An Integrated Engineering-Economic Vulnerability Assessment Tool

--An Assessment of Tsunami Impact on Coastal Communities

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I.   Introduction

The threat of the natural disasters is drawing more attentions due to their increased frequency, scale and impacts to the communities. The understanding of the impacts are particularly important to community resilience planning, especially in the cost-benefit analysis of the mitigation projects and estimating the level of post-disaster assistance. The disaster impacts are usually divided in two categories according to Okuyama (2008): damages and losses. Damages are defined as impacts on stocks which including physical structures and human capitals. Losses are defined as impacts on flows, which are further categorized into first order losses and high order losses. First order loss represents interruptions of economic activities in the disaster-affected zone, such as productions or consumptions, following the damages on stocks. Higher order losses indicate system-wide economic activity interruptions due to the flow losses through industry transactions. This paper will focus on impact assessment on flow losses after a Tsunami event. The model integrates economic impact assessment model with the engineer's tsunami damage estimations and provides a more comprehensive and accurate estimation of flow losses after a Tsunami event.

There has been multiple studies estimating the flow impacts of disastrous events. However, due to the limited information supporting flow loss estimations, current impact assessments are usually limited to selected infrastructures (Rose at al. 1997; Gordon et al., 1998; Cho et al, 2001; Sohn et al., 2004; Rose and Guha 2004; Santos and Haimes 2004; Rose and Liao 2005; Lian and Haimes 2006; Tatano and Tsuchiya 2008; Crowther and Haimes 2010). There are several comprehensive impact analyses of natural disaster affecting an entire area, but most of them are *ex-post* studies using after-disaster damage data (Hallegatte 2008; MacKenzie et al. 2012). Estimating flow losses requires linking physical damage with economic interruptions, which is a complex and data-demanding process. Taking tsunami impact assessment for example, the physical damage of a particular building depends on many factors: water depth, flow velocity, soil composition, building material, structure, and maintenance, etc. Those information are

spatially heterogeneous and very expensive to obtain at high spatial resolution for an entire area. Besides the difficulties in accurately estimating physical damages for each building, in order to further estimate flow losses, the economic activity in each building is required to connect with the physical damage prediction, which is also difficult to obtain. Because of these reasons, most of the past studies focused on key infrastructures such as bridges, highway and utilities, whose physical resistance to different levels of disasters and their economic activities are carefully tested and monitored. However, these studies could not provide comprehensive impact assessment of natural disasters that usually affect a wide spatial extent, because damages and losses from other inter-connected businesses are not taken into account. A rough estimation could be carried out using the estimated inundation zone and industry sector activities within the zone to approximate the damages and losses in an entire area. However, the estimation from that approach is likely to be inaccurate. As Henriet et al. (2012) pointed out, the economic losses vary greatly across the disaster affected area due to the spatial heterogeneity of disaster's magnitude, the building's resistance and economic activities. The heterogeneity of first losses greatly affect the higher order losses. Thus, an overlay of the natural disaster's heterogeneous spatial extent with the spatial distribution of the building and business activities is crucial for the accuracy of the impact assessment. In this paper, we provide an approach for more comprehensive and accurate economic impact assessment, using the case of the tsunami treat on Oregon's coastal communities. We first integrated engineer's data with economic model by connecting business activity data from GIS Business Analysis, building address and material information from state government's tax-lot data, and the latest estimation of building damages in Oregon's coastal communities using fragility curves (Wiebe and Cox 2014). We then built a county-level Computable General Equilibrium (CGE) model to assess the economic losses of Clatsop County after a tsunami event.

The rest of the sections are arranged as the following: Section II is the literature review on past economic impact assessments of disasters, the development of fragility curves in damage estimation and the application of fragility curves in economic loss assessment. Section III introduces the Tsunami threat to Clatsop County in Oregon. Section IV describes the data and procedure of integrating the engineer's damage estimation with economic model. Section V introduces Clatsop County CGE model for economic loss assessment. Section VI presents and discusses the economic impact assessment after a tsunami event using the engineering-economic

integrated approach under different tsunami magnitude scenarios. The results will also be compared with the estimation without considering heterogeneous economic losses. Section VII contains the conclusion and discussion of further improvements.

