study region at different time of study, the values still are different. Therefore, the behavior of CGE model is highly data dependent and it will behave differently depending on the information employed during development process.

6. CONCLUSION

6.1. CONCLUSION OF FINDINGS

Earthquakes are one of the most serious natural disasters. They can create a wide range of damage and consequences in terms of physical infrastructure, the economy, and social welfare. Without appropriate and adequate preparation, unforeseen natural catastrophes can cause tremendous losses, as evident for the 2005 Hurricane Katrina in the southern coastal United States (in particular in New Orleans) and the 1994 Northridge Earthquake in Southern California. Although, policy makers are concerned about the effect of these disasters, they generally focus on the direct losses or the destruction of the infrastructure caused by the disasters. They tend to overlook the consequences from these losses, such as business disruptions or reductions in final demand. The findings in this study reveal the significance of these indirect losses.

The study begins with translation of changes in a highway traffic model into the increase travel cost, or the initial indirect loss, as the result of the damaged bridges from an earthquake situation. In this translation module, there are important parameters within the calculation process for both the increased travel time and travel distance. This research shows that the assumption and parameters related to the travel time cost are more significant to the estimated increased travel cost than the ones related with the travel distance cost. This follows from the fact that the increased travel time cost is the major cost in the initial indirect loss. The second part of the study examined the estimation of the expanded indirect loss. The effect of the initial indirect loss on the entire economic system is estimated by applying the CGE model. In order to properly conduct the estimation process, the CGE model requires the given values of elasticity. The study reveals that the estimated result of the CGE model is moderately robust within the general range of elasticity values. Moreover, the estimated result from the CGE model is highly data dependent. Thus, the result from CGE model is more certain when presented as a percentage. Finally, when compared to the direct loss, the estimated initial indirect loss and expanded indirect loss are approximately 55% and 128%, respectively. Therefore, the results from this study clearly reveal that the consequences following the direct loss are significant and must be considered by policymakers.

6.2. LIMITATION OF THIS RESEARCH

As discussed earlier in Section 2.2.2, the study scope and focus needed to be indicated in order to achieve reliable indirect loss estimation. This study focuses on the indirect loss due to the damaged bridges within the St. Louis highway network. Although the focus of the study is clearly indicated, the study, however, cannot completely capture the total effect of these damaged bridges on the entire economy. The study does consider the changes within the highway traffic system as the initial indirect loss. Consequently, the effect of this increased travel cost on the entire economic system is estimated. However, this expanded indirect loss cannot be labeled as the total indirect loss from these damaged bridges. This is due to the fact that the CGE model analysis does not include the effects of repair or replacement cost of the damaged bridges or the direct loss on the entire economic system. After the earthquake incident, there will be increased demand in the construction sector as well as other related sectors in order to repair or replace the damaged bridges. These increase demand will surely have an effect on the entire economy. However, the direct loss is not included in the CGE analysis or the expanded indirect loss estimation due to the following reasons. First, it is ambiguous in how to allocate this repair/replacement cost. It is difficult to justify how much of the loss should be allocated to the construction sector, and how much should be allocated to other related sectors, such as the real estate sector. Moreover, if the reconstruction of the damaged bridges cannot be satisfied with only the available capacity of the domestic construction sector, additional construction commodities must be imported from other regions. The other reason is the source of the direct loss. Questions arise as to who will pay for this repair or replacement cost, where does the money come from, and how much money should be paid by each source. Therefore, many assumptions need to be made in order to include the direct loss into the CGE model analysis, and those assumptions are likely to have high influence on the estimated result of the CGE model.

The other limitation that prevents this study from capturing the exact loss is the timeframe conflict among each study module. The direct loss module and initial indirect loss module have the same time frame, which is the duration from the first day of the earthquake incident until the damaged bridges are fully recovered over the 500-day timeframe. On the other hand, the expanded indirect loss module is developed based on the CGE model, which is built from the annual economic information. Consequently, the expanded indirect loss module has the timeframe of 365 days. Therefore, only the increased travel time within the first 365-day duration can be transferred into the CGE model analysis. As a result, the expanded indirect loss estimated in this study is only for the first 365-day duration after the earthquake incident. In order to complete the expanded indirect loss for a 500-day timeframe, a dynamic CGE model that can adjust itself over space and time is required. The dynamic CGE model is the CGE model which can adjust itself to represent the future economic scenario. In order to achieve the dynamic model, one needs to make assumptions about the rate of economic growth, the rate of time preference, inflation, and depreciation, among others. (Paltsev, 2004). These necessary assumptions are difficult to validate and make the model somewhat unrealistic.

Another issue that creates difficulty and might also be considered as the limitation in this research is the availability of the data at the detailed regional level. Both the initial indirect loss module and the expanded indirect loss module are data intensive models. The accuracy of the information used in developing the module is crucial. However, only some of the regional information required in model development is currently available for public use. In addition, some of the available information, such as, the compensation, is not complete. Therefore, in order to obtain the required information, assumptions are required to be made. For example, the ratio of the specific industrial sector's compensation to the total industrial compensation at the given detail level is assumed to be the same as in the higher available level. In reality, that specific industrial sector's compensation might be a special characteristic of the study region, such that the same ratio assumption becomes totally incorrect. Thus, there is the possibility that these assumptions regarding the missing data can distort the results from the models.

6.3. CONTRIBUTIONS OF THIS RESEARCH

This study framework is designed as an integrated framework, which is the same as in many earlier studies (FEMA, 2001; Brookshire et al. 1997; Rose et al. 1997; Cho et al. 2001). The framework begins from the direct loss estimation and seamlessly continues through the indirect loss estimation. The study is designed to focus on the loss from the damaged bridges in the highway network. One factor that distinguishes this study from others is that the bridging between the direct loss module and indirect loss module is initiated by the highway traffic model. From the traffic model, the initial indirect loss is estimated and sent through the CGE model to estimate the effects of the loss on the entire economic system. Although the study in this dissertation is specifically conducted for the St. Louis Metropolitan area, which is the first CGE model for this region, the study framework itself is designed to be general and can be easily applied to other regions.

As for applying results from the study, it can be considered as an information source for policymakers. The study result provides information regarding to the potential loss that could occur from an earthquake situation. With accurate information, the regional government can propose appropriate policies in order to reduce the risk of large scale failure and the amount of overall damage. Other than policymakers, this information should be made available to the community in order to develop public safety awareness. Thus, individuals and businesses can properly prepare themselves for an unforeseen event. Another important issue of concern is the approach used to present the study results. Although the study is well constructed and the model performs well, if the produced information cannot reach the responsible personnel, the study benefit will be reduced. Therefore, an effective information presentation method is the key to maximize the benefits of the study (Tirasirichai and Enke, 2006).

6.4. RECOMMENDATION AND FUTURE RESEARCH

Accurate and up-to-date information is crucial to successful hazard preventive planning. Therefore, continuous improvement in the field of disaster loss estimation is necessary. Dynamic CGE can come in to improve the study for the timeframe conflict issue. With a reliable dynamic CGE model, indirect loss on the entire study timeframe will be captured. Additionally, the model should be updated periodically with the latest available information in order to accurately represent the current scenario.

Due to the generality of this study framework, it is convenient to follow the study approach and conduct the indirect loss estimation for other study regions. With the estimated potential loss information for multiple regions, responsible federal and regional agencies will recognize the overall risk they are actually encountering. Consequently, funds will be distributed more efficiently to support the policy that will best hedge their risk. This potential loss information will also increase the public safety awareness. Accordingly, individuals and businesses will be able to understand their risk and effectively prepare for the unexpected future losses.

Another area for future research is to apply the study as a policy analysis tool. In this study, taxes are assumed to be on the industrial outputs. Different tax policies, such as labor taxes, capital taxes, income taxes, etc., could be applied to make the model more realistic. The scenario study can be designed to response to a potential loss from the earthquake situation. The mitigation plan for the direct loss or the cost of repair or replacement of the damaged bridges can be specified by the amount and source of the relief fund, whether from the federal government, local government, or average payment from agents within the economic system. With this well defined scenario, the direct loss can be properly included into the CGE model and the complete total indirect loss can be estimated. Furthermore, with the study result, the most affected areas from the earthquake situation can be pinpointed and a preventive action or mitigation plan can be properly designed to alleviate the potential loss. Those plans have cost associated with them and should be evaluated for their effectiveness and benefits. The policy assessment can be conducted by modifying the model for the scenario where the plan is employed. Comparison of the estimated loss of the different policies to situations where there is no alleviation plan applied can be made. With incessant improvement in this field of study, the overall communities will encounter less suffering from the unforeseen events.

APPENDIX A.

