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Regional Indirect Impacts of Wildfire Damages on Outputs of Forest and Tourism Sectors

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이 논문을 경제학박사 학위논문으로 제출함
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Abstract

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry. The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage model, transportation demand model, and tourism expenditure model. The IRCGE model is described two macro regions under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model estimated burnt areas considering high uncertainty based on data of temperature, wind speed, humidity from the Ministration of Korea Meteorology and wildfire statistics, forest type, slope features by spatial unit from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The estimated burnt area in the wildfire damage area model affected to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

In order to examine the validity of the developed IRCGE, a simulation on the Goseong wildfire was conducted for Gangwon province considering Intergovernmental Panel on Climate Change (IPCC)'s prospects for climate changes, the emission scenario of the Representative Concentration Pathways(RCP8.5). There is a suitable place to analyze the indirect impact on forest and tourism industry because it is a typical tourist destination and mountains covered more than 80% of the total area of the province. Markov Chain Monte Carlo method was adopted to estimate ranged burnt areas considering the high uncertainty of climate and topography due to the nature of wildfire, the change of transportation accessibility, and the loss of tourism expenditure.

The economic effects of Goseong wildfire were analyzed by using the experiment of the wildfires damage under the cases of without or with climate change. Gross Domestic Product (GDP) in

Korea due to the wildfire damage decreased by −0.01% under the without climate change, −0.04% when considering climate change. The Gross Regional Product (GRP) of the Gangwon Province decreased from −0.25% to −0.55% (−0.069 ~ −0.153 billion US$) due to Goseong wildfire under the no climate change and from −0.51% to −1.33% (−0.143~−0.344 billion US$) under the climate change (RCP 8.5). The value added of industrial changes in Gangwon province decreased from −12.10% to −17.43% in forest sector and from −0.71 to 0.85% in tourism sector due to the fire damage. The value added losses of the industry under the climate change will be about 1.5 to 2.2 times larger than the scenario without climate change. On the other hand, GRP in the rest of Korea (ROK) enjoyed reflex benefits from 0.027~0.06 billion US$ due to the wildfire damage in Gangwon Province, and value added changed within the range of −0.191 ~ 0.182 billion US$ in ROK under the climate change scenario.

This dissertation developed a framework for estimating economic effects with considering the climate change applicable to other natural or manmade disasters. The developed framework was applied to wildfire damage and confirmed its usefulness. The results of the analysis can be used as a basis for establishing the government budget for disaster prevention and magnitude of the subsidy considering prioritized monetary losses by each industry. In addition, it can be used to calculate the insurance premium for damage compensation.

In the further research, it can be extended to develop a quarterly model to improve the accuracy of the economic estimates or dynamic model to consider the long−term recovery depending on the magnitude of the disaster. With regard to the policy, it need to be increasing the scale of the disaster prevention budget in response to the economic losses, providing a detour plan to improve transportation accessibility to damaged regions, and aggressive tourism marketing policy to promote tourist destinations.

Keyword: Economic impact, Disasters, Wildfires, Tourism Expenditure, Inter Regional Computable General Equilibrium Model

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Chapter 1. Introduction

1.1. Research Background and Purpose

The losses of disasters are increasing due to the unexpected abnormal weather and the rise of outdoor recreation activities. Many natural disasters, such as earthquakes and volcano eruptions, and social disasters, such as wildfires, car accidents and terrors, have occurred to affect regional economies. As an example, the massive earthquake above a 7.0-magnitude struck Haiti on 12th of January, 2010. This resulted more than 230,000 people were killed, and its direct economic damage was estimated up to 13.9 billion US$ (Cavallo *et al.*, 2010). Similarly, the most powerful typhoon Maemi hit the Korean peninsula on 12th of September 2003. According to the Fox News (2003), the property damage was estimated at 1.3 billion US$, with 5,000 houses destroyed or damaged and 20 major companies shut down on the southeastern coast[1]. Korea's economy growth rate was only 3.5% due to the typhoon in 2003. The wildfire is belonging to the social disaster in Korea, which is caused by humans, while the damage is determined

[1] http://www.foxnews.com/story/2003/09/15/typhoon-maemi-kills-6-in-south-korea.html

by climate and geographical conditions. The wildfire damage and its resulting loss is growing as accelerating fire severity and intensity through the case of California in the United States (Doerr and Santin, 2016). The wildfire is one of the most risky threats to concern about industrial production losses, and the reduction of travel demand. For instance, direct impacts of the 2017 wildfire season on Montana's visitor economy, the state lost up to 0.8 million visitors due to last summer's fires and smoke, resulting in a loss of 240.5 million US$ in visitor spending and translating to a 6.8% loss in expected annual spending from the Institute for Tourism and Recreation Research (Sage and Nickerson, 2017).

Economic outputs from disaster can be classified into direct and indirect ones, Direct and indirect effects are sometimes referred to as primary and secondary (or higher−order) effects, respectively. The former includes physical damages or the consequences such as business interruption and unemployment, while the latter is defined as the consequence of interactions between transactions across sectors (Cochrane, 2004; Rose, 2004; Ding *et al.* 2011). In particular, Rose *et al.* (1997) estimated regional economic impact of an earthquake into divided by direct and indirect effects of electricity lifeline disruptions. Ryu and Cho (2010) estimated the indirect impact of the Rusa typhoon which reduced 1.18% of GDP in Korea. Many direct impacts of natural or social disasters had been conducted to estimate economic output. Meanwhile, studies on the indirect impacts of disasters has been found in a few literatures (Rose *et al.*, 1997; Kim *et al.,* 2002; Ryu and Cho, 2010; Brounrn and Derwall, 2010; Strobl, 2012; Koks and Thissen 2016). The researches on indirect impacts of disasters were relatively lacking compared to that on direct impacts. Accordingly, it would be necessary to measure the indirect effects of disasters using quantitative tools.

In Korea, natural disasters such as heavy rains, typhoons, and heavy snow had caused many damages according to the Statistics Korea. The average annual losses with respect to dead or missing for the period 2000–2016 are 49 persons, and the average property loss is 1,190.9 million US$ (constant 2016). Among Korea's disasters, burnt areas of wildfire damages have been increased due to the occurrence of 33 large scale wildfires since year 2000. As the benchmark wildfire, 2000 Goseong wildfire in Gangwon province burned the forest areas 23,674 ha and 2005 Goseong wildfire destroyed Naksan temple which is well-known cultural heritage and over 1,400 years old. However, previous papers have mainly focused on assessing direct impacts of wildfires, which implied underestimated the damage scale for not considering indirect impacts caused by wildfire disasters. Still, indirect impact analysis is insufficient because the analytic method has not fully developed yet to investigate the inter-regional and inter-industrial effects. To address this problem, it is required to develop analytic framework to estimate indirect economic losses due to the various disasters.

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect economic impacts of wildfire damage on forest and tourism industry. It can be applied to analyze the indirect economic impacts of wildfires using the Inter Regional Computable General Equilibrium (hereafter IRCGE) model. The framework is based on a stylized interregional CGE model at two macro-regional level in Korea which linked to wildfire damaged area model, tourism expenditure model and transportation demand model at a city and county level. The IRCGE model with micro modules developed in this study utilized to the analysis of indirect effects on several types of natural disasters and spatial units. Climate change had a stronger signal in the wildfires including California's. Taking the climate change into consideration, it can be utilized different database such as spatial data from the climate observations and topographical data and economic statistical areas such as a city or county level in the wildfire sites. In the study, the IRCGE model is developed for two macro regions and 12 industrial sectors on the base year of 2013. It is applied to the simulation of the wildfire in

Gangwon province of Korea where represents large wildfire area in Korea, to measure indirect impacts. The expected result show advanced method to assess indirect economic losses and its utilization of various natural disasters and policy implication of budget scale, industrial efficiency, and investment of production factors. Figure 1 presents the structure of the dissertation with specifications of motivation, literature review, methodology, simulations, and summary with further research agenda.

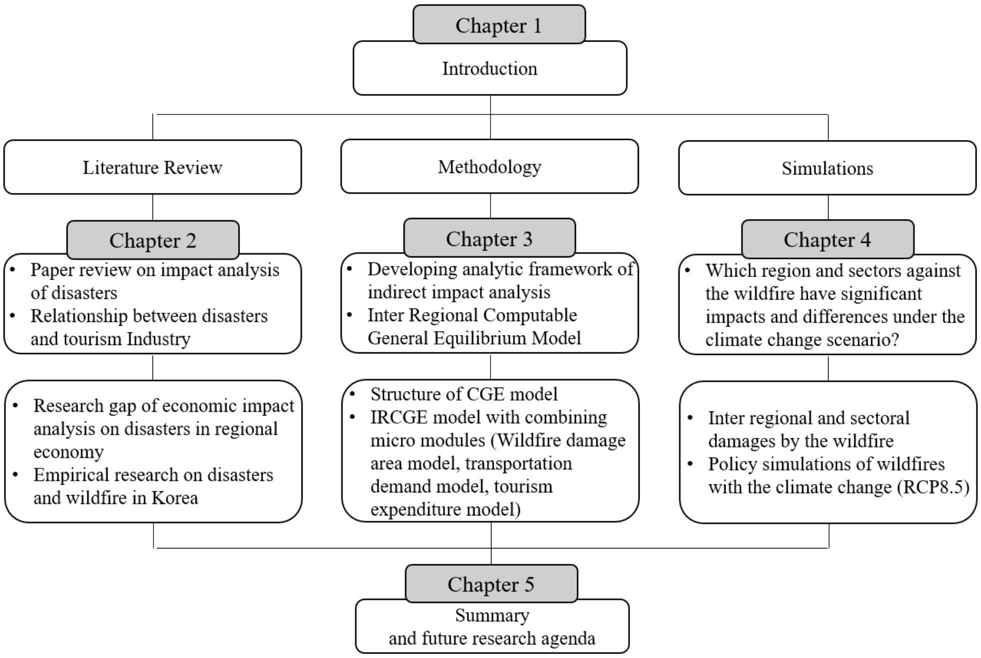

Figure 1. Structure of the Dissertation

1.2. Organization

This dissertation consists of five chapters. Chapter 1 describes the research background and the purpose of the dissertation. Chapter 2 discusses literature reviews on economic impact of wildfires, natural or manmade disasters, and tourism industrial losses of wildfires. Chapter 3 develops the IRCGE model for economic impact analysis of wildfire damages. Chapter 4 analyzes regional economic growth and value added changes through the simulations of the climate change on wildfires. Chapter 5 concludes the results and discusses policy implications for outputs of forest and tourism sectors.