II.   Literature Review

Past economic impact assessments of disasters has been focused on the damage of a particular infrastructure instead of zone damages of multiple sectors. Gordon et al. (1998), Cho et al. (2001), Sohn et al. (2004), and Tatano and Tsuchiya (2008) combined engineering's transportation networks and bridge/highway structure performance model with economic models. They performed impact assessment to support the cost-benefit analysis of disaster mitigation programs. Rose at al. (1997) and Rose and Guha (2004) connected the industry electric dependency network and the probability of electric disruptions under different earthquake magnitude with IO or CGE model. Rose and Liao (2005) assessed the economic resilience of water service disruptions for a hypothetical earthquake in Portland, Oregon, by incorporating information of water service networks, production adaptation mechanisms to water shortage, and estimates of water service disruption after earthquakes into a customized CGE model. Santos and Haimes (2004) and Lian and Haimes (2006) estimated the impacts of hypothetic terrorist attacks on air and ground transportation centers. Rose et al. (2007) connected engineer's modeling of power generation, distribution, and restoration with CGE to investigate the business interruption impacts of a terrorist attack on the electric power system of Los Angeles and the system's resilience to a total blackout. Crowther and Haimes (2010) estimated the impacts of a crude oil terminal outage. Comparing to studies of single-infrastructure damages, there are only a few studies investigating zone damages using after-disaster damage data. Hallegatte (2008) used post-event sector damage data of 2005 Hurricane Katrina to assess the impacts of hurricane to the State of Louisiana. MacKenzie et al. (2012) used changes in national industry productions before and after the 2011 earthquake and tsunami in Japan to investigate its impact on global economy. One of the reasons of the lack of zone damage impact assessment is the data availability. For a crucial infrastructure such as bridges and utility sector, the structure's resistance to disasters and its connections with the regional economy are well tested and monitored. However, those information are usually not available to other sectors.

Impact assessment on single infrastructure may be sufficient in estimating the impacts of human disasters causing point damages. However, it does not provide a comprehensive impact assessment of natural disaster affecting an entire area. The importance of the key infrastructure may be inaccurately estimated when other sectors' damages and their connections with the key infrastructure are not taken into account. On the other hand, the *ex-post* studies using after-disaster damage data are only applicable to the particular disasters. The impact assessment could not be generalized to estimating other potential events due to the uniqueness of the natural disasters.

To address the issue of data availability, this study will utilize the latest estimation of building damages in Oregon's coastal communities using fragility curves by Wiebe and Cox (2014). Fragility curve is a statistically derived function, which describes the probability of the structure damage level, giving a loading conduction such as flood depth, earthquake magnitude, building types. Fragility curves has been used in the past to measure particular crucial infrastructure's resistance to disasters. Until recently, with the improvements in field survey technologies and laboratory experiments, valid fragility curves have been developed to estimate physical damages of general buildings in certain areas. For buildings performance under tsunami events, the earliest fragility curve is developed by Koshimura et al. (2009), combining experiment and survey data from post-tsunami in Indonesia. The advantage of using fragility curves is that they incorporate all the uncertainty elements in the hazard into a single function, which provides a cost-effective and relatively accurate approach to estimate zone damages after the disaster. In Wiebe and Cox (2014)'s study, field surveys from the 2011 Tohoku event were used to develop fragility curves to estimate the building damages of a potential tsunami event in Oregon, due to the similar building quality and standard.

To conduct economic impact analysis, Input-Output (IO) and CGE models are usually used and CGE model will be applied in this study. Although IO model does a good job describing the inter-dependency among the industry sectors, it is based on rigid linear responses and thus does not consider the resource redistributions and price changes in response of resource shortages after the initial shock. Thus, without taking into account sectors' responses to disasters, IO model will give an inaccurate assessment of economic impacts after a Tsunami. Comparing to IO approach for impact analysis, CGE model allows supply and demand adjustment in response of

system shocks. It also allows substitutions through production and trade adjustment to reduce the impacts. Moreover the levels of those adjustments could be controlled to investigate disaster responses and shocks at different stages. There have been limited number of CGE model to estimate the impacts of a disastrous event. Liew (2005) analyzed the impacts of national-wide wage rate change on US industries, using a hybrid IO / CGE model with price response component. Rose and Guha (2004), and Rose and Liao (2005) used CGE model to evaluate the impacts of utility lifeline disruptions in the aftermath of earthquakes. Tatano and Tsuchiya (2008) developed a multi-regional CGE to investigate the impacts of damage to transportation networks.