SOURCE OF DATA FOR VALUE OF TRAVEL TIME AND DISTANCE ESTIMATION

Data Name	Description	Source	Conversion Approach	Year	Note
Cost of Tractor	cost of tractor using by	Annual Report: Motor Carrier Financial & Operation Information Database (Nation wide) (www.transtats.bts.gov)	Remove the missing case from the report and use only mid 80% of data (in order to remove extreme value) to find weight average and use that to represent the value, will be converted to 2004 US dollar by 10-year average in percentage increase of Motor Freight Transportation and Warehousing PPI projecting to year 2004	2001	
Cost of Truck	cost of truck using by			2001	
Cost of Trailer	cost of trailer using by			2001	
Annual repair cost of truck/tractor/trailer	cost of repair & maintenance per unit for commercial vehicle			2001	
Annual Insurance cost truck/tractor/trailer	cost of insurance per unit for commercial vehicle			2001	
Highway mile travel for commercial vehicle	Average highway mile traveled by commercial vehicle			2001	
Profit markup	Operating ratio between cost and	http://www.bizstats.com/corpnetincome.htm	Ratio of profit to expense	2003	
Hourly wage for truck driver	Hourly wage of truck driver in St. Louis metropolitan area	the Bureau of Labor Statistic (www.bls.gov)	Find the weight average of median hourly wage of heavy truck driver and light or delivery service driver in St. Louis Metropolitan area, and updated 2004 US dollar by 10-year average in percentage increase of Motor Freight Transportation and Warehousing PPI projecting to year 2004	2001	
Hourly wage for residence in each study zone	Hourly wage of residence in each zone in study area	EWG	Use the median of the interval for each income group, then find the weight average and use that as the represent value for that zone	2004	The value is the projection value onto year 2004
Price of vehicle	Average price of vehicle	National Automobile Dealers Association (NADA)	Converted to 2004 US dollar by 12-year average in percentage increase of all urban all item CPI projecting to year 2004	1998	Stated in FCIC article
Annual car insurance cost	Consumer average car insurance cost in Midwest region	Consumer Expenditure Survey from the Bureau of Labor Statistic (www.bls.gov)		2001	
Annual car repair and maintenance cost	Consumer average car repair and maintenance cost in Midwest			2001	
Percentage of different vehicle on road	Percentage of car, van and light truck on highway	Highways: 2000 Data from the Bureau of Labor Statistic	Use number of car and truck then find the ratio to total vehicle (car and truck)	2000	
Annual highway travel for consumer vehicle		Annual Energy Review from US Department of Energy at http://www.eia.doe.gov/emeu/aer/ep/motor.html	Projected into year 2004 by linear regression modeling from historical data	Series data to 2000	
Fuel consumption	Fuel consumption rate of different kind of vehicle		Use the last 10-year average of fuel consumption (number of mile per gallon)	Series data to 2001	
Fuel retail price	Weekly retail price of gasoline and diesel in US	US Department of energy at http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp	Average price for one year time frame (Year 2003) then update the value to year 2004 by using the CPI for Gasoline and PPI for Diesel	Updated weekly	
PPI	Producer Price Index	US Department of Labor: Bereau of Labor Statistics	Use to convert the dollar amount in producer side to current dollar value	Updated monthly	
CPI	Consumer Price Index		Use to convert the dollar amount in consumer side to current dollar value	Updated monthly	
Sales Tax	General Sales Tax	Missouri Department of Revenue	Use the tax value of St. Louis area for every zone in study area	January 2004	Valued at 6.95%

APPENDIX B.

CONSUMER PRICE INDEX AND PRODUCER PRICE INDEX DATA

CPI-U: All Urban Consumer, All Item

	Value		Percent Change	
YEAR	DEC.	AVG.	DEC-DEC	AVG-AVG
1991	137.9	136.2	3.1%	4.2%
1992	141.9	140.3	2.9%	3.0%
1993	145.8	144.5	2.7%	3.0%
1994	149.7	148.2	2.7%	2.6%
1995	153.5	152.4	2.5%	2.8%
1996	158.6	156.9	3.3%	3.0%
1997	161.3	160.5	1.7%	2.3%
1998	163.9	163.0	1.6%	1.6%
1999	168.3	166.6	2.7%	2.2%
2000	174.0	172.2	3.4%	3.4%
2001	176.7	177.1	1.6%	2.8%
2002	180.9	179.9	2.4%	1.6%
2003	184.3	184.0	1.9%	2.3%
2004	**188.9**	**188.9**	**2.5%**	**2.7%**

Note: 1982-1984 as the base year
Year 2004 value is the average value of year 1991-2003

PPI: Moter, Freight Transportation, and Warehousing Sector

YEAR	Average Value	Percent Change
1994	101.9	1.90%
1995	104.5	2.55%
1996	106.3	1.72%
1997	108.9	2.45%
1998	111.6	2.48%
1999	114.8	2.87%
2000	119.4	4.01%
2001	123.1	3.10%
2002	124.5	1.14%
2003	127.9	2.73%
2004	**131.2**	**2.49%**

Note: 1993 as the base year
Year 2004 value is the average value of year 1994-2003

Source: US Bureau of Labor Statistic

APPENDIX C.

CALCULATION ASSUMPTION FOR VALUE OF TRAVEL TIME AND DISTANCE

Numerical Assumption	Description	Value at	Source
Annual working hour		2,000 hours	U.S. DOT Document [DOT,1997]
Number of person per vehicle for commuting trip	Average of number persons per vehicle of all commuting trip purpose	1.316 persons	EWG
Percentage of each trip type in study area by trip purpose	The percentage of trips by purpose in St. Louis metropolitan area	Work Trip @ 22.82% Non-work Trip @ 63.78% Commercial Trip @ 13.4%	
Average age of tractor/truck		2.5 years	The same value used in the Waters et al. study [Waters, Wongs, and Migale, 1995]
Average age of trailer		4 years	
Depreciation per year of tractor/truck		16%	
Depreciation per year of trailer		12%	
Depreciation due to time		40%	
Repair/Maintenance due to time		20%	
Cost of money		12%	
Insurance due to time		15%	
Driver wage burden	Overhead cost in percentage of hourly wage	26%	

Variable	Additional Assumption
Depreciation due to distance	Other than travel time, depreciation depends only on travel distance
Repair/Maintenance due to distance	Other than travel time, repair/maintenance depends only on travel distance
Number of person per vehicle for commuting trip	This number is applicable for every commuting trip in the study area. Moreover, it also assumes that every person in the vehicle is adult
Percentage of each trip type in study area by trip purpose	This percentage is applicable for every zone in the study area

APPENDIX D.

FUEL CONSUMPTION AND VEHICLE MILEAGE DATA

Vehicle Type	10-year Average value of Mileage (miles per vehicle)	Fuel Consumption (gallons per vehicle)	Fuel Rate (miles per gallon)
Passenger Car	11,293	532.2	21.21
Vans, Pickup Trucks, and SUV	12,097	701.1	17.24
Trucks	25,840	4,240	6.08
All Motors Vehicles	11,844	702.6	16.84

Source: Table 2.9 Motor Vehicle Mileage, Fuel Consumption, and Fuel Rates, 1949-2000
From US Department of Energy (http://www.eia.doe.gov/emeu/aer/ep/motor.html)

	Gasoline	Diesel	
Year 2003 Price Average	$1.55	$1.49	per gallon

Source: U.S. Department of Energy, Energy Information Administration

	Car	Light truck and van	Commercial Vehicle
Fuel cost per mile ($)	$0.07	$0.09	$0.24

Note: These number are in year 2003

	Commuting Trip	Commercial Trip
Fuel cost per mile ($)	$0.08	$0.24

Note: Commuting trip is represented by weight average of car, and light truck and van
: These number are in 2003 USD

Percentage of	
Car	**Light truck and van**
62.91%	37.09%

Source: Year 2000: Highway Mile Travel Database

Year	Annual Highway Mileage Travel Car	Van & etc	Truck
2001	12208.26	12853.37	28621.77
2002	12377.55	12976.10	29098.35
2003	12546.85	13098.84	29574.93
2004	**12716.15**	**13221.58**	**30051.51**

Note: The number in table are the projected number from regression analysis of historical data from year 1965 - 2000

Source: Table 2.9 Motor Vehicle Mileage, Fuel Consumption, and Fuel Rates, 1949-2000
From US Department of Energy (http://www.eia.doe.gov/emeu/aer/ep/motor.html)

APPENDIX E.

VEHICLE INSURANCE AND MAINTENANCE COST DATA

	Consumer Vehicle	
Year	Insurance	Maintenance
1991	$544.00	$585.00
1992	$545.00	$567.00
1993	$594.00	$560.00
1994	$627.00	$611.00
1995	$689.00	$643.00
1996	$657.00	$641.00
1997	$684.00	$659.00
1998	$680.00	$615.00
1999	$722.00	$572.00
2000	$750.00	$610.00
2001	$803.00	$626.00
2004	**$856.62**	**$667.80**

Note: Year 2004 number is the number in year 2001 updated by CPI

Source: Consumer Expenditure Survey from US Bureau of Labor Statistic (http://www.bls.gov/cex/#data)

APPENDIX F.
TRUCK DATA

Commercial Vehicle Cost Information

	Average	Mid 80 Percentile Average	Weighted Average	Mid 80% Weighted Average
Cost of new tractor	$58,732.13	$55,160.48	$57,353.91	**$56,893.93**
Cost of new truck	$44,618.43	$39,750.01	$38,988.13	**$38,543.72**
Cost of new trailer	$28,096.22	$22,098.58	$17,627.43	**$17,940.78**
Maintenance & Repair & Tire	$13,793.67	$4,375.72	$2,998.25	**$3,000.48**
Cargo and Liability Insurance	$12,896.42	$3,280.71	$2,018.52	**$1,900.25**

Percentage of Commercial Vehicle Type Owned by Freight Companies

	Units	Percentage
number of truck own by freight company	86000	27.68%
number of tractor own by freight company	224699	72.32%

Note: These number are in Year 2001
Source: Annual Report: Motor Carrier Financial & Operation Information Database
Nation Wide Survey (www.transtats.bts.gov)

St. Louis Metropolitan Area Truck Driver Wage Information

			Wage Estimates			
SOC Code Number	Occupation Title	Employment	**Median Hourly**	Mean Hourly	Mean Annual	Mean RSE
53-3032	Truck Drivers, Heavy and Tractor-Trailer	**15,306**	**$16.67**	$18.20	$37,880	2.90%
53-3033	Truck Drivers, Light or Delivery Services	**10,040**	**$12.66**	$13.99	$29,100	3.50%

Note: These number are in 2001 US Dollar value
Source: Bureau of Labor Statistic (www.bls.gov)

Use the weight average of median hourly wage to represent commercial trip driver wage
Driver Hourly Wage = $15.08 (2001 US Dollar)

APPENDIX G.

INCOME MATRIX PREPARATION MATLAB CODING SCRIPT

```
%Income Matrix Preparation
clear all;

%Input the file
%The input file is the column vector of weight average income for each zone in
%comma delimited file

original_file = input('Enter name of original income file (w/o .csv extension):  ', 's');
weight_income = input('Enter weight average of income:  ');

income = dlmread([original_file,'.csv'], ',');
[num_of_zone,junk] = size(income);
x = diag(income);

for i=1:num_of_zone
   for j=1:num_of_zone
      if (x(i,i)~=0)&(x(j,j)~=0)
            a = (x(i,i)+x(j,j))/2;
            x(i,j)=a;
            x(j,i)=a;
      else
         a = x(i,i) + x(j,j);
         x(i,j)=a;
         x(j,i)=a;
      end
   end
end

for i=1:num_of_zone
   for j=1:num_of_zone
      if x(i,j)==0
         x(i,j)=weight_income;
      end
   end
end

dlmwrite('c:\temp\income.csv',x,',')
```

APPENDIX H.