Chapter 2. Literature Review

This chapter focuses on the definition and the types of disasters and then reviews previous papers on the impact of disaster on the economy and the tourism industry. There are many types of disasters, which affects the economic performance and the tourism industry directly or indirectly with various causes and magnitudes of disasters.

2.1. Definition and Typology of Disaster

There are several definitions of a disaster and its definition used seems dependent upon the discipline using the term (Turner and Pedgeon, 1997; PDM, 2002; Denis, 1995; Keller and AI−madhari, 1996; Aini *et al.*, 2001; Shaluf *et al.*, 2003). A disaster is different to a crisis in the traditional meaning of the word. A crisis is a situation in which important decisions involving threat and opportunity have to be made in a particular short time. Rather, disasters involve management procedures that must be maintained and management problems coped with under conditions of major technical emergency involving threats of injury and loss of life (Turner and Pedgeon, 1997; Richardson, 1994). To be specific, Turner and Pedgeon (1997) pointed out that no definition of “disaster” is accepted universally. Parker (1992) proposed that the definition of disaster is an unusual natural or manmade event, including an event caused by failure of technological system, which temporarily overwhelms the response capacity of human communities, groups of individuals or natural environments and causes massive damage, economic loss, disruption, injury, and loss of life. Hood and Jackson (1992) classified the disaster into three types: natural disaster, manmade disaster (socio-technical disaster), and hybrid disaster. Different terms have been used to describe the types of disasters, however, the natural and manmade disasters cover all types of disasters (Schaluf *et al.*, 2003).

Disasters defined as a natural event, manmade event, or both (Shaluf *et al.*, 2003). Natural disaster is unplanned and socially disruptive event with sudden and severe disruptive effects. Man-made disaster occurs due to interaction between human, organizational, and technological (HOT) factors and regulatory, infrastructure, and preparedness (RIP) factors. The impacts of man-made disaster sometimes transcend geographical boundaries and can even have trans-generational effects (Three Mile Island nuclear power plant disaster, Bhopal gas disaster, and Chernobyl nuclear power plant disaster). Disaster could be of a sudden impact disaster (e.g. air/road/rail accident) is usually of short duration and has a limited direct effect on local community; a high−impact disaster (e.g. flood) has a great direct effect on community over a longer period (Shaluf *et al.*, 2003). Disaster causes large scale damage to human life, physical environment and has large economic, social cost. Most disasters arise not because of a single factor but due to accumulated unnoticed events.

In Korea, disasters are defined as social disasters and natural disasters (Korea Ministry of the Interior and Safety, 2017). Social disasters are various kinds of accidents that can cause damage to lives and property. They include traffic accidents, collapses, explosions, fires, wildfires, cyber terrorism, infectious diseases, and AI. Natural disasters include storms, floods, heavy rain, strong winds, heat waves, lightning, heavy snow, droughts, earthquakes, yellow dust, cold waves, and thawing. To be specific, a disaster means a situation in which the living environment changes or damages human lives or property, so that human survival and property can not be preserved (Song, 2013). Also, a disaster can be defined as a situation in which the crisis is amplified, causing serious damage and threats to life or property, resulting in paralysis of various systems of society (Kim, 2005).

On the other hand, the types of disasters defined in the fundamental law on Disaster and Safety Management are as follows. As of 2017, the fundamental law classifies disasters into natural disasters, social disasters, and overseas disasters (revised on 26th July 2017) according to the Office of Legislation in Korea government. This is inconsistent with the disaster classification system in the field and national safety management plans and requires a clear conceptualization.

Table 1. The Types of Disasters Defined in the Fundamental Law in Korea

classification	List of disasters
Natural disaster	Storm, flood, heavy rain, strong wind, storm, flood, heavy snow, lightning, drought, earthquake, yellow sand, algal blooms, tidal water, volcanic activity, asteroids A collision or collision of a natural space object such as a meteoroid, or other natural phenomena
Social disaster	Damages caused by fire, collapse, explosion, traffic accidents (including air and water accidents), chemical, biological, and radiological accidents, environmental pollution accidents, and damages caused by the paralysis of national-based systems such as energy, telecommunications, transportation, finance, medical care, water supply, infectious disease or spread of livestock infectious diseases
Overseas disaster	Disasters that need to be dealt with at the government level as a disaster that could damage the lives, bodies and property of the Korean people outside the territory of the Republic of Korea

Source: Fundamental law on disaster and safety management in Korea (2017.7) and revised by the author.

In Korea, the study of tourism effects on disasters is at an early stage and have most likely being studied in terms of disaster management. Yoo (2014) defined that a disaster refers to an emergency state that can lead to a bad situation. The disaster is closely related to the crisis, and the disaster in the tourism sector is dealing with in the crisis management. Because disaster and crisis are two different events, however, they are related events where the crisis is more comprehensive than the disaster (Shaluf *et al.*, 2003). Yoo (2011) classified the disaster of the tourism industry into direct disaster and indirect disaster. The former includes tourism-related disputes, natural disasters, tourist-related disasters, and damage to tourists due to terrorism. The latter embrace impact of terrorism and military actions, economic crisis, and epidemics.

Table 2. Disaster Type and Contents in Tourism Industry

classification	Contents of disaster
Direct disasters	Tourism-related disputes, natural disasters, tourist-related disasters, and damage to tourists due to terrorism
Indirect disasters	impact of terrorism and military actions, economic crisis, and epidemics

In short, the wildfires covered in this study are natural disasters and manmade disasters. Wildfires belong to social disaster according to the fundamental law in Korea. In terms of characteristics of wildfires, the spread of wildfires and the magnitude of damage depends heavily on the natural environment including weather conditions and geographical features, although people cause wildfires.

2.2. Economic Impact of Disasters on Economy

This section reviewed previous papers on the impacts of natural disasters and man-made disasters. There have been numerous attempts to measure the regional economic impact of natural or man-made disasters. As discussed in Greenberg *et al.,* (2007) and Okuyama (2007), Input-Output (IO) model, the CGE model and other econometric models have been widely used in analyzing the economic impact of disasters.

Greenberg *et al.* (2007) classified impacts of disasters into with regard to the types of impacts, geographical scale, temporal scale, and ability to measure key policy consequences[2]. As the IO based

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[2] **Ability to Measure Costs and Benefits:**

1) Direct impacts—changes in business as a direct consequence of the event, and investments to mitigate, recover, and redevelop.
2) Indirect impacts—changes in sales of suppliers to directly affected businesses throughout the lifecycle, including preparedness-related investments prior to the event, impacts of suffering the event, and recovering from it.
3) Induced impacts—shift in sales due to changes in residential income.

Geographical Scale:

1) Local/county—the area directly hit by the event.
2) Regional/multicounty—surrounding area that suffers and/or benefits from the event and preparedness or recovery investments.
3) State—the host state(s) of the event.
4) National—the United States. International—nations that are impacted negatively or positively by the event.

Temporal Scale:

1) Short-term aftermath (initially monthly, then quarterly for two years).
2) Intermediate (initially quarterly, then annually for two to five years).
3) Long-term (annually for five or more years).

Ability to Measure Key Policy Consequences:

1) Investments in mitigative measures (e.g., upgrading bridges, dams, electric power transformers)
2) Investments in resiliency (e.g., education about alternative methods of production, changing schedules, use of alternative resources, etc.).
3) Impact on disadvantaged (e.g., isolated poor, immobile, and otherwise impaired).

model, Ryu and Cho (2010) estimated the indirect economic damages due to typhoons and heavy rains of Korea, and developed an 'event matrix,' which is designed to calculate new input-output structure after the outbreak of disasters. Rose *et al.* (1997) estimated the regional economic losses from earthquake-damaged electric utility lifelines in the New Madrid Seismic Zone of Tennessee with the IO and linear programming models. The potential production loss over the recovery period could amount to as much as 7% of GRP of the state. They showed how losses could be reduced by reallocating electricity resources and optimizing their recovery sequences through linear programming. Okuyama (2004) applied Miyazawa's extended input-output framework to estimate the spatial impacts of the Great Hanshin Earthquake of 1995 in Japan and its recovery process and the sequential inter-industry model (SIM) to investigate the dynamic process of the impact paths of the disaster. The SIM framework was originally developed to analyze inter-industry production in a dynamic economic environment such as large construction projects where the effects on production and employment are transitory. Gordon *et al.* (1998) also applied Southern California Planning Model, the IO based model to estimate business interruption costs of the 1994 Northridge earthquake, and found that business interruption accounted for 25-30% of the full costs of the earthquake.