III.   A Case Study of Cascadia Subduction Zone (CSZ) Tsunami in Clatsop County

In this case of study, I use the Cascadia Subduction Zone (CSZ) Tsunami as an example to illustrate the proposed assessment method. Many coastal communities in the west America are at risk to significant devastation and loss of life from a major CSZ earthquake and the resulting tsunami. The CSZ measures 1000 km in length and extends from the Mendocino Ridge off the coast of northern California to northern Vancouver Island, British Columbia (Figure 1). Along the CSZ the oceanic Juan de Fuca Plate is subducting beneath the continental North American Plate. However, due to friction the plates are locked together, preventing movement, and leading to an increase in stress and strain along the boundary (Geist, 2005). The strain deforms the plates, lowering the oceanic plate and raising the continental plate. Stress accumulates until it exceeds the frictional force and the plates slide past one another. At which time the strains in the oceanic and continental plates are suddenly released, resulting in a sudden uplift in the oceanic plate and a lowering of the continental plate (Stern, 2002). It is this sudden displacement of the oceanic plate which causes a perturbation of the water column from its equilibrium position and forms a tsunami. The last great CSZ event occurred more than three centuries ago on 20 January 1700. It was a full length rupture extending from the Mendocino Ridge, off the coast of northern California, to mid-Vancouver Island, Canada. The event is estimated to have had a moment magnitude (M_w) between 8.7 and 9.2 (Satake et al., 2003). Every unit increase in M_w represents a 31.6 fold increase in energy. Over the past 10,000 years full length CSZ events have ranged from 8.7 to 9.1 M_w (Goldfinger et al., 2012) which correspond to a 13 fold increase in energy. The average recurrence interval between CSZ events is 240 years (Goldfinger et al., 2012). According to Groat (2005), in the next 50 years, the west coast

ranging from northern California to southern Canada is exposed to a 10-14% chance of a 9.0 M_w earthquake and a 37% chance of an 8.0 M_w earthquake. The earthquake has great potential to trigger tsunamis that might affect more than 1000km coastlines and lead to substantial damage in coastal communities.
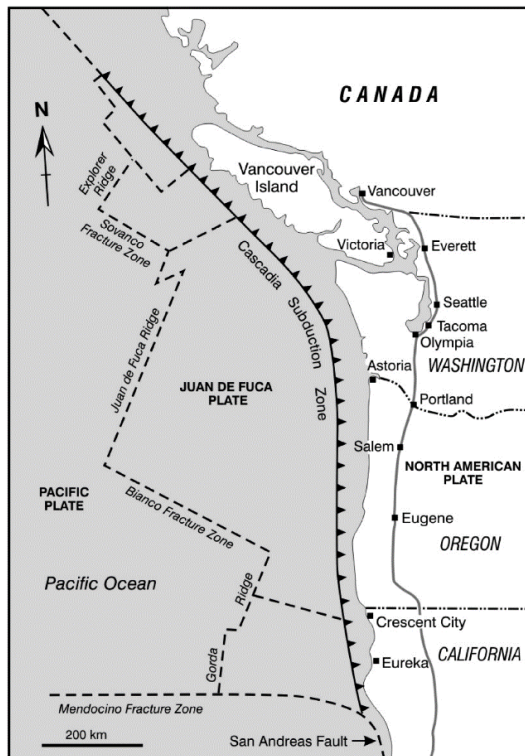
Figure 1. The map of CSZ and the affected areas

(Source: Adapted from the Cascadia Region Earthquake Workgroup (2005).

http://www.emeraldinsight.com/journals.htm?articleid=1742499&show=html)

Among all the coastal communities, we chose Clatsop County, one of the major five coastal counties in State of Oregon, as our study site. According to US Census Bureau, Clatsop County contributes 19% of population and 27% of sales to the five major coastal counties. Moreover, the county is also subject to threat of the potential tsunami events. According to Oregon Senate Bill 379, which enacts the Tsunami regulatory map depicting the estimated inundation zone from a typical tsunami event in 1995, although only 15% of the land area in the county is in the inundation zone, 29% of county residents and 46% of the production activities locate within the inundation area.