INITIAL INDIRECT LOSS ESTIMATION MATLAB CODING SCRIPT

```
% Indirect Loss Estimation
clear all;
format bank;

% Input the information
% All of the input files except for the income file are the output from MinUTP and CUBE
% which are in comma delimited file with first row and first column represent the zone
% For the income file, it is the comma delimited file generated from "Income Matrix
% M-file.

baseline_distance_file = input('Enter name of baseline distance file (w/o .csv extension):  ',
scenario_distance_file = input('Enter name of scenario distance file (w/o .csv extension):  ',

baseline_time_file = input('Enter name of baseline time file (w/o .csv extension):  ', 's');
scenario_time_file = input('Enter name of scenario time file (w/o .csv extension):  ', 's');
income_file = input('Enter name of income file (w/o .csv extension):  ', 's');

percent_work_trip = input('Enter percentage of traffic which is work trip:  ')/100;
percent_nonwork_trip = input('Enter percentage of traffic which is non-work trip:  ')/100;
percent_business_trip = input('Enter percentage of traffic which is business trip:  ')/100;
person_in_vehicle = input('Enter average number of passenger per vehicle:  ');
value_of_work_trip = input('Enter value of work trip time by percentage of income:  ')/100;
value_of_nonwork_trip = input('Enter value of non-work trip time by percentage of income:
value_of_business_trip = input('Enter value of hourly business trip time in dollar value:  ');
consumer_operating_cost = input('Enter value of consumer vehicle operating cost in dollar
business_operating_cost = input('Enter value of frieght business vehicle operating cost in
dollar value:  ');

working_hour_per_year = input('Enter number of working hour per year:  ');

baseline_time = dlmread([baseline_time_file,'.csv'], ',', 1, 1);
scenario_time = dlmread([scenario_time_file,'.csv'], ',', 1, 1);
baseline_distance = dlmread([baseline_distance_file,'.csv'], ',', 1, 1);
scenario_distance = dlmread([scenario_distance_file,'.csv'], ',', 1, 1);
hourly_income = dlmread([income_file,'.csv'], ',')/working_hour_per_year;

% Calculation of the difference
difference_time = (scenario_time - baseline_time)/6000;
difference_distance = (scenario_distance - baseline_distance)*1.61/100;

increase_travel_time = sum(sum(difference_time));
increase_travel_distance = sum(sum(difference_distance));

increase_travel_distance
increase_travel_time
```

```
% Calculation of the distance cost
distance_cost =
((percent_work_trip+percent_nonwork_trip)*consumer_operating_cost*difference_distance)+(
percent_business_trip*business_operating_cost*difference_distance);
scenario_distance_cost = sum(sum(distance_cost));
scenario_distance_cost

% Calculation of the time cost
time_cost =
(person_in_vehicle*percent_work_trip*value_of_work_trip*difference_time.*hourly_income)+(
person_in_vehicle*percent_nonwork_trip*value_of_nonwork_trip*difference_time.*hourly_inco
me)+(percent_business_trip*value_of_business_trip*difference_time);
scenario_time_cost = sum(sum(time_cost));
scenario_time_cost

% Calculation of the total cost occurred
total_cost=distance_cost+time_cost;

total_scenario_cost = scenario_time_cost + scenario_distance_cost;
total_scenario_cost

Total = [scenario_distance_cost scenario_time_cost total_scenario_cost]

%Most Affected Route

[max_value,column]=max(max(total_cost));
[max_value,row]=max(max(total_cost,[],2));
format bank
disp(sprintf('The most affected route is the route from zone number %d to zone number
%d',row,column));
disp(sprintf('with the indirect loss at $%f',max_value));
```

APPENDIX I.

DATA SOURCES FOR SAM DEVELOPMENT

Data Name	Description	Source	Year	Note
National I-O Table	Use Table, Make Table, Direct Requirement Table	Industry Economic Accounts, Bureau of Economic Analysis (http://www.bea.gov/industry/index.htm)	2004	
Personal Income	Local Area Personal Income for both national and regional level	Table CA06N, Regional Economic Accounts, Bureau of Economic Analysis, (http://www.bea.gov/bea/regional/reis/)	2004	Part of information is not complete. It is fulfill by weight average technique or use higher level information for regional data
Earnings	Local Area Earning for both national and regional level	Table CA05N, Regional Economic Accounts, Bureau of Economic Analysis, (http://www.bea.gov/bea/regional/reis/)	2004	Part of information is not complete. It is fulfill by weight average technique or use higher level information for regional data
Gross State Product	Total Value Added for production provided by domestic	Regional Economic Accounts, Bureau of Economic Analysis, (http://www.bea.gov/regional/index.htm)	2004	Part of information is not complete. It is fulfill by weight average technique or use higher level information for regional data
Gross Operating Surplus	The estimated value assumed to represent the return on capital			
Compensation of Employee	The estimated value of labor supply			
Taxes Information	Taxes collected by local and federal government in the area			
ATUS	American Time Use Survey used to estimate the leisure time	Bureau of Labor Statistic, (http://www.bls.gov/tus/)	2004	

APPENDIX J.

MIXED SLQ VALUE FOR STUDY REGION

IOCode	Description	Mixed SLQ Type	Mixed SLQ Value
111CA	Farms	Earning	0.439845524
113FF	Forestry, fishing, and related activities	Earning	0.714974248
211	Oil and gas extraction	Earning	0.003843627
212	Mining, except oil and gas	Earning	0.96629271
213	Support activities for mining	Income	0
22	Utilities	Earning	0.785044124
23	Construction	Income	1
311FT	Food and beverage and tobacco products	Income	0.880541515
313TT	Textile mills and textile product mills	Earning	0.389109226
315AL	Apparel and leather and allied products	Income	1
321	Wood products	Earning	0.252814427
322	Paper products	Earning	0.695020089
323	Printing and related support activities	Earning	1
324	Petroleum and coal products	Earning	0.186515863
325	Chemical products	Earning	1
326	Plastics and rubber products	Earning	0.943699336
327	Nonmetallic mineral products	Earning	1
331	Primary metals	Earning	0.879079931
332	Fabricated metal products	Earning	0.92171173
333	Machinery	Income	1
334	Computer and electronic products	Earning	0.23083561
335	Electrical equipment, appliances, and components	Earning	0.951550824
3361MV	Motor vehicles, bodies and trailers, and parts	Income	0.509949387
3364OT	Other transportation equipment	Income	0.150337008
337	Furniture and related products	Income	1
339	Miscellaneous manufacturing	Income	0.900483233
42	Wholesale trade	Income	1
44RT	Retail trade	Income	0.879956584
481	Air transportation	Income	0.827514326
482	Rail transportation	Earning	1
483	Water transportation	Income	1
484	Truck transportation	Earning	1
485	Transit and ground passenger transportation	Income	0.999871587
486	Pipeline transportation	Earning	0
487OS	Other transportation and support activities	Earning	0.81860041
493	Warehousing and storage	Earning	0.860357272
511	Publishing industries (includes software)	Income	0.711985743
512	Motion picture and sound recording industries	Earning	0.216820695
513	Broadcasting and telecommunications	Earning	1
514	Information and data processing services	Earning	0.190400933
521CI	Federal Reserve banks, credit intermediation, and related activities	Earning	0.93873564
523	Securities, commodity contracts, and investments	Earning	0.497690718
524	Insurance carriers and related activities	Earning	0.928271869
525	Funds, trusts, and other financial vehicles	Income	1
531	Real estate	Income	0.707892703
532RL	Rental and leasing services and lessors of intangible assets	Earning	0.971776821
5411	Legal services	Earning	0.941338278
5412OP	Miscellaneous professional, scientific and technical services	Earning	0.941338278
5415	Computer systems design and related services	Income	0.917411092
55	Management of companies and enterprises	Earning	1
561	Administrative and support services	Earning	0.951475925
562	Waste management and remediation services	Earning	0.91194243
61	Educational services	Income	1
621	Ambulatory health care services	Income	0.94274727
622HO	Hospitals and nursing and residential care facilities	Income	1
624	Social assistance	Income	0.906183022
711AS	Performing arts, spectator sports, museums, and related activities	Earning	1
713	Amusements, gambling, and recreation industries	Income	1
721	Accommodation	Income	0.513639416
722	Food services and drinking places	Income	1
81	Other services, except government	Income	1
GFE	Federal government enterprises	Earning	0.946399416
GSLE	State and local government enterprises	Income	0.712457417

APPENDIX K.

INDUSTRIAL SECTOR AGGREGATION

2-Digit NAICS	Description	3-Digit NAICS
11	Agriculture, Forestry, Fishing and Hunting	111CA, 113FF
21	Mining	211, 212, 213
22	Utilities	22
23	Construction	23
31-33	Manufacturing	311FT, 313TT, 315AL, 321, 322, 323, 324, 325, 326, 327, 331, 332, 333, 334, 335, 3361MV, 3364OT, 337, 339
42	Wholesale Trade	42
44	Retail Trade	44RT
48-49	Transportation and Warehousing except Truck Transportation	481, 482, 483, 485, 486, 487OS, 493
484	Truck Transportation	484
51	Information	511, 512, 513, 514
52	Finance and Insurance	521CI, 523, 524, 525
53	Real Estate and Rental and Leasing	531, 532RL
54	Professional, Scientific, and Technical Services	5411, 5412OP, 5415
55	Management of Companies and Enterprises	55
56	Administrative and Support and Waste Management and Remediation Services	561, 562
61	Educational Services	61
62	Health Care and Social Assistance	621, 622HO, 624
71	Arts, Entertainment, and Recreation	711AS, 713
72	Accommodation and Food Services	721, 722
81	Other Services (except Public Administration)	81
92	Public Administration	GFG, GFE, GSLG, GSLE

APPENDIX L.