Using multi regional input output (MRIO) model, in den Baumen *et al.* (2015) estimated the total indirect loss of production possibilities in national and global economy due to the 2013 flood in Germany. Direct losses of production are reduced by €3.1 billion in Bayern of Germany, other regions in Germany were investigated in the model. Economies outside Germany lost €33.8 million of their production possibilities due to reduced export of German commodities. Most severely indirectly affected by losses in production are the real estate service sector, transport equipment production, and other business services in Bayern. When it comes to reducing damages and disruption from disasters, secondary effects of disaster are taken into account and supply chain restrictions from other partner economies are involved with recovery of production possibilities in the risk management.

A transportation network was integrated with the IO model such as Cho *et al.* (2001) and Sohn *et al.* (2003) to analyze the economic impact of the earthquake on transportation network for the Midwest states. The modeling system of Sohn *et al.* (2003) included a transportation network loss function, a final demand loss function, and an integrated commodity flow model. The paper showed that the economic significance was not always determined by not only the level of disruption but also the volume of flow on the link, relative location (topology) on the highway network, and the strength of the economic activities near the network link. Cho *et al.* (2001) developed an integrated and operational model of losses due to the earthquake impacts on transportation and industrial capacity, and showed how these losses affected the metropolitan economy. The model could trace the effects of an earthquake on the Los Angeles economy, including its impact on the transportation services delivered by the highway network. It also incorporated bridge and other structure performance models, transportation network models, spatial allocation models, and the IO models into a composited operational system. They found that the spatial distribution of these losses were sensitive to changes in network costs by transportation structure losses. Kim *et al.* (2002) estimated earthquake impacts on transportation cost using input-output analysis integrated with transportation demand model based on the U.S. interstate highway system. The regional impacts of transportation disruptions caused by the earthquake was calculated in three scenarios, one of three evaluated the reduction of overall shipment cost 186 billion ton mile/year and average 10.82 miles. The results provide a basis fro making policy decisions to mitigate unexpected disasters and for planning to construct new highway network sections to strengthen the existing network. Koks and Thissen (2016) considered production technologies and constraints of supply side of transportation demand in the integrated recursive dynamic multiregional supply−use model and investigated economic impacts caused by three floods of Rotterdam in Netherlands. Although abundant studies have developed models to estimate the economic impacts from disasters, they asserted that more research focuses on assessing the indirect losses outside the affected region in more detail as well. Baghersad and Zobel (2015) provided a new linear programming model, based on Leontief' s input−output model, to investigate the economic consequences of production capacity bottlenecks caused by disasters. An important contribution of the paper is the incorporation of industry sectors' preferences in allocating limited products/services between final domestic demand, foreign final demand, and intermediate industries. This provides support for estimating some of the indirect economic impacts of disasters when the electricity sector of Singapore is disrupted. An extension of the model is provided recovery operations within disrupted sectors, from the standpoint of evaluating the performance of the economy during the transition period after a disaster. The results of 12 different scenarios showed that the total average inoperability and total inoperability of the entire economy decrease with decreasing initial loss and increasing recovery within the electricity sector. This implies that improving the robustness of the electricity sector can have a stronger impact on the total average inoperability of the economy than decreasing the recovery time.

The CGE is another popular analytic framework measuring economic impact of disasters and well-documented approach include supply side effects and price flexibility due to the non-linearity. Bosello *et al.* (2007) used the CGE model to measure the amount of land and capital loss due to sea level rise in the coastal regions. The GDP and the energy consumption would fall down without the coastal protection, but could increase in the regions with substantial dike building in spite of a reduction in the utility level with the coastal protection. Tatano (2008) presented an analytical framework to estimate the economic losses incurred due to transportation network disruption after a catastrophic earthquake. The Spatial CGE model was designed to capture properties involving time and integration with the transportation network, and was applied to estimate the transport-related loss arising from the Niigata-Chuetsu earthquake. The simulation found that a spillover pattern of economic losses arising from the earthquake over regions with respect to the intra- and interregional trade. This paper discussed that countermeasures were needed to reduce negative spillovers to the unaffected regions as well as the adoption of mitigation policies for the reduction of damage to houses and facilities. Rose *et al.* (2005) analyzed the economic impact of a disruption of water services in the Portland Metro economy. It showed how indirect economic losses depended on water shortages, the extent of pre-event mitigation, and post event inherent and adaptive resilience.

Recently, it is proposed incorporated micro models with Input output or CGE model to get detailed estimates of economy-wide disaster losses. Husby and Koks (2017) suggested estimating the impact of disasters specified on household migration, which can be a transmission way of disasters to other regions and industries through combining Input output model or CGE model with ABMs. A main advantage of these models is their capability to capture the ripple effects, whereby the impacts of a disaster are transmitted to regions and sectors that are not directly affected by the event. They emphasized that the literature of disaster impact analysis contains no examples of studies attempting to hard link IO or CGEs with ABMs. An example of a soft-linked model CGE-ABM was Husby (2016) who applied an ABM of opinion dynamics to analyze the impact of public concern of disaster losses predicted by a spatial CGE model. Increasing public concern reduces the utility flow from amenities in the disaster struck region, making this region less attractive as a place of residence.

In addition to the most commonly used IO and CGE models, the economic effects of disasters were analyzed by means of econometric models, cost analysis, and synthesis control method. As it is discussed in Richard *et al.* (1984), Hong *et al.* (1996), and Strobl (2012), econometric models were utilized for investigating economic losses combined with several specified models such as transportation model, supply side model, and longitudinal model. Richard *et al.* (1984) developed a regional econometric model that was mainly focused on supply−side factors such as capital investment, migration, and transportation in the model structure. It identified how regions received different economic impacts from the natural disasters in terms of the degree of spatial disaggregation. They argued that the reconstruction was a key factor on the long−run growth and recovery path of regions in a sense that the income gains from the post−disaster period could offset income losses.

In the aftermath of the disaster, post−natural disaster in the long−run might benefit from a process of "creative destruction" (Skidmore and Toya, 2002; Cuaresma *et al.*, 2008). It is argued that interactions with income variables indicate that the level of development of the country has an effect on the elasticity of R&D

spillovers to catastrophic risk, with richer countries eventually experiencing creative destruction after a disaster (Coe and Helpman, 1995; Coe *et al.*, 1997; Cuaresma, 2008). Hong *et al.* (1996) calculated monetary losses due to the natural disaster of the nuclear power plant, although it was less relevant to the economic impact analysis. They estimated economic cost incurred by accidents in the nuclear power plants, while the overall costs were disaggregated into replacement power cost, capital investment cost, plant repair cost, early decommissioning cost, health cost, evacuation cost, relocation cost, agricultural product disposal cost, and decontamination cost. Strobl (2012) investigated the macroeconomic impact of hurricanes in developing regions, which are Central American and Caribbean areas. The average hurricane strike caused the growth rate in GDP to fall by at least 0.83 percentage points in the region using wind field model and econometric panel model.

Analysis of post- disaster effects on the regional economy has been widely conducted through econometric models. Belasen and Dai (2014) investigated the impact of hurricanes in Florida on county level taxable sales revenues using the econometric model. Within six months after a hurricane strikes a county, revenues declined as much as 17%, whereas revenues in neighboring counties increased by upward of 17% over that same time frame. Particular focus is given to tourism-related sectors within the regional economy.

Lastly, they showed that along the pathways of hurricanes, initially hit counties face a more severe burden, ranging as high as a 33% immediate decline in taxable revenues in one month for coastal counties. Agnolucci *et al.* (2017) estimated the causal impact of GDP on domestic material consumption (DMC) applying the number of storm occurrences as an instrument for GDP. Some material prices affected in the short term but this effect disappears two years after a storm occurs. The outcome addressed new evidence that increasing the GDP growth rate causes an increase in the DMC growth rate for Western Europe based on a panel dataset of 32 European countries from 2000 to 2014. Lis and Nickel (2010) assessed the impact of large scale extreme weather events on changes in public budgets and their implications based on a panel data set for 138 countries and from 1985 until 2007. Extreme weather events comprise the following disasters: drought, extreme temperature, flood, mass movement dry, mass movement wet, storm, wildfire. Budgetary impact of disasters ranges between 0.23% and 1.4% of GDP depending on country group using the econometric model. The fiscal policy can be a crucial instrument on reducing disaster damage and its recovery but none of these studies examined the impact of change on public finances before this paper.

There are utilized synthetic control method for capturing long term economic impact by post disasters including hurricanes and earthquakes. Coffman (2012) measured the long-term economic impact by the Hurricane Iniki 1992 for Kauai' s economy. The damage was estimated US$ 7.4 billion for 2008 but has yet to recover, 18 years after the disaster. Barone and Mocetti (2014) examined the impact of two large-scale earthquakes that occurred in two different Italian regions in 1976 and 1980 through the synthetic control approach. The short-term effects were negligible in both regions, though they became negative if we simulate the GDP that would have been observed in absence of financial aid.

In the long-term, the findings indicated a positive effect in one case and a negative effect in the other, largely reflecting divergent patterns of the TFP. DuPont and Noy(2015) also used synthetic control method to reinvestigate 1995 Earthquake in Japan even 13 years after the quake. A decline in per capita GDP for 2008 was yen 400,000 per person lower (12% decrease) than it would have been had the earthquake not occurred. Importantly, the adverse long term impact is identified in a rich region of a high income country and with the backing of a deep-pocketed fiscal authority.