IV.   Integration of the Engineer's damage estimations with Economic Model

In this section, we will first introduce the data of engineer's damage probability estimation. Then, we will introduce the taxlot data, which links physical damage probability with business activities. Last, we will present the business activity and transaction data.

In order to derive the estimation of damage probability, Wiebe and Cox (2014) first simulated the maximum flow depth in the disaster-affected area after tsunami events using the Method of Splitting Tsunami (MOST) maintained by the Pacific Marine Environmental Laboratory (PMEL) of the National Oceanic and Atmospheric Administration (NOAA). The simulation used in this study consists of three magnitudes of the tsunami, measured by the distances of slip of Juan de Fuca Plate beneath the continental North American Plate, which are 20m, 17.5m, and 15m. Then, they used fragility curve to incorporate flow depth, building types and other uncertainties and calculated probability of major damage, which is defined as "window and larger part of wall are damaged" according to Suppasri et al., (2012). A fragility curve is a statistical function which describes the damage state for a given loading condition. In this study, fragility curves developed from the 2011 Tohoku event is used. The detailed descriptions of fragility curve and damage probability calculation could be found in the paper by Wiebe and Cox (2014).

Taxlot data is used to link physical damage probability with business activities. Tax lot data collected by the Clatsop County Assessment and Taxation Department contains building type and location information on each parcel. On one hand, each parcel is categorized with a three digit property classification which is used to assign a building type (wooden or concrete/steel). As a simplifying assumption, all residential structures are taken as wooden and all commercial structures are taken as concrete/steel. Based on several site visits, this assumption is reasonable, particularly for residential buildings which are nearly all wood and for large, newer hotels which typically have modern construction. Some of the older, smaller hotels and small businesses are a mix of wood and concrete construction. The building type information is incorporated into the fragility curve with flow depth to calculate the probability of major damages for each parcel.

On the other hand, the location information of the taxlot will be linked with business activity and transaction data from GIS Business Analyst and IMPLAN. Business Analysis® ESRI provides geocoded data on business location, number of employees, total revenues, and the NAICS code for each business. The 2010 data for Clatsop County consists of 2,716 businesses, with a total of 20316 employees, which is close to IMPLAN and BEA's estimates of 23,782 and 21,894 respectively. However, in this dataset, the geographical location, that is the latitude and longitude location, of each business is generated using address-matching geocoding, which is less accurate. As a result, the business location as measured in the latitude and longitude location may not coincide with the location of the taxlot under the same address. To fix this problem, we matched the business location data in Business Analyst with the taxlot data from County Assessment Office by street addresses.[1] This gives us the spatial distribution of economic activities in the county. It is the taxlot level data on the employment and sales as well as the business' NAISC code.

After connecting physical damage probability with business activities, we now know the probability of major damage, commercial or residential use, types of business, revenues and employment for each taxlot. Assuming the major damage on the taxlot will destroy all the capitals (buildings, machinery, utilities, etc.) on the parcel, and such capital damage will cause complete business interruption. Then, we could derive the probability of business interruptions, which is reflected as the expected revenues on each taxlot. Moreover, we know the NAISC code for each business at the parcel level, which allows us to aggregate expected revenue damages by economic sectors. This in term gives us the estimate of the direct tsunami captial damage in the inundation zone in Clatsop County by sector, which would be integrated in the economic tracation data in IMPLAN and inplemented in the CGE model to estimate ecnomic impacts. The construction of Clatsop County CGE model will be discussed in the following section.

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[1] A Matlab program is written to match the street addresses from two datasets considering the possibility of different abbreviations. The unmatched businesses are checked individually using google and google map. 99% of the businesses in Clatsop County in the Business Analyst dataset are successfully matched with the tax-lot data. The remaining 1% includes no significant contributors to either employment or sales.