SAM TABLE FOR THE STUDY REGION

	Industrial Sector											
Industrial Sector	11	21	22	23	31-33	42	44-45	48-49	484	51	52	53
11	219320.2	5.922766	1.638821	6866.384	664224.2	1139.401	323.6535	45.48365	2.074573	38.89851	10.05566	5679.623
21	2368.631	50172.53	83195.16	77104.41	152712.1	257.3637	157.2628	2072.008	124.2656	107.3139	26.7075	5494.489
22	15999.39	6009.204	2344.272	23215.87	242793.1	42994.05	84450.54	11438.31	3837.054	28159.81	13371.41	203398.6
23	6747.815	4.961635	17012.64	11869.09	62502.27	25324.45	44924.4	4253.896	5207.635	28379.93	34145.93	209811.9
31-33	184130.7	45688.38	26535.79	2527238	7566708	280454.4	225799.5	158612.4	140789.6	420506.4	56324.36	214742.8
42	53856.4	12355.56	9401.565	407319	1802694	305459.5	57769.33	69618.35	111016.9	106960.8	10817.14	38869.62
44	630.8081	887.5568	453.6889	697468.8	88791.5	28871.25	44465.07	3052.472	22668.62	6829.72	2287.221	70570.6
48-49	16949.92	15557.59	36659.98	54678.62	312941.8	128835.5	134463.5	200592.4	163839.8	61526.49	78866.64	64526.16
484	15235.9	10492.48	9430.673	140434.1	550881.1	10523.53	16018.13	9642.223	339913	12751.09	3519.58	12869.92
51	6535.099	1299.937	2100.181	172180.2	261559.1	174033.8	168129	42961.38	49829.8	1812283	121159.8	132472.7
52	22385.96	7705.506	22396.38	158066.3	410009.1	228614	260225	73598.41	56786.73	318973	2724584	814966.1
53	34686.93	10032.01	3081.195	171403.6	320402.3	205268.9	403492.6	112520.5	71041.16	243218.5	236274.6	541797.5
54	18608.71	6885.197	18862.41	628548.8	1054608	394771.5	466178.5	122482.1	73140.05	727882.6	418818	440666.6
55	562.6997	11103.71	412.0422	18502.82	936863	258947.2	568576.5	17171.32	50672.63	55643.68	89240.69	31422.8
56	2871.713	1097.502	5379.971	143881.4	218675.3	314076.5	249606.4	140272.4	21289.98	207147.7	124945.6	563837.6
61	83.80215	427.3743	1465.101	936.124	14186.81	6352.049	4140.812	2794.172	429.0768	18139.25	2485.836	3415.828
62	0	0	0	0	0	0	16.70768	32.53805	1316.809	0	2.408446	0
71	1764.943	1001.882	174.8041	7956.772	24561.66	11503.41	9122.402	922.966	982.0982	95273.15	12365.08	11548.67
72	617.7489	646.1739	3705.02	13894.17	101929.1	40530.61	48909.12	32402.28	3877.228	49635.89	70059.88	49666.09
81	14930.23	516.2179	1165.572	121351.8	299657.8	89962.8	74704.62	18892.4	66491.84	154973.8	40423.91	156193.1
92	11847.5	2861.32	3583.728	30834	146187.8	68306.92	84251.93	24699.31	11761.08	71306.59	66324.01	99808.38
Labor	173526.5	136490.3	340749.1	4462485	6198156	4162139	4172773	1410057	829398	2067341	3906495	817848
Capital	587742.7	92561.84	788326.2	1820308	3755115	2116091	1523163	535437.7	429729.2	2210666	3100613	9033638
Non-Comparable Import	180812.7	100739.6	1114403	1266377	3937728	647521.9	405653.5	520851.1	237526.1	896276.4	1075273	1183204
Tax	-2361.68	24922.67	274543.3	57147.94	301233.6	1223846	1430925	116669.1	25025.58	484100.7	254614.7	1721053
Total	1569855	539465.4	2765384	13020069	29425121	10765825	10478240	3631093	2716696	10078122	12443049	16427501

Note: The number in table are in thousands of dollar.

	Industrial Sector									Final Demand		
Industrial Sector	54	55	56	61	62	71	72	81	92	**Domestic**	**Foreign**	**Total**
11	508.4186	3.373156	22705.72	59.02025	2250.105	1413.279	46374.69	1521.603	8074.231	508414.1	80873.21	1569855
21	1725.041	88.84335	195.3917	81.85657	1170.544	32.95457	550.6075	478.795	29305.05	113922.5	18121.6	539465.4
22	39256.56	87305.2	23693.72	11400.36	67603.63	25135.17	82194.31	40539.05	212834.8	1291906	205503	2765384
23	42499.53	99048.53	11293.13	53831.16	58739.93	23595.58	46494.67	33129.52	356911.2	10218835	1625506	13020069
31-33	332557.8	213125	181386.3	106030.2	996786.9	60519.7	875644.8	622410.7	1060232	11327101	1801797	29425121
42	60257.92	27405.43	61026.26	27107.98	167034.6	12152.69	175811.2	121230.5	211712.8	5966810	949137.9	10765825
44	23352.57	211.2045	51335.66	2713.351	25329.72	4102.704	26526.06	65603.08	185.3146	8033946	1277956	10478240
48-49	124558.5	2693.429	48056.07	16274.38	100590.9	12177.5	33360.25	32608.51	150968.5	1587796	252570.1	3631093
484	10688.14	5771.627	15358.57	6323.947	27296.51	3402.839	37041.03	23154.8	108294.8	1162702	184950.5	2716696
51	432433.7	423292.1	119593.6	79925.75	282471	49494.17	111392.7	120802.4	445437.3	4373107	695628.2	10078122
52	190740.3	80876.09	79805.95	37273.14	212978.6	58278.11	143841.6	55035.18	183394.7	5437564	864951	12443049
53	457292.1	410904.1	112356.4	273105.4	657688.8	116687.8	256908.7	261775.7	238578.6	9739695	1549289	16427501
54	1003227	1033504	223908.1	93528.42	457774.3	108906	166431.1	177765.9	1190244	2635724	419263.5	11881730
55	59478.26	0	82894.07	12639.55	145715.3	34917.49	20395.06	58017.8	1948.807	5151751	819486.8	8426363
56	643260.1	13588.16	258860.3	114701.5	518917.7	67183.4	83210.87	161770.5	448247.4	414151.2	65878.85	4782852
61	12112.66	37.32599	1995.66	21583.05	11652.1	3260.257	761.5374	4042.228	104431.1	2437119	387671.5	3039523
62	2347.831	0	285.1832	392.657	80923.36	505.89	5.942048	285.3344	107237.8	10926968	1738148	12858469
71	61710.99	2275.984	11679.98	8084.925	14026.78	177382.2	29222.1	20171.68	28910.63	1713717	272600.2	2516960
72	144977.1	275.3128	44886.67	8445.631	187839.1	7797.667	44368.41	22379.42	110940.2	3819434	607555.7	5414772
81	101186.9	153233.6	85276.78	27717.61	94299.13	33308.11	54157.01	66366.19	249518.2	2966564	471890.1	5342782
92	133599.5	50287.73	50222.52	32787.82	180903.8	23720.87	49978.65	55491.59	208574.2	14367201	2285384	18059924
Labor	5203431	4068287	2221233	1772768	6398248	967011	1788830	2057208	9580112	**Leisure Time Consumed by**		
Capital	2165704	1425842	770432.8	111596.9	1375713	431871.8	640592.5	518795.2	1084295	**Domestic Households =**		
Non-Comparable Import	518188	284895.4	232991.4	196323.6	643338.1	-11861.1	401657.1	673733.9	2068530			34861610
Tax	116635.6	43411.6	71379.08	24826.62	149177.6	305964.3	299021.5	148464.5	-128995			
Total	11881730	8426363	4782852	3039523	12858469	2516960	5414772	5342782	18059924			

Note: The number in table are in thousands of dollar.

APPENDIX M.

TRUCK TRANSPORTATION SECTOR INPUT ADJUSTMENT FOR STUDY REGION

Additional Input Require from	
11	$ -
21	$ 8,960.55
22	$ 286,737.74
23	$ 389,037.40
31-33	$ 10,512,970.30
42	$ 8,290,006.13
44	$ 1,692,798.05
48-49	$ 12,234,143.44
484	$ 25,381,516.70
51	$ 3,720,870.16
52	$ 4,240,582.31
53	$ 5,304,648.13
54	$ 5,461,457.83
55	$ 3,783,594.04
56	$ 1,589,751.67
61	$ 32,108.65
62	$ 98,566.10
71	$ 73,177.86
72	$ 289,724.59
81	$ 4,964,893.78
92	$ 878,134.32
Capital	$ 32,088,491.57
Labor Supply	$ 61,932,364.30
Non-Comparable Import	$ 17,736,670.48
Total	$ 200,991,206.11

APPENDIX N.