With changes in GDP caused by disasters, Padli *et al.* (2010) employed cross−sectional analysis to investigate a relationship between economic condition and the economic impact of natural disasters. The major independent variables were GDP per capita, the government consumption ratio to GDP, the years of schooling attainment, the land area and the population size. Cerqua and Pietro (2017) investigated effects of 2009 L'Auila earthquake on educational outcomes in developed countries using the synthetic control method. This event killed 309 people, injured more than 1,500 individuals, and caused widespread damage and destruction. The potential decline in the university enrolment following the disaster could have considerable detrimental economic effects given the important role of students in providing jobs, rental income and demand for local goods and services. With this in mind, the analysis showed that the subsequent enrolment at the local university in Germany had no statistically significant effect on first−year in the three academic years after the disaster. The natural disaster, however, caused a compositional change in the first−year student population, with a substantial change in the number of students aged 21 or above.

The man−made disaster research is relatively inferior to the natural disaster and has focused on the effects of stock market, taxable sales in regional economy due to terrors and riots. Brounrn and Derwall (2010) estimated the price effects of the 9/11 terror on international stock markets, using a multivariate dummy regression model. Compare to the price impact of a different set of unexpected natural disasters, it is found that the effect of terrors have greater economic and statistical importance than one of natural disasters. The immediate price reaction to the major terror attacks that have occurred since 1990 averages −0.34%, which translates into a negative annual price impact of over 134%. However, these findings are severely weakened when the 9/11 attacks are excluded from the sample. Baade *et al.* (2007) examined taxable sales in the Los Angeles and Miami metropolitan areas to find evidence of the short− and long−run effects of the Rodney King riots 1992 and Hurricane Andrew 1992 on their respective economies using the intervention analysis. The comparison of these two events shows that the man−made disaster, King riots, had a long−term negative effect on Los Angeles' economy while the natural disaster, Hurricane Andrew, had a short−term positive effect on the Miami economy.

Table 3. Impact Analysis of Disasters

Author	Type of Disasters	Model	Impacts / Key Issues
Richard *et al.* (1984)	Earthquake	Econometric model	Long run and short run impacts
Hong *et al.* (1996)	Nuclear plant disruption	Cost analysis	Cost analysis
Rose *et al.* (1997)	Earthquake	Input Output model and Linear programming	Reduction in GRP (7%)
Gorden *et al.* (1998)	Earthquake	Input Output model	Cost of business interruption
Cho *et al.* (2001)	Earthquake	Input Output model	Integration of network model, spatial allocation model and IO model
Kim *et al.* (2002)	Earthquake	Input Output model	IO model combined transportation model
Sohn *et al.* (2003)	Earthquake	Input Output model	Network effects on transportation
Okuyama (2004)	Earthquake	Sequential inter-industry model	Impacts on inter-regional and inter-industrial sectors
Rose *et al.* (2005)	Disruption in water service	CGE model	Impacts of water service disruptions
Baade *et al.* (2007)	Hybrid disaster	Intervention analysis on ARIMA model	Taxable sales dropped 1.29%p in the city during the Rodney king riots
Bosello *et al.* (2007)	Sea level rise	CGE model	Impacts on GDP and energy consumptions
Tatano (2008)	Earthquake	Spatial CGE model	Direct and indirect spillover effect on regional economies
Ryu and Cho (2010)	Typhoon and heavy Rain	Input Output model	Reduction in GDP (1.18%)
Padli *et al.* (2010)	Natural disaster	Econometric model	Linkage between economic condition and impacts
Brounrn and Derwall (2010)	Terrorist attack	Econometric model	Negative price effects on financial markets (−0.34%)

Table 3. (Continued)

Author	Type of Disasters	Model	Impacts / Key Issues
Brounrn and Derwall (2010)	Terrorist attack	Econometric model	Negative price effects on financial markets (−0.34%)
Strobl (2012)	Hurricane	Econometric model	Average hurricane strike caused output to fall by at least 0.83 %p in the developing region
Barone and Mocetti (2014)	Earthquake	Synthesis Control method	Financial aid might either increase technical efficiency
Belasen and Dai (2014)	Hurricanes	Econometric model	Reduction of taxable sales revenues 17%
Baade *et al.* (2007)	The Rodney King riots and Hurricane Andrew	Intervention analysis	The King riots had a long−term negative effect on LA' economy while Hurricane Andrew had a short−term positive effect on the Miami economy.
Lis and Nickel (2010)	Extreme weather events	Econometric Analysis	Impact of climate change on public finances 0.23%~1.4% of GDP
In den Baumen *et al.* (2015)	Flood	MRIO model	Indirect loss of production €6.2 billion
Baghersad and Zobel (2015)	Disasters	New linear programming model with IO system	Indirect economic impacts of disasters
Koks and Thissen (2016)	Floods	IO model	Supply driven regional IO model with transport disruption
Klomp (2016)	1,000 natural disasters	Econometric model	The amount of damage caused by a single meteorological or geophysical event is on average about 2.5 times larger than for a flood or major drought

Table 3. (Continued)

Author	Type of Disasters	Model	Impacts / Key Issues
Cerqua and Pietro (2017)	Earthquake	Synthetic control method	Increase of number of students aged 21 or above after the disaster
Agnolucci *et al.* (2017)	Storm	Econometric Analysis	Increases of domestic material consumption
Husby and Koks (2017)	Disasters	IO, CGE model with ABMs	Suggesting combining micro model with IO or CGE model

* This table is revised from Kim and Kwon(2016) in the book chapter of 『Quantitative Regional economic and Environmental Analysis for Sustainability in Korea』.

The disaster causes an instantaneous destruction of capital stock in the neoclassical growth system. The reduction of production factors such as capital, labor, and land due to disasters can cause economic damage and reduce economic growth in developing analytic frameworks. Post-disaster economy converges towards its long-run, steady-state equilibrium through faster capital accumulation. Therefore, it can be found that decrease of the GDP in the short run while no effects in the long run. However, this is clearly an oversimplification since it does not capture other channels through which the disaster might impact on the production function, on the inputs and on their use. In more detail, more traditional neo-classical growth models, like the Solow model, predict that the reduction of the capital-labor ratio drives countries temporarily away from their long run growth path, while the endogenous growth models provide less clear-cut predictions. For example, models based on Schumpeter's creative destruction theory may even predict higher growth rates as a result of natural disasters since these shocks can work as an accelerator for upgrading the destroyed capital stock (Klomp and Valckx, 2014; Loayza *et al.*, 2012; Cavallo *et al.*, 2013).

On the other hand, West and Lenze (1994), Klomp (2016) have pointed out, there are several difficulties in assessing the economic impact of the natural disasters because the majority of all disasters happen in different spatial units, where macroeconomic research is hampered due to the unreliable economic data. First of all, the event size is uncertain and unknown, and is not classified into industrial sectors as proposed in the IO and CGE models. These might cause a double-counting problem to measure benefits and costs of the disasters. Klomp (2016) exemplified that based on the estimates of EM-DAT (2013) the amount of damage caused by a single meteorological or geophysical event is on average about 2.5 times larger than for a flood or major drought. It would be difficult to regard the disasters as exclusive supply or demand events, and to expect the exact behavioral patterns of households and firms after the outbreak of disasters. The final outcomes of the analysis tend to be very sensitive to initial conditions and assumption underlined in the model and research design.

This study focused on the trend that the risk of large scale wildfires, damaged areas are above 100 ha in Korea, has increased sharply since 2000 (Lee and Lee, 2011). Looking at the 33 large-scale wildfires since 2000, Gangwon province has 17 wildfires occurred according to the Chosun Newspaper in Korea[3]. More than 50% of the large wildfires in Korea have been concentrated in Gangwon province, where depends heavily on the tourism industry in the regional economy, therefore it was decided to be the study area in this research for analyzing economic impacts of the wildfire.

There are previous papers on impact analysis of wildfires and mostly focused on estimating direct economic effects of wildfire losses. Cost approach of suppression has been a primary method for the economic analysis of the wildfire (Rahn, 2009). Mercer *et al.* (2000) examined an economic impact of catastrophic wildfires and efficacy of fuel reduction in Florida with spatial and econometric models. The loss by the 1998 Florida wildfires was estimated as 622-880 million US$ including costs of timberland owners (345-605 million US$), the tourism industry (138 million US$), and the resources diverted to fighting the fires (100 million US$). Kunji *et al.* (2002) reviewed the effect of the wildfire on air quality and health

[3]http://news.chosun.com/site/data/html_dir/2017/05/19/2017051901911.html

in Indonesia. More than 90% of respondent had respiratory symptoms, and elderly individuals suffered a serious deterioration of overall health. Between September 1997 and November 1997 in Indonesia, there were 527 hazed-related deaths, 0.30 million cases of asthma, 58,095 cases of bronchitis, and 1.45 million cases of acute respiratory infection reported.

Multivariate analysis showed that severity of respiratory problems relied on gender, history of asthma, and frequency of wearing a mask. The wildfire and the trans-boundary haze resulting from the fires affected several neighboring countries for a period of about four months, having a significant impact on health, daily life, transportation and air traffic (Kreimer, 2001). Rahn (2009) estimated the overall economic impact of wildfires on regional economies in San Diego. The total economic impact of the 2003 wildfire in San Diego County was approximately 2.45 billion US$ or $6,500 per acre. The total suppression cost was less than 2% of the entire economic impact, which was a relatively negligible cost in contrast to the overall loss.