V. Clatsop County CGE Model

In the Clatsop County CGE model, there are 15 business sectors: agriculture, forestry, fishing, energy, construction, other manufacturing, seafood processing, wood processing, trade, transportation, information, financial and real estate, business service, education, health, tourism, other service, and public service. Following Hosoe's (2010) standard CGE framework, it is assumed that firms' production follows Constant Elasticity of Substitution (CES) function, under conditions of constant returns to scale. Firms maximize their profits in competitive markets. Household maximizes its utility from the consumption of the sectors' productions, subject to income constraint. County government generates tax revenues from households and firms, and purchases sectors' outputs with fixed patterns. Household's and government's savings are collected and invested on each sector with a fixed proportion. There are several market clearing conditions: first, county's input and final consumption demands are satisfied through supplies from local sectors' productions and imports from rest of the world (ROW). The composition the supply depends on the elasticity of substitution between local products and imports. It also depends on the transportation cost of importing goods. Second, local sectors' productions are distributed among local demand and exports to ROW. The allocation depends on the elasticity of substitution between local products and exports. Third, imports and exports are balanced through fixed county account deficit / surplus. Fourth, the sum of factor inputs equals to the total endowments of the household.

In this study, the county CGE model is adjusted to estimate the short-run impact after the tsunami event. We first assume that most of the sectors in the county could get supports from the rest of world (ROW) because only coastal area is directly affected by the disaster and most of the trade activities could still be operated through inland transportation. However, products in forestry, wood processing, fishery and seafood processing could not be substituted easily due to perishability and high transportation cost. Second, production technology and procedure could not be easily adjusted in the short run. Thus, intermediate inputs have low elasticity of substitution. Also, labor and capital could not be adjusted across sectors and total endowments of labor and capital are fixed.

To link physical damages to flow losses, expected capital damages is applied to each sector, which is estimated by connecting engineer's physical damage probability with business activity

data through taxlot data. To illustrate the importance of taking into account the heterogeneity of physical damages and economic activities across the disaster-affected area, we will compare economic impact assessment using engineering-economic integrated approach with the estimation without information on spatial distributions of physical damage probability and economic activities.

VI.   Results and Discussions

Using County CGE model, economic impacts from three magnitudes of tsunami are estimated. In this case study, the magnitudes of tsunami depends on the distance of oceanic Juan de Fuca Plate sliding beneath the continental North American Plate. The longer the slide distance is, the higher magnitude the tsunami it will cause. In our analysis, tsunamis from 20m-slide, 17.5m-slide, and 15m-slide and simulated. Then, for each scenario of magnitude, estimations using engineering-economic approach is compared with the one without spatial information on physical damage probability and economic activities. The differences between those estimated approaches could be observed from the "Capital Damage" columns under "Heterogeneous Damage" column, and "Homogeneous Damage" column for each tsunami magnitude in table 1. The expected capital damage from "Heterogeneous Damage" column is estimated through engineering-economic approach by overlaying spatially heterogeneous physical damage probability with economic activities. Thus, each sector's expected capital damages depends on locations, infrastructure quality, and economic activities of the companies in the sector. On the other hand, the expected capital damage under "Homogeneous Damage" column is estimated by counting businesses within the inundation zone for each sector and applying the same damage probability on those sectors. In order to make the two approaches comparable, we assign the probability in "Homogeneous Damage" columns so that the total expected capital damage is the same as the one in "Heterogeneous Damage" column in the same tsunami magnitude scenario. Comparing the values of expected capital damages between "Heterogeneous Damage" and "Homogeneous Damage" estimation approaches, we could find that the estimations from several sectors are significantly different: the engineering-economic approach estimates lower capital damages for wood processing and seafood processing sectors, but higher damages for education and tourism sectors, due to the locations, infrastructure quality, and economic activities of the companies in those sectors.