EXPANDED INDIRECT LOSS MODULE GAMS/MPSGE SYNTAX CODING

```
$title  MPSGE Model for 2004 St. Louis Metropolitan Area Policy Analysis

* Written by Chakkaphan Tirasirichai
* All of the required information/data is included withing the coding for
* other researcher to be able to replicate the model.

set     i       SAM row and column indices /1*47/,
        S       Sectors and Goods /SA,SB,SC,SD,SE,SF,SG,SH,SI,SJ,SK,SL,SM,SN,SO,
                                   SP,SQ,SR,SS,ST,SU/,
        f       Primary factors / CAP, LAB/,
        h       Households      / HH_D, HH_F/,
        Wel     Welfare /W_D, W_F/,
        EC      Non-comparable import /HH_F/
        k       Iteration /1*10000/
        LossRep Use to report and export the file to excel /TotalL,OutL,WelL,
                                                         IncomeL,TotalL2/;


* Goods and sectors are identical:
* Sector and goods is starting from SA, SB, SC, ..., to SU instead of
* NAICS 2-digit number code in order to avoid confusion.
* Sector (SA,SB,SC,SD,SE,SF,SG,SH,SI,SJ,SK,SL,SM,SN,SO,SP,SQ,SR,SS,ST,SU) are
* equilivant to Sector Code (11,21,22,23,31-33,42,44,48-49,484,51,52,53,54,55
*                            56,61,62,71,72,81,92), respectively.
* All of the number shown below are in millions of dollar


alias (i,j),(S,G);

TABLE PremlMake(*,*) Make table: Non-comparable Import: Tax information

              Output             HH_F               TAXX
 SA         1569.855267        180.8126556        -2.361682903
 SB         539.4654492        100.73962          24.92267004
 SC         2765.383705        1114.403234        274.5432984
 SD         13020.06851        1266.377149        57.14794237
 SE         29425.12098        3937.727671        301.2335819
 SF         10765.82498        647.5219179        1223.845601
 SG         10478.23965        405.6535298        1430.925041
 SH         3631.092673        520.8510503        116.6691028
 SI         2716.696212        237.5260842        25.02557793
 SJ         10078.12198        896.2764072        484.1007408
 SK         12443.0487         1075.273438        254.6146879
 SL         16427.50143        1183.203572        1721.052846
 SM         11881.72965        518.1879549        116.6355902
 SN         8426.362944        284.8953935        43.41159909
 SO         4782.852203        232.9913537        71.37908241
 SP         3039.522784        196.3235942        24.82661786
 SQ         12858.4691         643.3380517        149.1775695
 SR         2516.960313        -11.86109331       305.9643337
 SS         5414.772333        401.6570857        299.0215395
 ST         5342.782079        673.7338565        148.4645374
 SU         18059.92415        2068.53036        -128.9945624
 W_D        104194.42738
 W_F        16574.162885

TABLE UseTable(*,*) The use table information

          SA            SB            SC            SD            SE
 SA   219.3202159   0.005922766   0.001638821   6.866383638   664.2241941
 SB   2.368631446   50.17252549   83.19515678   77.10441397   152.7121476
 SC   15.99939201   6.009204298   2.34427246    23.21586718   242.7930577
 SD   6.747814722   0.004961635   17.01264055   11.86909445   62.50226703
 SE   184.1306604   45.68838426   26.5357862    2527.237582   7566.708316
 SF   53.85639535   12.35555617   9.401565034   407.31903     1802.693749
 SG   0.630808113   0.887556766   0.453688907   697.4688167   88.79150068
 SH   16.9499181    15.55759058   36.65998483   54.67862425   312.9418366
 SI   15.23590055   10.49248422   9.430673081   140.4341258   550.8810749
 SJ   6.535098665   1.29993708    2.10018057    172.1802102   261.5591418
 SK   22.3859642    7.705506337   22.39637708   158.0662722   410.0090601
 SL   34.68693252   10.03200542   3.08119451    171.4035956   320.4022661
 SM   18.60870626   6.88519659    18.86241371   628.548835    1054.608477
 SN   0.562699745   11.10371472   0.412042172   18.50281935   936.8630072
 SO   2.871713077   1.097502238   5.379970745   143.8814122   218.6753216
 SP   0.083802149   0.42737428    1.465100719   0.936124036   14.18680715
 SQ       0             0             0             0             0
 SR   1.764943209   1.001881597   0.174804132   7.956772329   24.56166286
 SS   0.617748851   0.646173858   3.705020122   13.89417493   101.9291305
 ST   14.93023052   0.516217943   1.165572158   121.3517656   299.6578369
 SU   11.84749517   2.861320006   3.583728353   30.83399635   146.1877583
 CAP  587.7427277   92.56184229   788.3262313   1820.308498   3755.114864
 LAB  173.5264956   136.4903006   340.7491306   4462.485      6198.156256

          SF            SG            SH            SI            SJ
 SA   1.139401403   0.323653465   0.045483647   0.002074573   0.038898515
 SB   0.25736368    0.15726282    2.072007743   0.124265559   0.107313854
 SC   42.994053     84.45053697   11.43830848   3.837053742   28.15981198
 SD   25.3244501    44.92440469   4.253896378   5.20763497    28.37992781
 SE   280.4544203   225.7994723   158.6123913   140.7895914   420.5064001
 SF   305.459485    57.76932562   69.61834748   111.0169361   106.960785
 SG   28.87125475   44.46507186   3.052471872   22.66862201   6.829720212
 SH   128.8354563   134.4634699   200.5924105   163.8397799   61.5264924
 SI   10.52353414   16.01813452   9.642222629   339.9129594   12.75108533
 SJ   174.0337528   168.1289817   42.96137661   49.82979702   1812.283122
 SK   228.6140281   260.2249542   73.59840989   56.78673113   318.9730324
 SL   205.2688528   403.4925843   112.5204861   71.04115549   243.2185454
 SM   394.7715277   466.1785335   122.4820687   73.14004668   727.8826328
```

SN	258.9471585	568.576527	17.17131759	50.67263276	55.64368145
SO	314.0765306	249.6064067	140.2724165	21.28998305	207.1476788
SP	6.352048651	4.140811947	2.794171683	0.429076847	18.13924719
SQ	0	0.016707681	0.032538054	1.316809227	0
SR	11.50341008	9.122401657	0.922966015	0.982098191	95.27315217
SS	40.53060945	48.90911712	32.40227753	3.877228303	49.63589229
ST	89.96280224	74.70461584	18.89240396	66.49183971	154.9738332
SU	68.30691927	84.25193352	24.69931123	11.76107923	71.30659382
CAP	2116.091404	1523.163175	535.4377489	429.7291548	2210.665987
LAB	4162.139	4172.773	1410.057487	829.398	2067.341

	SK	SL	SM	SN	SO
SA	0.01005566	5.679622862	0.508418645	0.003373156	22.70572311
SB	0.026707501	5.494489482	1.725041335	0.088843347	0.195391668
SC	13.37141002	203.3986113	39.25655571	87.30520325	23.69371561
SD	34.14593289	209.8118807	42.49953	99.04852586	11.29313392
SE	56.32435562	214.7427703	332.5578152	213.1249663	181.3863062
SF	10.8171382	38.8696242	60.25791865	27.4054323	61.02625996
SG	2.287220828	70.57059957	23.35257343	0.211204473	51.33566071
SH	78.86664296	64.52615936	124.5585092	2.693428798	48.05606778
SI	3.519580085	12.86992332	10.68813888	5.771627015	15.35856626
SJ	121.1598367	132.4726734	432.4337091	423.2921117	119.5935572
SK	2724.583803	814.9660732	190.7403206	80.87608713	79.8059454
SL	236.2746396	541.7974587	457.2921375	410.9040605	112.3563983
SM	418.8179828	440.6666043	1003.227296	1033.504123	223.9080639
SN	89.24069323	31.42280374	59.47826162	0	82.89407022
SO	124.9455846	563.8376222	643.2601439	13.58816276	258.8603039
SP	2.485836382	3.4158281	12.11265749	0.037325986	1.995659842
SQ	0.002408446	0	2.347831288	0	0.285183173
SR	12.36508457	11.54866885	61.71099249	2.275983862	11.67998264
SS	70.05988044	49.666092	144.9771215	0.275312827	44.88667201
ST	40.42391056	156.1931392	101.1868927	153.2336109	85.27678332
SU	66.32401219	99.80837827	133.5994569	50.28772977	50.22252084
CAP	3100.61276	9033.637987	2165.703782	1425.841838	770.4328006
LAB	3906.495098	817.848	5203.431	4068.287	2221.233

	SP	SQ	SR	SS	ST
SA	0.059020247	2.250104963	1.413278956	46.37468541	1.521603018
SB	0.081856566	1.170543568	0.032954568	0.550607455	0.478795022
SC	11.40035501	67.60362687	25.13516505	82.19430791	40.53904782
SD	53.83116431	58.7399277	23.59557545	46.49467477	33.12952311
SE	106.0301884	996.7868897	60.51970225	875.6448094	622.4107043
SF	27.1079792	167.0345756	12.15268694	175.8111514	121.2304773
SG	2.713351088	25.32972365	4.102703978	26.52606433	65.60307728
SH	16.27437811	100.5909357	12.17749947	33.36025394	32.60850575
SI	6.323946822	27.29651075	3.402838786	37.04102677	23.15480102
SJ	79.92574729	282.4710445	49.49417367	111.3926865	120.8023936
SK	37.27314259	212.9786334	58.27811315	143.8415743	55.03518097
SL	273.1054043	657.6888433	116.6877547	256.9086973	261.7756744
SM	93.52841574	457.7743193	108.9059661	166.4311038	177.7659055
SN	12.63955154	145.7152801	34.91748598	20.39505888	58.01780487
SO	114.7015024	518.9176993	67.18339583	83.2108654	161.7705355
SP	21.58304731	11.6521035	3.260257109	0.761537395	4.042227733
SQ	0.392657018	80.92335514	0.505889987	0.005942048	0.285334385
SR	8.084925123	14.0267762	177.3822203	29.22210276	20.17168114
SS	8.445631113	187.8391349	7.797666794	44.36840812	22.37942364
ST	27.71760689	94.29912965	33.30811352	54.15700991	66.36619466
SU	32.78782446	180.9037693	23.72087044	49.97864836	55.49158927
CAP	111.5968763	1375.712556	431.8717592	640.5924911	518.7952045
LAB	1772.768	6398.248	967.011	1788.83	2057.208

	SU
SA	8.074230613
SB	29.30504533
SC	212.8348392
SD	356.9112459
SE	1060.231871
SF	211.7128365
SG	0.185314636
SH	150.9684632
SI	108.2948246
SJ	445.437267
SK	183.3946765
SL	238.5785916
SM	1190.243568
SN	1.94880749
SO	448.2473997
SP	104.4310583
SQ	107.2378114
SR	28.91063251
SS	110.9401962
ST	249.5182156
SU	208.5742498
CAP	1084.295211
LAB	9580.112