In recent years, there have been an increasing number of cases in economic effects analysis of wildfires for specific fields in the economy: studies on the effects of wildfire on housing price, labor market, medical cost, and climate changes. Most frequently used method are econometric model or input output model in the study following the cost analysis. However, the analysis on indirect effects of tourism industry caused by wildfires are still insufficient and have focused on direct effects, that is, calculating wildfire damages only.

Moseley *et al.* (2012) analyzed the effects of large wildfires in California during 2004−2008 on labor markets and how wildfire suppression spending may mediate these effects. Local employment and wages in a county increased during the wildfire; the economic impact of the suppression effort outweighed the economic disruption from wildfires in the short term. The wildfires caused a longer−term instability in local labor markets by amplifying seasonal variation in the employment in tourism and natural resource sectors. Kiel and Matheson (2015) analyzed housing price effect of canyon forest fire in Colorado 2010 captured by home owner' s perceptions about the risk of living in forested area subject to wildfires. The sale price of housing expected to be declined 21.9% caused by wildfire through the difference−in−difference approach. Kochi *et al.* (2016) investigated economic cost of wildfire smoke exposure as counting medical cost in hospital admissions at the period of 2007 through time−series count model and negative binomial model. The total medical cost were estimated over 3.4 million US$ associated wildfires in Southern California.

In the context of global climate change, Melvin *et al.* (2017) focused potential economic implications from changes of wildfire by climate, which is the burned area and its respond cost along to the RCP8.5 and RCP4.5 scenario using Alaskan Frame-based Ecosystem Code (ALFRESCO) model. Estimated cumulative response costs were of 1.2-2.1 billion US$ with averaged burned 46.7 million ha for RCP8.45 and 1.1-2.0 billion US$ with 42.1 million ha for RCP4.5 between 2006and 2100 across Alaska.

The analysis of the economic effects of wildfires in Korea is considerably insufficient in comparison with the large scale damage of wildfires. With regard to the methodology of wildfire effects analysis, there were recently used input-output model, cost analysis, and contingent valuation method (CVM) similar to that of overseas studies. Lee *et al.* (2017) analyzed the local economic effects of wildfire restoration grants from the government. In detail, it was analyzed a ripple effect of government aid for 2000 the east coast wildfire restoration through the input-output analysis. Direct production inducement effect was higher than indirect production inducement effect except for construction sector. In addition, The economic effects of production, employment, and income in three damaged regions affected by forest fires were compared and its efficiency of government aid. Woo *et al.* (2001) estimate overall timber losses of the east coast wildfire 2000 in Gangwon province in Korea using cost analysis. Not including economic impact of the wildfire, total timber losses were calculated 96.5 million US$ and among them pine trees were recognized the most vulnerable type as occupied 69% of total estimated amount.

Exceptionally, it has been studied in terms of loss of value of forests caused by wildfires. Ko *et al.* (2016) estimated the value of one mountain using CVM method consuming the forest will be disappeared by wildfires. They asserted the importance of Seowoo-bong in Jeju island as natural resources for utilizing recreational, historical, iconological, and scenic value in regional economy.

Table 4. Impact Analysis of Wildfires

Author	Country / Region	Method	Impacts
Malanson and Westman (1991)	USA / California	Computer simulation model	Interactive effects of CO2-induced climate on a drought-deciduous shrub land in California
Mercer *et al.* (2000)	USA / Florida	Spatial and Econometric Analysis	Economic losses of 1864$ per acre by 1998 Florida Wildfires
Kunji *et al.* (2002)	Indonesia	Econometric Analysis	Change in mortality by 1997 Indonesian wildfire smoke
Fried *et al.* (2004)	USA / California	Cost analysis	Increased burned area by climate changes
Rahn (2009)	USA / California	Cost analysis	Cost of 2.45 billion US$ by 2003 wildfires in San Diego County
Moseley *et al.* (2012)	USA/ California	Econometric Analysis	Increases in local employment and wages during large wildfires of 2008 California.
Duffield *et al.* (2013)	USA / Yellowstone National Park	Input Output Analysis	Losses for recreational use at US$108.29 per ha and regional economic impacts at 159 million US$ in Great Yellowstone Area for the 1986-2011
Kiel and Matheson (2015)	USA / Colorado	Econometric Analysis	Housing sale prices declined 21.9% wildfire in Colorado, 2010
Kochi *et al.* (2016)	USA / California	Econometric Analysis	Medical costs caused by wildfire smoke exposure were over 3.4 million US$ from the wildfires in Southern California 2007
Melvin *et al.* (2017)	USA/ Alaska	Cost analysis	Burned cost 1.2-2.1 billion US$ for RCP8.5 and 1.1-2.0 billion US$ for RCP4.5

Upon the analytic database used, previous papers on wildfires have focused on the changes of forests appearance due to wildfires and its damage scale analysis on the forest trees and crops. However, the application of the spatial micro data which has a great influence on the occurrence and spread of wildfires was insufficient. The spatial micro data have the advantage of accurately analyzing the probability of occurrence of wildfires and the spatial diffusion area. Diffusion and damage areas of wildfires vary depending on the conditions of environmental factors, including the characteristics of local wildfires, are important guidelines for disaster prevention and suppression. The research based on spatial microdata can provide information to help prevent wildfires from spreading early and contribute to reducing damage from wildfires.

On the other hand, previous studies on the calculation of wildfire damage tend to focus mainly on forest timber loss, partly included wildfire suppression budgets and recovery costs. In addition to the primary forest products loss, which has concentrated on previous research, it is necessary to consider secondary damages to the regional economy, such as the suspension of industrial production activities such as agriculture, forestry and tourism service, the reduction of visitor demand, congestion of transport traffic from the road control. Furthermore, indirect damages caused by large-scale wildfires can have a negative impact on the related industries, leading to long-term economic recession in the developing region, which could be beyond direct cost of forest damages. It is required to use spatial micro data for examining regional economic impacts of wildfires for the accuracy, because indirect damage analysis can be sensitive to the damaged area of wildfires. Assessment of the economic effects of developing areas based on the calculation of the damaged area of wildfires can be used to increase the economic understanding of the wildfire disaster prevention and to estimate the investment amount of the government budget.

2.3. Economic Impact of Disasters on Tourism Industry

Disasters resulting from natural and human-made hazards are frequent occurrences throughout the world (International Federation of Red Cross and Red Crescent Societies, 2006). Tourism destinations located in high-risk disaster regions face greater challenges in developing a tourism economy (Tsai *et al.*, 2016). Prideaux (2003) recognized the next three types of disaster focused on tourism activities: (1) several types of disasters (e.g. earthquakes, typhoons, floods, droughts, and wildfires); (2) sudden climate change in a long term perspective; and (3) global epidemics caused by a new types of influenza or undiscovered diseases, for such events give rise to the most frequent and serious losses at tourism industry.

The unexpected damages in previous papers resulting from tsunamis, floods, typhoons, earthquakes, often disrupt tourism businesses in destination economies. In comparison with most other industries, tourism is highly reliant on the natural environment and weather conditions (Bode *et al.*, 2003). The impacts of tourism industry caused by disasters may have both positive and negative consequences (Ap and Crompton, 1998; Mathieson and Wall, 1982).

With regard to the analytic method, Econometric model, IO model, and CGE model mainly have applied to investigate the economic effects of disasters on tourism behavior, tourism industry, and regional economy.

Disasters have tremendous impacts on tourism industry, as discovered by hurricane Katrina in 2005, the South-Asia tsunami in 2004 and severe acute respiratory syndrome (SARS) in 2003 (Tsai *et al.* 2016). The analysis of hurricane impacts on tourism investigated in Woosnam and Kim (2014), Belasen and Dai (2004), Kim and Marcouiller (2015) that showed tourism visitor volumes, revenue decline, tourism-based economy within the context of social vulnerability and resiliency. To be specific, Woosnam and Kim (2014) considered impacts of hurricanes in the southeastern United States containing coastal national parks based on two longitudinal data methods such as panel logit and autoregressive integrated moving average model. This paper focused on the relationship between the duration, intensity, and damage of hurricanes; existing climate conditions; and tourism demand on park visitation during hurricane and tourism seasons. With regard to the response of tourism economies to disaster damages, the park that encountered stronger catastrophes can be closed for a longer period in order to reconstruct facilities or natural/cultural resources damaged by storms.

Another hurricane damages, Belasen and Dai (2004) examined the impact of hurricanes in Florida on taxable sales revenues using an econometric model. Revenues declined by 17% for six months after a strike of the hurricane and tourism sector in Florida is the largest source of revenue. However, it was not possible to analyze the impact on the tourism sector due to data limitations. Kim and Marcouiller (2015) developed a conceptual model of disaster loss factors to estimate the vulnerability and resiliency of 10 tourism based regional economies including US national parks or seashores affected by several hurricanes over 26-year period through a negative binomial panel regression and a difference-in-difference model. Both direct and indirect economic effects investigated to regional economy affected by disasters in tourism-based economy and disaster-prone areas.

The storm triggered a major flood in Charente-Maritime, which had a number of impacts: oyster farms (a major employer in the area) were destroyed, the tourism sector suffered, and productivity of agricultural land (including wine production) was affected by salty sea water (Lumbroso and Vinet 2011; Genovese and Przyluski 2013). Yeoman *et al.* (2007) considered the impact of oil and energy price rises on Scottish tourism industry using CGE model, as transport and oil have been recognized the most influential factor of tourism growth. Therefore, there are selected key variables such as oil forecasts, security of supply, cost of production, world demand, alternative forms of energy including renewables and nuclear power. The triggers can be considered as unexpected disasters, political instability, and economic shocks for oil price fluctuations. As oil price rises, international expenditure drops by 37% and 27% in two different scenarios, which are energy inflation, paying for climate change respectively because the tourist can be burdened transportation cost for long distance travel by airplane. In terms of inflation caused by increasing oil prices, consumer price index (CPI) affected to the threat of stag-inflation which leads to a reduction in disposable income and discretionary spending because of slow value added growth and rising inflation.