Table 1. Comparison of Economic Impact Assessment ($million) of Three Tsunami Magnitude Scenarios under Two Approaches

Sectors	County Output	20m-Slide Tsunami				17.5m-Slide Tsunami				15m-Slide Tsunami			
		Heterogeneous Damage		Homogeneous Damage		Heterogeneous Damage		Homogeneous Damage		Heterogeneous Damage		Homogeneous Damage	
		Capital Damage	Total Economic Impact	Capital Damage	Total Economic Impact	Capital Damage	Total Economic Impact	Capital Damage	Total Economic Impact	Capital Damage	Total Economic Impact	Capital Damage	Total Economic Impact
AG	21	>-1	>-1	>-1	-1	>-1	>-1	>-1	-1	>-1	>-1	>-1	>-1
Forestry	62	>-1	>-1	>-1	-3	>-1	>-1	>-1	-2	>-1	>-1	>-1	-2
Fishing	12	>-1	-3	>-1	>-1	>-1	-3	>-1	>-1	>-1	-3	>-1	>-1
Energy	36	0	-2	0	-2	0	-2	0	-2	0	-2	0	-2
Constr	201	-3	-31	-3	-23	-3	-28	-2	-21	-2	-22	-2	-17
Other_Manuf	102	-4	-6	-5	-8	-4	-6	-5	-7	-3	-5	-4	-6
Seafood_Pros	84	>-1	-1	-5	-8	>-1	-1	-5	-7	>-1	>-1	-4	-6
Wood_Pros	492	>-1	-1	-24	-37	>-1	>-1	-22	-34	>-1	>-1	-19	-27
Trade	312	-5	-22	-5	-19	-4	-20	-4	-17	-4	-16	-4	-14
Trans	59	>-1	-3	-1	-3	>-1	-2	-1	-3	>-1	-2	-1	-2
Info	53	-4	-9	-2	-4	-4	-8	-2	-3	-3	-7	-1	-3
Finan_Estate	513	-8	-50	-4	-32	-7	-45	-4	-29	-6	-35	-3	-23
Busi_Serv	208	-7	-17	-9	-15	-7	-16	-8	-14	-5	-12	-7	-11
Edu	271	-51	-28	-25	-20	-50	-25	-24	-18	-46	-20	-20	-15
Health	360	-1	-28	-4	-23	-1	-26	-4	-21	-1	-20	-3	-17
Tourism	339	-22	-86	-8	-21	-21	-80	-7	-19	-18	-59	-6	-15
Other_Serv	148	-2	-10	-3	-10	-2	-9	-3	-9	-2	-7	-3	-7
Pub	443	-28	-43	-39	-40	-24	-39	-37	-37	-16	-29	-31	-30
Total	**3716**	**-137**	**-340**	**-137**	**-268**	**-129**	**-312**	**-129**	**-246**	**-109**	**-241**	**-109**	**-197**

Using expected capital damages as the inputs, county CGE model estimates the short-run economic equilibriums after the tsunami event. "Total Economic Impact" column calculates the differences of the total outputs for each sector, which includes changes of economic activities such as production, employment, and imports. We first observe that heterogeneous damage triggers more total economic impact than homogeneous damages. Second, we observe greater economic impacts on education and tourism sectors. While this is largely due to the greater capital damages, other sectors like fishing, construction, business service, and health sectors have greater economic impact although their expected capital damages are similar to "Homogeneous Damage" approaches. This observation indicates that an unbalanced sector damage may trigger more overall economic damages through bottleneck effects in economic transactions.

Table 2. Comparison of Ranks of Sectors' Total Impacts ($million) under Two Approaches

Sectors	Ranks of Total Impacts under Heterogeneous Damage Approach	Sectors	Ranks of Total Impacts under Homogeneous Damage Approach
Tourism	-108	Pub	-79
Edu	-79	Wood_Pros	-61
Pub	-70	Edu	-45
Finan_Estate	-58	Finan_Estate	-36
Constr	-34	Tourism	-29
Health	-29	Health	-26
Trade	-27	Constr	-26
Busi_Serv	-25	Trade	-23
Info	-12	Busi_Serv	-23
Other_Serv	-11	Other_Manuf	-13
Other_Manuf	-10	Other_Serv	-13
Fishing	-4	Seafood_Pros	-12
Trans	-3	Info	-5
Energy	-2	Trans	-5
Seafood_Pros	-2	Forestry	-3
Wood_Pros	-2	Energy	-3
AG	>-1	AG	-2
Forestry	>-1	Fishing	-1

The other observation that is useful for policy makers is the changes in the rankings of the sectors' total impacts. As the Table 2 in the above shows, comparing with Homogeneous Damage Approach, the Heterogeneous Damage approach much greater impacts on tourism

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sector and much lower impacts on the wood processing sector. The more accurate information will be useful for the local government to estimate the loss and assistant needed by different sectors. In the future study, we will build on the current engineering-economic integrate impact assessment tool to provide a more accurate estimation of industry transactions. With that information, we will be able to identify key sectors and transactions that supports local economy and evaluate the benefits of different disaster resilience plans.