TABLE Endowm(*,*) The endowment from Household

	HH_D
CAP	34518.2349
LAB	62734.58677

TABLE DemandFunc(*,*) The goods composition in demand function

	HH_D	HH_F

```
 SA         508.4140747        80.87320886
 SB         113.9224838        18.12160064
 SC         1291.906324        205.502985
 SD         10218.83465        1625.505646
 SE         11327.10057        1801.797031
 SF         5966.809843        949.1378833
 SG         8033.94626         1277.956387
 SH         1587.796204        252.5700613
 SI         1162.701763        184.9504708
 SJ         4373.106938        695.6282454
 SK         5437.563862        864.9509519
 SL         9739.695036        1549.289113
 SM         2635.724325        419.2635382
 SN         5151.750744        819.4867818
 SO         414.151198         65.87885349
 SP         2437.119178        387.6715025
 SQ         10926.96845        1738.148186
 SR         1713.71695         272.6002203
 SS         3819.433734        607.5556863
 ST         2966.56425         471.8901033
 SU         14367.20054        2285.384429

TABLE LossTable(*,*) The additional loss due to earthquake

                SI                 HH_D
 SB         0.008960554
 SC         0.286737737
 SD         0.389037398
 SE         10.5129703
 SF         8.290006131
 SG         1.692798045
 SH         12.23414344
 SI         25.3815167
 SJ         3.720870163
 SK         4.240582311
 SL         5.304648131
 SM         5.461457831
 SN         3.783594043
 SO         1.589751671
 SP         0.032108653
 SQ         0.098566097
 SR         0.07317786
 SS         0.289724588
 ST         4.964893782
 SU         0.878134319
 CAP        32.08849157      -66.20734253
 LAB        61.9323643       549.584295
 HH_F       17.73667048

PARAMETERS

 A(S)            Benchmark Output
 AA(Wel)         Benchmark Welfare
 B(G,S)          Use Matrix (Goods input by sector)
 BB(G,Wel)       Use Matrix for Welfare
 C(Wel,H)        Household Demand
 FD(F,S)         Factor Demand by Sector
 FDH(F,Wel)      Factor Demand by Household
 E(F)            Domestic Household Factor Endowment
 FX(S)           Non-Comparable Import
 DEF             Foreign Household Endowment in Deficit
 Tax(S)          Tax Paid by Sector
 Toutput(S)      Output tax by Sector
 ELAS(S)         Elasticity of Sector S
 ELAS_W(Wel)     Elasticity of Welfare or Utility Function
 PTaxOut(S)      Price of output with output tax of Sector S
 LossFlag        Flag parameter for loss
 BL(G,S)         Additional Intermediate Required due to Loss
 FL(F,S)         Additional Factors Required due to Loss
 FXL(S)          Additional Import Required due to Loss
 EL(F)           Lower Endowment due to Loss
 Wel_D_to(k)     Domestic Welfare loss for iteration k
 Wel_F_to(k)     Domestic Welfare loss for iteration k
 Elastt(k,S)     random production elasticity
 Elastw(k,Wel)   random demand elasticity
 Outloss(k)      Output loss for iteration k
 Welloss(k)      Welfare loss for iteration k
 Outto(k,S)      Dummy parameter to keep changed output value
 ABC(k,S)        Dummy parameter to keep benchmark output value
 PABC(k,S)       Dummy parameter to keep changed output price value
 PWel(k,Wel)     Dummy parameter to keep welfare price value
 CCD(k)          Dummy parameter to keep domestic welfare value
 CCF(k)          Dummy parameter to keep foreign welfare value
 Taxloss(k)      Tax loss for iteration k
 TotalLoss(k)    Total loss for iteration k
 IncomeLoss(k)   Income loss for iteration k
 ReportL(k,LossRep) The output vehicle to write to excel;

* Extract Data from the table

A(S) = PremlMake(S,"Output");
B(G,S) = UseTable(G,S);
AA(Wel) = PremlMake(Wel,"Output");
C("W_D","HH_D") = PremlMake("W_D","Output");
C("W_F","HH_F") = PremlMake("W_F","Output");
FD(F,S) = UseTable(F,S);
```

```
FDH("LAB","W_D") = 34861.61;
DEF = PremlMake("W_F","Output");
FX(S) = PremlMake(S,"HH_F");
Tax(S) = PremlMake(S,"TAXX");
E(F) = Endowm(F,"HH_D");
BB(G,"W_D") = DemandFunc(G,"HH_D");
BB(G,"W_F") = DemandFunc(G,"HH_F");

Toutput(S) = (Tax(S)/A(S));
PTaxOut(S) = (1/(1-Toutput(S)));
ELAS(S) = 0.7;
ELAS_W("W_F") = 1;
ELAS_W("W_D") = 0.85;
LossFlag = 0;
BL(G,S) = LossTable(G,S);
FL(F,S) = LossTable(F,S);
FXL(S) = LossTable("HH_F",S);
EL(F) = (-LossTable(F,"HH_D"));

$ONTEXT

$MODEL:Prem

$SECTORS:
        AL(S)   WE(Wel)   T

$COMMODITIES:
        P(G)    P_W(Wel)   W(F)    PFX    PLS

$CONSUMERS:
        HH_Dom    ! Income level for Domestic Households
        HH_For    ! Income level for Foreign Households

$AUXILIARY:
        Left      ! Left over of the non-comparable import

$PROD:AL(S)  s:ELAS(S)  ma:0 va:1
        O:P(S)        Q:A(S)      P:PTaxOut(S) A:HH_Dom   T:Toutput(S)
        I:P(G)        Q:B(G,S)    ma:
        I:P(G)        Q:(LossFlag*BL(G,S))   ma:
        I:PFX         Q:FX(S)     ma:
        I:PFX         Q:(LossFlag*FXL(S))    ma:
        I:PLS         Q:FD("LAB",S)   va:
        I:PLS         Q:(LossFlag*FL("LAB",S))   va:
        I:W("CAP")    Q:FD("CAP",S)   va:
        I:W("CAP")    Q:(LossFlag*FL("CAP",S))   va:

$PROD:WE(Wel) s:ELAS_W(Wel) cons:1
        O:P_W(Wel)    Q:(AA(Wel)+FDH("LAB",Wel)+FDH("CAP",Wel))
        I:P(G)        Q:BB(G,Wel)  cons:
        I:W(F)        Q:FDH(F,Wel)

$PROD:T
        O:PLS         Q:E("LAB")
        I:W("LAB")    Q:E("LAB")

$DEMAND:HH_Dom
        D:P_W("W_D")  Q:(C("W_D","HH_D")+FDH("LAB","W_D")+FDH("CAP","W_D"))
        E:W(F)        Q:E(F)
        E:W(F)        Q:FDH(F,"W_D")
        E:W(F)        Q:(LossFlag*EL(F))

$DEMAND:HH_For
        D:P_W("W_F")  Q:C("W_F","HH_F")
        E:PFX         Q:DEF
        E:PFX         Q:(-LossFlag*DEF)   R:Left

$CONSTRAINT:Left
        PFX =G= 1;

$REPORT:
        V:W_HH_Dom  W:HH_Dom
        V:W_HH_For  W:HH_For

$OFFTEXT
$SYSINCLUDE mpsgeset Prem

*Benchmark Equilibrium Replicate Check

Prem.ITERLIM = 0;
P_W.FX("W_D")=1;

$INCLUDE Prem.GEN
SOLVE Prem USING MCP;

Prem.ITERLIM = 2000;

$INCLUDE Prem.GEN
SOLVE Prem USING MCP;

*Introduction of Loss

Prem.ITERLIM = 0;
LossFlag = 1;

$INCLUDE Prem.GEN
SOLVE Prem USING MCP;
```

```
Prem.ITERLIM = 2000;

execseed = 1+gmillisec(jnow);
loop(k,Elas(S) = uniform(0.35,1.05);
ELAS_W("W_D") = uniform(0.5,1.20);
$INCLUDE Prem.GEN
SOLVE Prem USING MCP;
Outto(k,S)=AL.L(S);
PABC(k,S)=P.L(S);
PWel(k,Wel)=P_W.L(Wel);
Elastt(k,S)=Elas(S);
Elastw(k,"W_D")=ELAS_W("W_D");
ABC(k,S)=A(S);
CCD(k)=C("W_D","HH_D")+FDH("LAB","W_D");
CCF(k)=C("W_F","HH_F");
Wel_D_to(k)=WE.L("W_D");
Wel_F_to(k)=WE.L("W_F");
Outloss(k)=sum(S,ABC(k,S)*(1-(Outto(k,S)*PABC(k,S))));
Welloss(k)=(CCD(k)*(1-(Wel_D_to(k)*PWel(k,"W_D"))))
            +(CCF(k)*(1-(Wel_F_to(k)*PWel(k,"W_F"))));
Taxloss(k)=sum(S,(ABC(k,S)*Toutput(S)*(1-(AL.L(S)*P.L(S)))));
IncomeLoss(k)=(E("CAP")-(W.L("CAP")*E("CAP")*1.00191803963012))+(E("LAB")
               -(W.L("LAB")*E("LAB")*T.L))+Taxloss(k);
TotalLoss(k)=Outloss(k)+Welloss(k);
ReportL(k,"TotalL")=TotalLoss(k);
ReportL(k,"OutL")=Outloss(k);
ReportL(k,"WelL")=Welloss(k);
ReportL(k,"IncomeL")=IncomeLoss(k);
ReportL(k,"TotalL2")=Incomeloss(k)+Outloss(k)
                    +(CCF(k)*(1-(Wel_F_to(k)*PWel(k,"W_F"))));)

Display ReportL;

$LIBINCLUDE XLDUMP ReportL result10.xls Sheet1
$LIBINCLUDE XLDUMP Outto result10.xls Sheet2
$LIBINCLUDE XLDUMP PABC result10.xls Sheet3
$LIBINCLUDE XLDUMP Elastt result10.xls Sheet4
$LIBINCLUDE XLDUMP Elastw result10.xls Sheet5
```

APPENDIX O.

EXPANDED INDIRECT LOSS NUMBERS FOR SENSITIVITY ANALYSIS

Production Elasticity $\sigma_{p,i}$	Demand Elasticity $\sigma_{u,d}$	Total Indirect Loss (Million $)	Total Indirect Loss (Percentage)
0.0	0.50	$ 1,524.84	0.446%
0.3	0.50	$ 1,593.75	0.466%
0.4	0.50	$ 1,616.72	0.473%
0.5	0.50	$ 1,639.69	0.480%
0.6	0.50	$ 1,662.65	0.486%
0.7	0.50	$ 1,685.62	0.493%
0.8	0.50	$ 1,708.58	0.500%
0.9	0.50	$ 1,731.55	0.507%
1.0	0.50	$ 1,754.51	0.513%
0.0	0.85	$ 1,503.40	0.440%
0.3	0.85	$ 1,573.39	0.460%
0.4	0.85	$ 1,596.70	0.467%
0.5	0.85	$ 1,620.01	0.474%
0.6	0.85	$ 1,643.31	0.481%
0.7	0.85	$ 1,666.61	0.488%
0.8	0.85	$ 1,689.90	0.494%
0.9	0.85	$ 1,713.18	0.501%
1.0	0.85	$ 1,736.45	0.508%
0.0	1.20	$ 1,483.98	0.434%
0.3	1.20	$ 1,554.90	0.455%
0.4	1.20	$ 1,578.52	0.462%
0.5	1.20	$ 1,602.12	0.469%
0.6	1.20	$ 1,625.72	0.476%
0.7	1.20	$ 1,649.30	0.483%
0.8	1.20	$ 1,672.87	0.489%
0.9	1.20	$ 1,696.43	0.496%
1.0	1.20	$ 1,719.98	0.503%

APPENDIX P.