There was no significant impact on tourism industry in the short term, but long term impact of rising oil prices came on Scottish tourism. Guo *et al.* (2017) focused on economic impacts of visitor spending for coastal economy, where is highly sensitive to natural and human disasters and changes in economic conditions. Using IMPLAN input-output model, Survey Sampling International (SSI) presented approximately 16.4% million travelers visited Alabama and Mississippi Gulf Coast in 2013 and the average per visitor spending was $730.11. In total , sales revenue $17.6 billion was estimated and it can be transferred value added $7.4 billion, labor income $5.9 billion, and 200,000 full and part−time job in the five coastal counties.

The wildfire is one of the most risky threats we need to be concerned about industrial production losses, travel demand declines, and places images of tourist destination and resources. According to the 2017 wildfire damage of Montana tourism industry, its direct impacts was estimated on the Montana's visitor economy during the wildfire season using the cost analysis. The entire state lost up to 800,000 visitors due to last summer's fires and smoke, resulting in a loss of US$240.5 million in visitor spending and translating to a 6.8 percent loss in expected annual spending from the Institute for Tourism and Recreation Research (Sage and Nickerson, 2017). Pyke *et al.* (2016) focused on the direct impact of 2013 bushfire in North East Victoria, Australia due to the fire and post−fire flooding. During the burnt for 55 days in early 2013, visitor spending losses were approximately $1.5 million based on the visitor survey with personal average expenditure of $184 per day. To minimize the economic effects of fire events, they asserted that the tourism planning and improved stakeholder communications are necessary to be emerged as key priorities and revealed adaptations through the destination sustainability framework (DSF) in the paper.

There are still recognized as shortage of research investigating impact analysis on tourism industries after disasters including wildfires. In addition to disasters on tourism destinations, increasing losses of tangible and intangible cultural heritage as tourism resources during these disasters need to pay attention to the protection policy (Marrion, 2016). More attention can be given to indirect effect of disasters on the region and its neighboring regions regarding to sectoral linkages to minimize overall effects by disasters and to prepare recovery management.

2.4. Implication of Literature Review

The literature review is summarized in the following three sections. Firstly, the frequency of disasters increases with the climate change, and the scale of damage is also growing. In previous papers, there are discussed with major disasters such as a hurricane, storm, earthquake, flood in the natural disaster and also a terror, wildfire, nuclear plant disruption in the human-made disaster. The analytic method of economic indirect impact analysis are repeatedly used Input-output model, CGE model. Direct losses of disasters have been mainly investigated through the econometric model and Cost analysis. In analysis of economic effects on disasters, double counting problems arise due to the uncertainty and unknown characteristics of disasters. Additionally, the magnitude of disaster damages is likely to be increased by an average of 2.5 times depending on climate conditions and terrain features. The final output of disaster impacts are sensitively changed depending on the initial damage conditions. The idea suggested by Husby and Koks (2017) need to be advanced to improve disaster damages as combining with micro models based on CGE model considering both side of demand and supply changes.

Secondly, the economic effects of wildfires were mainly conducted in the United States, where wildfires are large and frequent. Input output model, Econometric model, Cost analysis are mainly utilized in the analysis of regional economic effects. Mostly, direct damages to timber losses were mainly estimated, however, analysis of indirect economic effects were insufficient. In addition, analysis of regional economic effects on the damage of wildfires caused by climate change was limited.

Third, impacts of disasters on tourism have largely been examined with emphasis on economic damages and recovery policies. However, there are shortage of impact analysis caused by wildfires on tourism industry and tourism destinations. Similar to the disaster impacts on the general economy, analysis of wildfire impacts on tourism have applied by the cost analysis, econometric model, input output model, and CGE model. With regard to the wildfire on tourism industry, it is necessary to capture indirect impacts on regional or sectoral spillover from the unexpected events. The overall losses of wildfires need to be analyzed from the long term perspective. At the same time, secondary wildfire damages such as flooding and its smoke can be significant on property loss and human health not only for neighboring areas but also for linked industries including service sectors.

Chapter 3. Methodology

This chapter introduces the outline of the whole methodology and explains the CGE model structure, wildfire damage area model, transportation demand model, and tourism expenditure model as the micro modules.

3.1. Overview of Analytic Framework

The main objective of this study is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry of Korea. Figure 2 presents the structure of this dissertation with specification of analysis methodology corresponding to the main object. Among various disasters in Korea, this dissertation focuses on the wildfire as increasing risk of forest resources and its growing burnt areas in Korea after 2000. Mountainous areas with natural or cultural heritages have been widely used as the tourist attractions, particularly, climbing or hiking mountain is the most popular activity in outdoor recreations in Korea.

The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage area model, transportation demand model, and tourism expenditure model. The

IRCGE model is described two macro regional economy under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model predicts wildfire losses with high uncertainty and complexity based on database of temperature, wind speed, and humidity from the Ministration of Korea Meteorology. And wildfire statistics of forest type and slope features by spatial unit are from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The dependent variable is explained by personal income, previous year's daily travel costs, number of establishments in a destination, population of origin places, number of culture legacy, and road accessibility. The estimated burnt area in the wildfire damage area model affects to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

To estimate the indirect economic impact of wildfires on the regional economy and sectoral effects, the analytic framework is applied after connecting stylized IRCGE model with three sub-modules. The three modules are consisted of as follows in detail.

First, the wildfire burnt area is calculated in the wildfire damage area model by converting into land assets and timber assets based on statistics in Bank of Korea on the base year of 2013. The amount of wildfire damages is directly linked to reduce the capital stock in production factor inputs and final demand losses of timber for landscape gardening in IRCGE model. It resulted in losses of the gross regional production (GRP). Second, this dissertation assumed that certain radius of wildfires restricts passage of people and vehicles across the roads. Accordingly, they need to detour to other roads while paying additional transportation costs. These changes in transportation accessibility increase the production cost to be included in the production function. Finally, the rising transportation costs in personal travel budget can affect to decrease tourist numbers, as tourists choose alternative destinations considering the risk aversion behavior of tourists instead of the prescheduled destination.

The losses of capital stock in the production, final demand, and tourism destination revenues will be the inputs as the shock variables into the IRCGE model. The damages generated in the region spread positive or negative effects on other regions beyond the border through the economic linkages in the production, consumption, and price mechanism. This analysis process explores regional economic impacts on Gangwon and the rest of Korea (ROK) caused by wildfire of the Gangwon province. The impacts will be included production, income, consumption, and value added changes of industrial sectors of the two regions of Korea through the IRCGE framework.

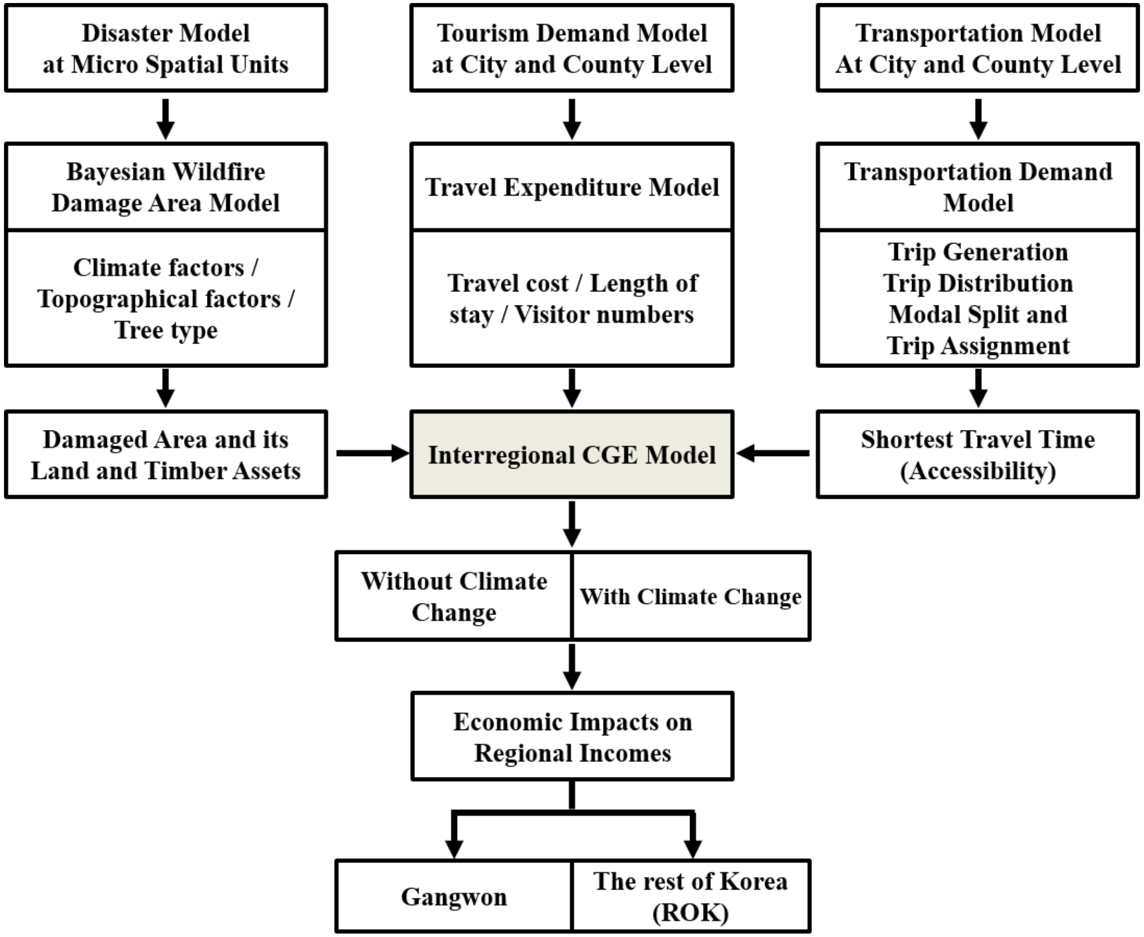

Figure 2. Structure of IRCGE Model for Economic Analysis of Wildfires

3.2 Computable General Equilibrium (CGE) Model

The Computable General Equilibrium (CGE) model indicates an economic system that describes the process of balancing the equilibrium state between demand and supply by flexible price adjustments. The economic agents in the model consist of the household, producers, and government. It is assumed that markets of production factors and commodities are perfectly competitive and all the agents are price takers.