Appendix A. Description of County CGE Model

Data Sources

CGE model uses Social Accounting Matrix (SAM) as the input of initial status. In our study, we derived a 15-sector SAM of Clatsop County in year 2010 from IMPLAN. We first extracted sector output, intermediate inputs, factor inputs, imports, intermediate input demand, factor input demand, household consumptions, government spending, investments and exports from IMPLAN. A Matlab program is then used to aggregate IMPLAN's 528 industrial categories into aggregated 15-sector category and construct the 15-sector SAM of Clatsop County.

Structure of CGE

Figure A-1 provides on overview of the County CGE model following the standard CGE framework of Hosoe et al. (2010). The figure shows the flow from supply to demand for an industry sector *i*. The firm produces *i* using labor, capital and intermediate inputs, via a CES production function. The production is allocated between domestic good and export following a CES allocation function. Domestic good is combined with import to form composite good following a CES production function. Composite good is used to supply the local demand, including household consumption, government spending, investment and intermediate input supplies, reaching market equilibrium. In this equilibrium system, household's utility is maximized.

Production

All the firms are aggregated into 15 industry sectors: agriculture, forestry, fishing, energy, construction, other manufacturing, seafood processing, wood processing, trade, transportation, information, financial and real estate, business service, education, health, tourism, other service, and public service. All the sectors produces using labor, capital and intermediate inputs from its own and other sectors' outputs, via CES production function and constant return to scale. We assume in the short-run, labor and capital for each sector are specialized and cannot be adjusted through other sectors. Most intermediate inputs are able to be substituted through imports except for forestry, wood processing, fishery, and seafood processing. Producers maximize their profits.

Household Behavior

Household choose consumptions of goods produced by all the sectors subjected to budget constraint. Household's budget constraint is the summation of income from labor and capital inputs in each sector. We assume household are subjected to an income tax with fixed proportion and will set a fixed amount of income to the saving.