DETAILED NUMBERS OF ESTIMATED INDIRECT LOSS FOR SENSITIVITY ANALYSIS

	Production Elasticity = 0					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.257%	-0.614%	-0.252%	-0.602%	-0.247%	-0.591%
21	0.032%	-0.417%	0.033%	-0.407%	0.035%	-0.397%
22	-0.208%	-0.521%	-0.205%	-0.510%	-0.202%	-0.500%
23	-0.016%	-0.481%	-0.015%	-0.471%	-0.015%	-0.462%
31-33	0.047%	-0.415%	0.048%	-0.405%	0.049%	-0.395%
42	-0.170%	-0.490%	-0.169%	-0.480%	-0.168%	-0.470%
44	-0.138%	-0.492%	-0.137%	-0.482%	-0.136%	-0.473%
48-49	-0.106%	-0.311%	-0.106%	-0.302%	-0.105%	-0.293%
484	8.461%	4.291%	8.462%	4.302%	8.463%	4.311%
51	-0.235%	-0.515%	-0.232%	-0.505%	-0.229%	-0.495%
52	-0.245%	-0.492%	-0.243%	-0.482%	-0.240%	-0.473%
53	-0.513%	-0.590%	-0.505%	-0.578%	-0.499%	-0.567%
54	-0.155%	-0.491%	-0.154%	-0.481%	-0.153%	-0.472%
55	-0.148%	-0.483%	-0.147%	-0.473%	-0.147%	-0.464%
56	-0.106%	-0.430%	-0.106%	-0.421%	-0.105%	-0.412%
61	-0.031%	-0.491%	-0.032%	-0.481%	-0.033%	-0.472%
62	-0.075%	-0.494%	-0.075%	-0.484%	-0.075%	-0.475%
71	-0.173%	-0.496%	-0.172%	-0.486%	-0.171%	-0.477%
72	-0.060%	-0.478%	-0.059%	-0.468%	-0.058%	-0.459%
81	-0.056%	-0.422%	-0.056%	-0.412%	-0.055%	-0.403%
92	0.014%	-0.480%	0.013%	-0.470%	0.013%	-0.461%
Capital	-0.775%	-0.584%	-0.763%	-0.573%	-0.753%	-0.563%
Labor	0.082%	-0.490%	0.078%	-0.480%	0.074%	-0.472%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.508%	-0.319%	-0.507%	-0.310%	-0.507%	-0.302%

	Production Elasticity = 0.3					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.252%	-0.678%	-0.247%	-0.666%	-0.243%	-0.655%
21	0.033%	-0.486%	0.035%	-0.476%	0.036%	-0.467%
22	-0.205%	-0.555%	-0.202%	-0.544%	-0.199%	-0.535%
23	-0.015%	-0.496%	-0.015%	-0.486%	-0.014%	-0.477%
31-33	0.048%	-0.458%	0.049%	-0.448%	0.051%	-0.439%
42	-0.169%	-0.524%	-0.168%	-0.514%	-0.167%	-0.506%
44	-0.137%	-0.509%	-0.136%	-0.499%	-0.136%	-0.490%
48-49	-0.105%	-0.361%	-0.105%	-0.352%	-0.104%	-0.343%
484	8.460%	4.203%	8.461%	4.213%	8.463%	4.222%
51	-0.232%	-0.547%	-0.229%	-0.537%	-0.227%	-0.527%
52	-0.243%	-0.532%	-0.240%	-0.522%	-0.238%	-0.513%
53	-0.505%	-0.612%	-0.498%	-0.601%	-0.492%	-0.591%
54	-0.154%	-0.533%	-0.153%	-0.524%	-0.153%	-0.515%
55	-0.147%	-0.510%	-0.147%	-0.500%	-0.146%	-0.492%
56	-0.106%	-0.483%	-0.105%	-0.474%	-0.105%	-0.466%
61	-0.032%	-0.503%	-0.033%	-0.493%	-0.034%	-0.485%
62	-0.075%	-0.504%	-0.075%	-0.495%	-0.075%	-0.486%
71	-0.172%	-0.514%	-0.171%	-0.504%	-0.170%	-0.496%
72	-0.059%	-0.496%	-0.058%	-0.486%	-0.057%	-0.477%
81	-0.056%	-0.453%	-0.055%	-0.444%	-0.055%	-0.435%
92	0.013%	-0.494%	0.013%	-0.485%	0.012%	-0.476%
Capital	-0.763%	-0.573%	-0.753%	-0.562%	-0.743%	-0.553%
Labor	0.078%	-0.494%	0.074%	-0.485%	0.071%	-0.477%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.509%	-0.391%	-0.509%	-0.383%	-0.508%	-0.375%

	Production Elasticity = 0.4					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	Price Changes	Output Change	Price Changes	Output Change	Price Changes	Output Change
11	-0.251%	-0.699%	-0.246%	-0.687%	-0.242%	-0.677%
21	0.033%	-0.509%	0.035%	-0.499%	0.036%	-0.491%
22	-0.204%	-0.566%	-0.201%	-0.556%	-0.198%	-0.546%
23	-0.015%	-0.500%	-0.014%	-0.491%	-0.014%	-0.482%
31-33	0.048%	-0.472%	0.050%	-0.462%	0.051%	-0.453%
42	-0.169%	-0.535%	-0.167%	-0.526%	-0.166%	-0.517%
44	-0.137%	-0.514%	-0.136%	-0.505%	-0.135%	-0.496%
48-49	-0.105%	-0.378%	-0.105%	-0.369%	-0.104%	-0.360%
484	8.460%	4.174%	8.461%	4.184%	8.462%	4.193%
51	-0.231%	-0.557%	-0.228%	-0.547%	-0.226%	-0.538%
52	-0.242%	-0.545%	-0.240%	-0.535%	-0.238%	-0.527%
53	-0.503%	-0.620%	-0.496%	-0.609%	-0.490%	-0.598%
54	-0.154%	-0.548%	-0.153%	-0.538%	-0.152%	-0.530%
55	-0.147%	-0.518%	-0.146%	-0.509%	-0.146%	-0.501%
56	-0.106%	-0.500%	-0.105%	-0.491%	-0.105%	-0.484%
61	-0.032%	-0.507%	-0.033%	-0.498%	-0.034%	-0.489%
62	-0.075%	-0.508%	-0.075%	-0.499%	-0.075%	-0.490%
71	-0.171%	-0.520%	-0.170%	-0.510%	-0.169%	-0.502%
72	-0.058%	-0.502%	-0.057%	-0.492%	-0.057%	-0.484%
81	-0.055%	-0.464%	-0.055%	-0.454%	-0.055%	-0.446%
92	0.013%	-0.499%	0.012%	-0.489%	0.011%	-0.481%
Capital	-0.759%	-0.569%	-0.749%	-0.559%	-0.740%	-0.549%
Labor	0.076%	-0.496%	0.073%	-0.487%	0.070%	-0.478%
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
Welfare Change	-0.509%	-0.415%	-0.509%	-0.407%	-0.509%	-0.400%

	Production Elasticity = 0.5					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	Price Changes	Output Change	Price Changes	Output Change	Price Changes	Output Change
11	-0.249%	-0.720%	-0.245%	-0.708%	-0.240%	-0.698%
21	0.034%	-0.532%	0.035%	-0.523%	0.037%	-0.514%
22	-0.203%	-0.577%	-0.200%	-0.567%	-0.197%	-0.558%
23	-0.015%	-0.505%	-0.014%	-0.496%	-0.014%	-0.488%
31-33	0.049%	-0.486%	0.050%	-0.476%	0.051%	-0.468%
42	-0.168%	-0.547%	-0.167%	-0.537%	-0.166%	-0.529%
44	-0.136%	-0.520%	-0.136%	-0.511%	-0.135%	-0.502%
48-49	-0.105%	-0.395%	-0.104%	-0.386%	-0.104%	-0.377%
484	8.460%	4.144%	8.461%	4.154%	8.462%	4.163%
51	-0.230%	-0.568%	-0.228%	-0.558%	-0.225%	-0.549%
52	-0.241%	-0.558%	-0.239%	-0.549%	-0.237%	-0.540%
53	-0.501%	-0.627%	-0.494%	-0.616%	-0.488%	-0.606%
54	-0.154%	-0.562%	-0.153%	-0.553%	-0.152%	-0.544%
55	-0.147%	-0.527%	-0.146%	-0.518%	-0.146%	-0.510%
56	-0.105%	-0.518%	-0.105%	-0.509%	-0.105%	-0.501%
61	-0.033%	-0.511%	-0.034%	-0.502%	-0.034%	-0.493%
62	-0.075%	-0.512%	-0.075%	-0.502%	-0.075%	-0.494%
71	-0.171%	-0.525%	-0.170%	-0.516%	-0.169%	-0.508%
72	-0.058%	-0.507%	-0.057%	-0.498%	-0.056%	-0.490%
81	-0.055%	-0.474%	-0.055%	-0.465%	-0.055%	-0.457%
92	0.013%	-0.503%	0.012%	-0.494%	0.011%	-0.486%
Capital	-0.756%	-0.565%	-0.746%	-0.555%	-0.737%	-0.546%
Labor	0.075%	-0.497%	0.072%	-0.488%	0.068%	-0.480%
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
Welfare Change	-0.510%	-0.440%	-0.509%	-0.431%	-0.509%	-0.424%