Specifically, the commodities are produced by the producers with the factor input to maximize its profit, which are assumed subject to its production technology constraint under given output and input prices. The factor income is created by the producers and paid back to the provider of the factors such as the household. The household spends received factor income to purchase the commodities. In the commodity market, the produced commodity is consumed by the household for maximizing its utility subject to the household budget constraint. Their optimization problems are only dependent on the relative prices of given commodity and factors. Market demand and supply of any commodity are continuous, non-negative, and homogeneous of degree zero. The market-clearing condition for commodities ensures equality of its demand and supply quantities and that of factors indicating that the total demand for each factor must be equal to its given endowments. Solving the system of simultaneous equations of the household, producers, and market clearing conditions, the price of one commodity or one factor need to be fixed as a numeraire. Then, all other prices are expressed as relative prices in CGE model excepting the fixed one numeraire.

The theoretical basis of CGE modelling is Walras' Law. As early as in 1874, Walras (1954) showed that equilibrium conditions in different markets in an economy are not independent and general equilibrium is available at any set of prices. Arrow and Debreu (1954), Debreu (1954), and Arrow and Hahn (1971) turned Walrasian general equilibrium theory into the Arrow-Debreu framework. The framework forms the foundation for CGE modelling based on following four types of equations as explained. (1) The equations for equilibrium conditions for each market to ensure that supply equals demand for each good and services. (2) The equations for income-expenditure identities to ensure the balance of each account. (3) The equations for behavioral relationships to describe economic agents' reactions to changes in prices and incomes. (4) The equations for production function to determine the output for each sector and how production factors can be allocated.

The predecessor of CGE modelling is Input-Output (IO) analysis. Considering inter-industry linkage, IO analysis is based on Walrasian general equilibrium theory and highly relies on the IO table. The IO analysis was popular in 1950s to 1980s because of its ability to estimate the aggregate as well as sectoral level economic impacts and to trace the linkages between industries. However, shortcomings of IO analysis is widely criticized by CGE modelers (Briassoulis, 1991; Johnson, 1999; Blake, 2000; Dwyer et al., 2004, 2006). There is a strict and unrealistic assumption in IO analysis including assuming fixed IO ratios like as mechanical production, rigid and lacking explanatory power. Thus, a fixed technical coefficient in IO model does not reflect the production technology at certain time. Another assumption of IO analysis is that there are no constraints on the capacity of production activities in an industry to meet additional demands, which is of course unrealistic in any economy. It means that there are not considered of price effect and substitutions between production factors.

The CGE model can remove the limitations of the IO model. The CGE model is more realistic, flexible, and comprehensive general equilibrium model with the advent and development of computer technology. Although the initial CGE model was criticized as unrealistic assuming perfect competition, it developed complexity by developing imperfect competition and dynamic CGE models (Dixon *et al.*, 1982; Harris, 1984; Palstev, 2000).

To begin with three basic elements of CGE model, there are composed of theoretical foundation of CGE model, numerical specification of parameters in the model, and economic effects analysis of executing policy experiment. There are four key features of the CGE model (Kim, 2000). It is a multi-sectoral model that considers the mutual relationship between sectors. Therefore, the model enables examination of the dynamic impact of external shock. Second, it allows simulation studies to be conducted because it includes the concept of optimality, such as maximizing the profit of producers. Third, it is a macro-micro system based on microeconomic and macroeconomic theory. Thus, the result of a shock does not show contradictions. Fourth, quantity and price are determined in the process of eliminating excess demand.

The Inter Regional CGE model used in this dissertation specifies regional production, consumption, saving (investment), government revenue (expenditure), foreign trade, and labor mobility in the regional economy. The model structure follows the neoclassical elasticity approach of Robinson (1989) to simultaneously determine prices and quantities on one hand, and to limit the degree of substitution in sectoral supply and demand on the other hand. Unlike the IO analysis, IRCGE model is considered of all economic agents such as the producer, household and government, each producer and household is assumed to be a price-taker, choosing an optimal set of factor inputs and commodity demands under the maximization principle of constrained profit and private utility, respectively. In the process of IRCGE model, the internalized the commodity quantity, its price and consumption level determined by the households' income. The market clearing price operates to get the profit maximization of firms and utility maximization of households according to the neoclassical economic theory.

The difference of IRCGE model in this dissertation compared to previous one is specialized on micro-simulation modules for estimating wildfire damages and this model can be applied to various unexpected disasters in the future. The model is a linked system of a stylized IRCGE model for regional economic analysis at a region level with three micro modules: a wildfire damage area module, transportation demand module, and tourism demand module at a city and county level or a lower spatial level. In particular, a bottom-up approach is applied to calculation of the value-added at the macro region level which are the sum of those to be specified with econometric production functions at city and county level.

The IRCGE model estimates the indirect economic impacts of the wildfire on outputs of forest and tourism sectors in Korea. The IRCGE model is developed for two macro regions and 12 industrial sectors on a base year of 2013, and is applied to the experimental simulation for the wildfire damages in Gangwon province to measure the loss of regional income. The two regions in the model are Gangwon and the rest of Korea(ROK). 12 Industrial sectors are divided into four forest sectors, five tourism sectors, and the other three sectors in the table 5. To be specific, the forest industry is defined as the sectors that have a high input ratio of timber and forest products based on sales of the Interregional 2013 Input-Out table composed of 82 sectors from the Bank of Korea. In fact, forest sectors are damaged directly from the wildfire. In the model, the forest sectors are as follows: (1) Forest products, (2) Timber and wood products, (3) Pulp and paper product, and (4) Other manufacturing products and processing of timber. The tourism industry consists of five different sectors such as (5) wholesale and retail services, (6) transportation services, (7) food and accommodation services, (8) culture service, (9) sports and entertainment services sector according to the classification of Tourism Satellite Accounts (TSA:RMF, 2008). The rest three sectors are classified into (10) Primary industry, (11) Manufacturing industry, and (12) Service industry.

Table 5. Industrial Classification of 12 Sectors for IRCGE model

Classification	Sub−Sector
Forest sectors	1. Forest Products
	2. Wood and wood products
	3. Pulp and paper products
	4. Other manufacturing products and processing of timber
Tourism sectors	5. Retail and wholesale services
	6. Transportation services
	7. Restaurants and accommodation services
	8. Cultural Services
	9. Sports and entertainment services
General sectors	10. Primary Industry
	11. Manufacturing Industry
	12. Service Industry

The study area of this dissertation is designated as Gangwon province in Korea. Gangwon Province is covered by mountainous areas with more than 80% in total land areas. In addition, the region has the highest risk of wildfires occurrence in more than half of Korea's large wildfires after 2000. Gangwon is an interior position with less accessibility to road transportation network than other regions, an indicating having difficulty to suppress wildfires. Therefore, wildfires of Gangwon easily spread with strong wind, steep slope of mountains, and abundant timber fuel. Figure 3 shows the location of the wildfire in Goseong County, Gangwon Province. The damaged areas of the Goseong wildfire are determined by conditions of climate and terrain, and the area will change according to the climate change scenarios.

The IRCGE model explains demand, supply, and its equilibrium conditions under the macroeconomic closure rule. The supply sector of the IRCGE model consists of production function, labor demand, export and import, and demand sector includes household income, household consumption, and the government accounts. The macroeconomic closure rules were applied by labor fixed or wage fixed in the simulations.