Government Spending

We assume that government will purchase goods from each sector with a fixed proportion. Government's revenue is from the tax collection from all the industry sectors and household. Government will set aside a fixed proportion of their revenue to saving and spend the rest on purchasing.
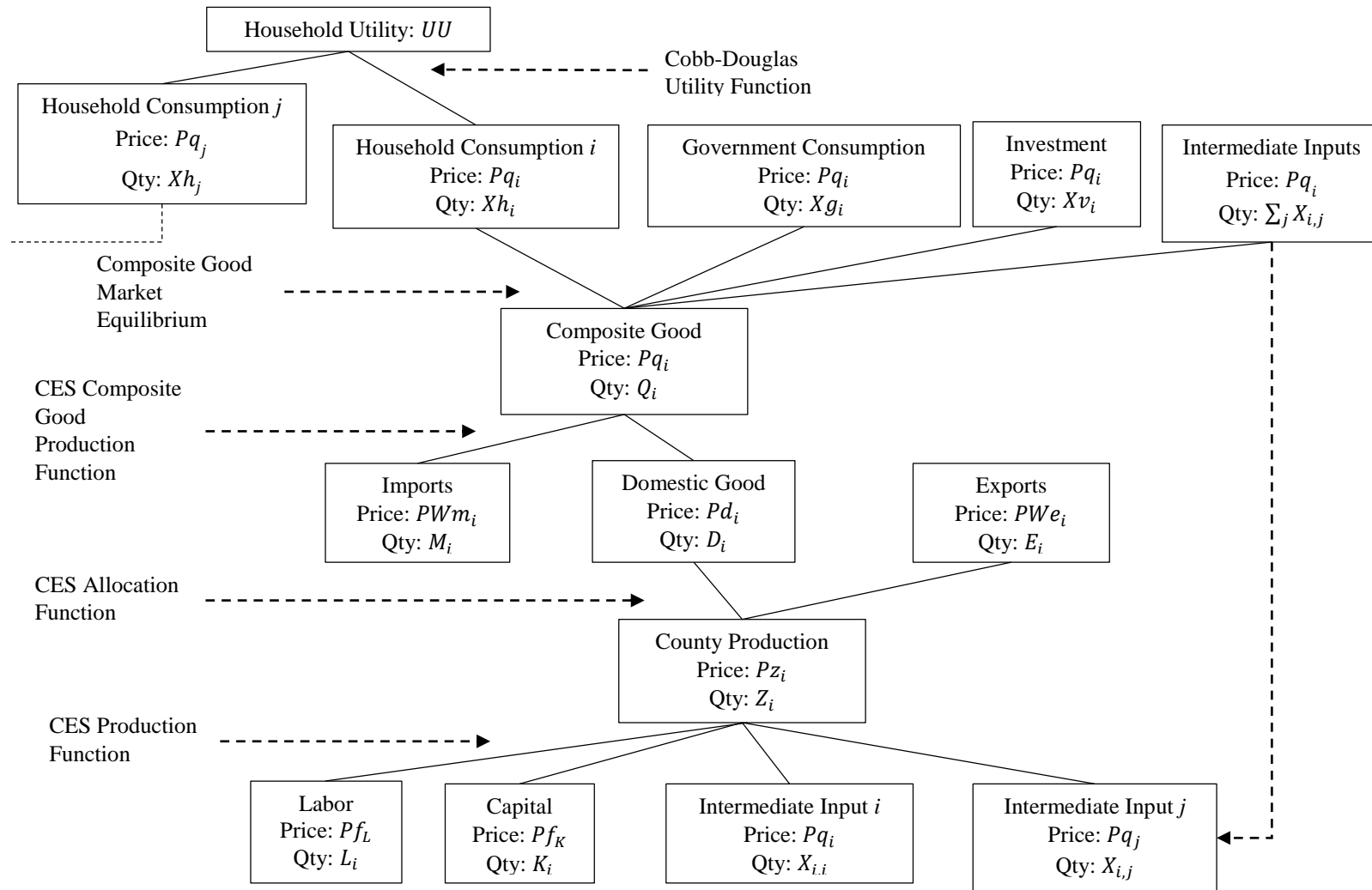
Investment

We assume that savings from household and government are used to invest on sectors with fixed proportions, after balancing with county account deficit / surplus through import-export account balance.

Model Closure

There are several market clearing conditions: first, county's demand including household consumption, government spending, investment and intermediate input supplies, are satisfied through composite good, which consists of imports and domestic goods. Second, sectors' productions are allocated between domestic goods and exports. Third, imports and exports are balanced through fixed county account deficit / surplus. Fourth, the sum of factor inputs equals to the total endowments of the household.

Figure A-1. Overview of the County CGE Model

Household Utility: UU

Cobb-Douglas Utility Function

Household Consumption j
Price: Pq_j
Qty: Xh_j

Household Consumption i
Price: Pq_i
Qty: Xh_i

Government Consumption
Price: Pq_i
Qty: Xg_i

Investment
Price: Pq_i
Qty: Xv_i

Intermediate Inputs
Price: Pq_i
Qty: $\sum_j X_{i,j}$

Composite Good Market Equilibrium

Composite Good
Price: Pq_i
Qty: Q_i

CES Composite Good Production Function

Imports
Price: PWm_i
Qty: M_i

Domestic Good
Price: Pd_i
Qty: D_i

Exports
Price: PWe_i
Qty: E_i

CES Allocation Function

County Production
Price: Pz_i
Qty: Z_i

CES Production Function

Labor
Price: Pf_L
Qty: L_i

Capital
Price: Pf_K
Qty: K_i

Intermediate Input i
Price: Pq_i
Qty: $X_{i.i}$

Intermediate Input j
Price: Pq_j
Qty: $X_{i,j}$

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