	Production Elasticity = 0.6					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.247%	-0.741%	-0.243%	-0.730%	-0.239%	-0.720%
21	0.034%	-0.555%	0.036%	-0.546%	0.037%	-0.537%
22	-0.202%	-0.588%	-0.199%	-0.579%	-0.196%	-0.570%
23	-0.015%	-0.510%	-0.014%	-0.501%	-0.013%	-0.493%
31-33	0.049%	-0.500%	0.050%	-0.491%	0.052%	-0.482%
42	-0.168%	-0.558%	-0.167%	-0.549%	-0.166%	-0.541%
44	-0.136%	-0.525%	-0.136%	-0.516%	-0.135%	-0.508%
48-49	-0.105%	-0.411%	-0.104%	-0.402%	-0.104%	-0.394%
484	8.459%	4.115%	8.461%	4.125%	8.462%	4.133%
51	-0.229%	-0.578%	-0.227%	-0.568%	-0.225%	-0.560%
52	-0.240%	-0.571%	-0.238%	-0.562%	-0.236%	-0.553%
53	-0.498%	-0.635%	-0.492%	-0.624%	-0.486%	-0.614%
54	-0.153%	-0.576%	-0.153%	-0.567%	-0.152%	-0.559%
55	-0.147%	-0.536%	-0.146%	-0.527%	-0.145%	-0.519%
56	-0.105%	-0.535%	-0.105%	-0.527%	-0.105%	-0.519%
61	-0.033%	-0.515%	-0.034%	-0.506%	-0.035%	-0.498%
62	-0.075%	-0.515%	-0.075%	-0.506%	-0.075%	-0.498%
71	-0.171%	-0.531%	-0.169%	-0.522%	-0.168%	-0.514%
72	-0.058%	-0.513%	-0.057%	-0.504%	-0.056%	-0.496%
81	-0.055%	-0.484%	-0.055%	-0.476%	-0.055%	-0.468%
92	0.013%	-0.508%	0.012%	-0.499%	0.011%	-0.491%
Capital	-0.752%	-0.562%	-0.742%	-0.552%	-0.733%	-0.543%
Labor	0.074%	-0.498%	0.071%	-0.490%	0.067%	-0.481%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.510%	-0.464%	-0.510%	-0.456%	-0.509%	-0.448%

	Production Elasticity = 0.7					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.246%	-0.762%	-0.242%	-0.751%	-0.238%	-0.741%
21	0.035%	-0.578%	0.036%	-0.569%	0.037%	-0.560%
22	-0.201%	-0.600%	-0.198%	-0.590%	-0.196%	-0.581%
23	-0.014%	-0.515%	-0.014%	-0.506%	-0.013%	-0.498%
31-33	0.050%	-0.514%	0.051%	-0.505%	0.052%	-0.497%
42	-0.167%	-0.570%	-0.166%	-0.561%	-0.165%	-0.552%
44	-0.136%	-0.531%	-0.135%	-0.522%	-0.135%	-0.514%
48-49	-0.105%	-0.428%	-0.104%	-0.419%	-0.104%	-0.411%
484	8.459%	4.086%	8.460%	4.095%	8.461%	4.104%
51	-0.228%	-0.589%	-0.226%	-0.579%	-0.224%	-0.570%
52	-0.240%	-0.584%	-0.238%	-0.575%	-0.236%	-0.566%
53	-0.496%	-0.642%	-0.490%	-0.631%	-0.484%	-0.622%
54	-0.153%	-0.590%	-0.152%	-0.581%	-0.152%	-0.573%
55	-0.146%	-0.545%	-0.146%	-0.536%	-0.145%	-0.528%
56	-0.105%	-0.553%	-0.105%	-0.544%	-0.104%	-0.537%
61	-0.033%	-0.519%	-0.034%	-0.510%	-0.035%	-0.502%
62	-0.075%	-0.519%	-0.075%	-0.510%	-0.075%	-0.501%
71	-0.170%	-0.537%	-0.169%	-0.528%	-0.168%	-0.520%
72	-0.057%	-0.519%	-0.057%	-0.510%	-0.056%	-0.502%
81	-0.055%	-0.495%	-0.055%	-0.486%	-0.055%	-0.478%
92	0.012%	-0.513%	0.011%	-0.504%	0.011%	-0.496%
Capital	-0.749%	-0.558%	-0.739%	-0.549%	-0.730%	-0.540%
Labor	0.073%	-0.500%	0.069%	-0.491%	0.066%	-0.483%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.511%	-0.488%	-0.510%	-0.480%	-0.510%	-0.473%

	Production Elasticity = 0.8					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.245%	-0.783%	-0.240%	-0.772%	-0.237%	-0.762%
21	0.035%	-0.601%	0.037%	-0.592%	0.038%	-0.583%
22	-0.200%	-0.611%	-0.197%	-0.601%	-0.195%	-0.593%
23	-0.014%	-0.520%	-0.014%	-0.511%	-0.013%	-0.503%
31-33	0.050%	-0.528%	0.051%	-0.519%	0.052%	-0.511%
42	-0.167%	-0.581%	-0.166%	-0.572%	-0.165%	-0.564%
44	-0.136%	-0.537%	-0.135%	-0.528%	-0.135%	-0.520%
48-49	-0.104%	-0.445%	-0.104%	-0.436%	-0.103%	-0.428%
484	8.459%	4.057%	8.460%	4.066%	8.461%	4.074%
51	-0.228%	-0.599%	-0.225%	-0.590%	-0.223%	-0.581%
52	-0.239%	-0.597%	-0.237%	-0.588%	-0.235%	-0.580%
53	-0.494%	-0.649%	-0.488%	-0.639%	-0.482%	-0.630%
54	-0.153%	-0.604%	-0.152%	-0.596%	-0.151%	-0.588%
55	-0.146%	-0.554%	-0.146%	-0.545%	-0.145%	-0.537%
56	-0.105%	-0.570%	-0.105%	-0.562%	-0.104%	-0.555%
61	-0.034%	-0.523%	-0.035%	-0.515%	-0.035%	-0.507%
62	-0.075%	-0.522%	-0.075%	-0.513%	-0.075%	-0.505%
71	-0.170%	-0.543%	-0.169%	-0.534%	-0.168%	-0.526%
72	-0.057%	-0.525%	-0.056%	-0.516%	-0.056%	-0.508%
81	-0.055%	-0.505%	-0.055%	-0.497%	-0.054%	-0.489%
92	0.012%	-0.517%	0.011%	-0.508%	0.010%	-0.501%
Capital	-0.745%	-0.555%	-0.736%	-0.545%	-0.727%	-0.537%
Labor	0.072%	-0.501%	0.068%	-0.492%	0.065%	-0.484%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.511%	-0.512%	-0.511%	-0.504%	-0.510%	-0.497%

	Production Elasticity = 0.9					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.243%	-0.804%	-0.239%	-0.793%	-0.235%	-0.784%
21	0.036%	-0.624%	0.037%	-0.615%	0.038%	-0.606%
22	-0.199%	-0.622%	-0.196%	-0.613%	-0.194%	-0.604%
23	-0.014%	-0.524%	-0.013%	-0.516%	-0.013%	-0.508%
31-33	0.050%	-0.543%	0.052%	-0.534%	0.053%	-0.526%
42	-0.167%	-0.592%	-0.166%	-0.584%	-0.165%	-0.576%
44	-0.136%	-0.542%	-0.135%	-0.534%	-0.134%	-0.526%
48-49	-0.104%	-0.461%	-0.104%	-0.453%	-0.103%	-0.445%
484	8.459%	4.027%	8.460%	4.036%	8.461%	4.045%
51	-0.227%	-0.610%	-0.224%	-0.600%	-0.222%	-0.592%
52	-0.238%	-0.610%	-0.236%	-0.601%	-0.234%	-0.593%
53	-0.492%	-0.657%	-0.486%	-0.647%	-0.480%	-0.637%
54	-0.152%	-0.619%	-0.152%	-0.610%	-0.151%	-0.603%
55	-0.146%	-0.563%	-0.145%	-0.554%	-0.145%	-0.546%
56	-0.105%	-0.588%	-0.104%	-0.580%	-0.104%	-0.573%
61	-0.034%	-0.527%	-0.035%	-0.519%	-0.036%	-0.511%
62	-0.075%	-0.526%	-0.075%	-0.517%	-0.075%	-0.509%
71	-0.169%	-0.549%	-0.168%	-0.540%	-0.167%	-0.533%
72	-0.057%	-0.531%	-0.056%	-0.522%	-0.055%	-0.515%
81	-0.055%	-0.516%	-0.055%	-0.507%	-0.054%	-0.500%
92	0.012%	-0.522%	0.011%	-0.513%	0.010%	-0.505%
Capital	-0.742%	-0.551%	-0.733%	-0.542%	-0.724%	-0.534%
Labor	0.070%	-0.502%	0.067%	-0.494%	0.064%	-0.486%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.512%	-0.536%	-0.511%	-0.528%	-0.511%	-0.521%

	Production Elasticity = 1.0					
	Demand Elasticity = 0.5		Demand Elasticity = 0.85		Demand Elasticity = 1.2	
Sector	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**	**Price Changes**	**Output Change**
11	-0.242%	-0.825%	-0.238%	-0.815%	-0.234%	-0.805%
21	0.036%	-0.647%	0.037%	-0.638%	0.039%	-0.630%
22	-0.198%	-0.633%	-0.196%	-0.624%	-0.193%	-0.616%
23	-0.014%	-0.529%	-0.013%	-0.521%	-0.012%	-0.513%
31-33	0.051%	-0.557%	0.052%	-0.548%	0.053%	-0.540%
42	-0.166%	-0.604%	-0.165%	-0.595%	-0.164%	-0.588%
44	-0.135%	-0.548%	-0.135%	-0.539%	-0.134%	-0.532%
48-49	-0.104%	-0.478%	-0.103%	-0.470%	-0.103%	-0.462%
484	8.458%	3.998%	8.459%	4.007%	8.460%	4.015%
51	-0.226%	-0.620%	-0.224%	-0.611%	-0.222%	-0.603%
52	-0.237%	-0.623%	-0.235%	-0.614%	-0.234%	-0.606%
53	-0.490%	-0.664%	-0.484%	-0.654%	-0.479%	-0.645%
54	-0.152%	-0.633%	-0.151%	-0.625%	-0.151%	-0.617%
55	-0.146%	-0.571%	-0.145%	-0.563%	-0.145%	-0.555%
56	-0.105%	-0.605%	-0.104%	-0.597%	-0.104%	-0.590%
61	-0.034%	-0.531%	-0.035%	-0.523%	-0.036%	-0.515%
62	-0.075%	-0.529%	-0.075%	-0.521%	-0.075%	-0.513%
71	-0.169%	-0.555%	-0.168%	-0.546%	-0.167%	-0.539%
72	-0.057%	-0.537%	-0.056%	-0.528%	-0.055%	-0.521%
81	-0.055%	-0.526%	-0.055%	-0.518%	-0.054%	-0.510%
92	0.011%	-0.526%	0.011%	-0.518%	0.010%	-0.510%
Capital	-0.738%	-0.548%	-0.729%	-0.539%	-0.721%	-0.531%
Labor	0.069%	-0.504%	0.066%	-0.495%	0.063%	-0.487%
	Domestic	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Welfare Change	-0.512%	-0.560%	-0.512%	-0.552%	-0.511%	-0.545%

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