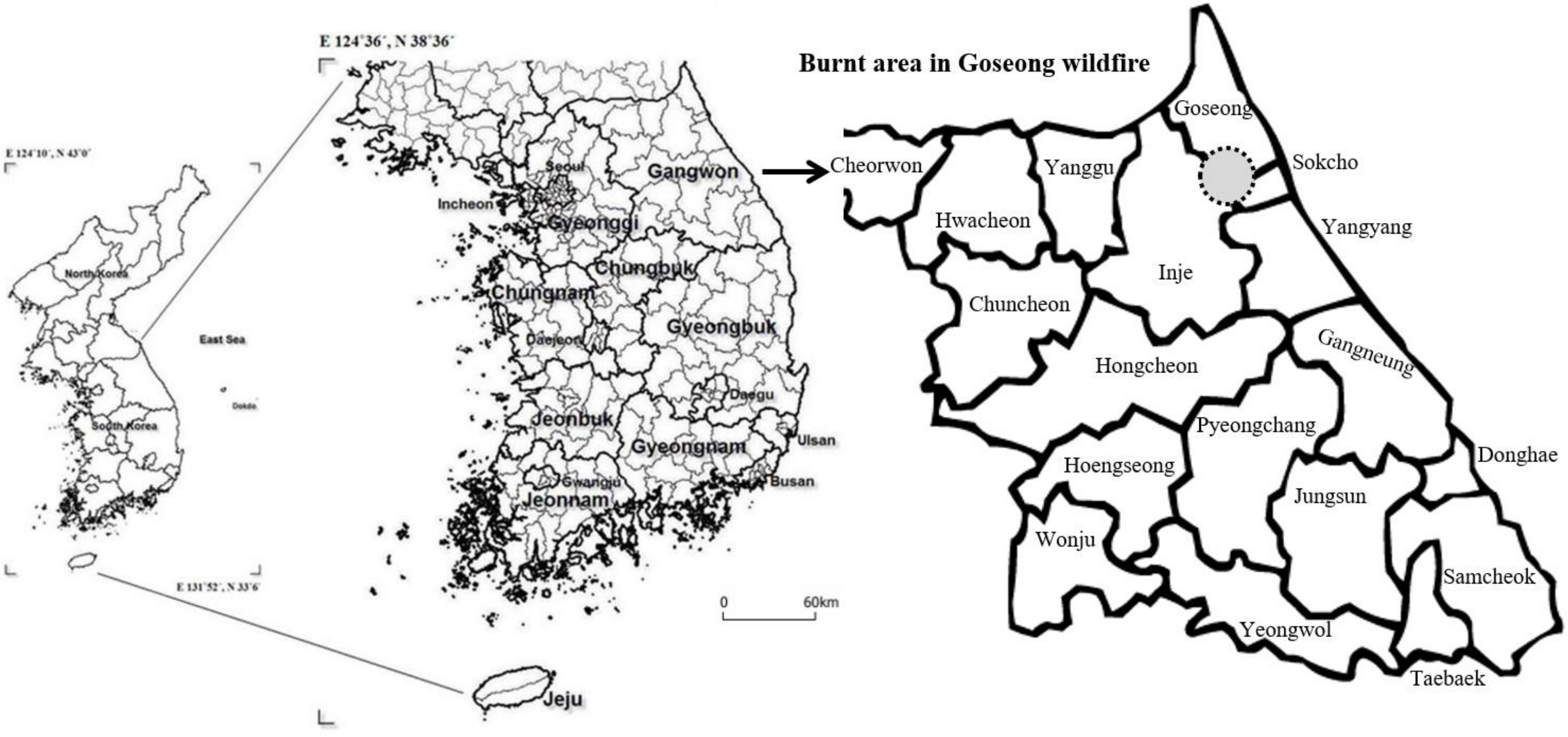

Figure 3. Study area of Gangwon Province and Burnt Area of Goseong Wildfire in Gangwon

The IRCGE model is based on the conceptual framework of the real SAMs, is highly disaggregated with 12 production sectors (goods) and one household group in each region, one representative government, and rest of the world. The two regional commodities are disaggregated into intraregional demands, regional imports, and foreign imports in terms of the product origin and intraregional supplies, regional exports, and foreign exports in terms of the product destination, which are introduced to allow the model to capture imperfect substitution between domestic goods and goods in the rest of world (ROW). The prices of commodity and factor input are adjusted to balance between supply and demand in the market. The structure of IRCGE model is designed to present two regional economies in Korea based on a year of 2013 as a short-run model.

The IRCGE model primarily relies on the basic assumptions of standard microeconomics as its foundations. The household is supposed to maximize its utility subject to its budget constraint, while the producers maximize their profits subject to given constraints on production technology. The household and all the producers are assumed to be price takers which means the markets are perfectly competitive. In the IRCGE model, the production activities are disaggregated into three categories: forest, tourism, and general sectors. And each production activity i is assumed to produce only one corresponding commodity i. It is explained the flows of goods and factors at each stage where they are combined for either production or consumption in the CGE model. The flows are presented from the bottom to the top in Figure 4.

(1) Labor and capital can be aggregated into the composite factor through the composite factor production function

(2) The composite factor is combined with the intermediate inputs of commodities to produce the gross domestic output using the gross domestic output production function (Leontief)

(3) The gross domestic output is transformed into the exports and domestic good using the gross domestic output transformation function such as Constant elasticity of transformation (CET) function

(4) The domestic good is combined with the imports to produce the composite good with the composite good production function such as Armington function

(5) The composite good is distributed among household consumption, government consumption, investment, and intermediate uses in composite good market equilibrium

(6) Household utility is generated by consumption of private expenditure as the utility function indicates.

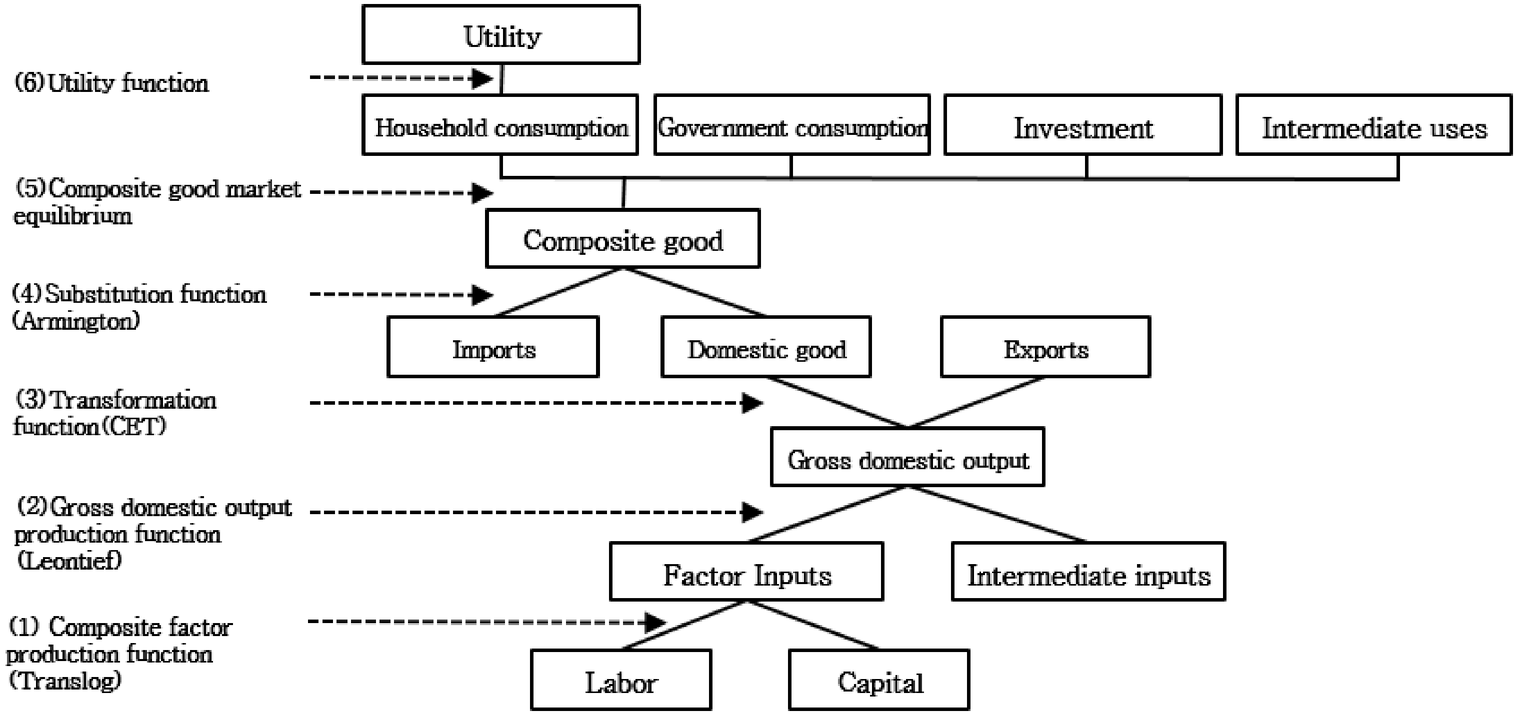

Figure 4. Overall Structure of CGE model

3.2.1. Production

In the next section dealing with the real sectors in the model, a simplified version of IRCGE model is presented starting with the supply part including key equations. The supply part in the IRCGE model consist of production function, labor demand, export, and import. To begin with production, the IRCGE model accounts for the economic behavior of producers and consumers on the real side economy based on the approach of neoclassical elasticity (Robinson, 1989). The production structure of IRCGE model is composed of three stages (Kim and Kwon, 2016; Kim *et al.*, 2004, 2017).

In the first step, the gross output by region and sector is established by the Leontief production function of value added and intermediate inputs. The intermediate input is derived from interregional input−output coefficients, and the value−added at macro regional level is simply the sum of those of cities and counties through the production function. These are specified with spatial econometric production function of labor and capital inputs with the forest area variable, and an external factor such as accessibility variable[4]. It is assumed that the producer select the optimal size of

[4] The accessibility index is defined as a weighted average of population of the node and link impedances (travel distance) generated from a gravity−type estimator as a proxy for transportation services in the production function (Kim et al., 2004, 2017). The travel time is calibrated by the shortest inter−zone travel time using road network among 254 cities and counties in Korea with the aid of

the production factors under the maximization principle of constrained profit. The regional labor demand is derived from the value−added maximization of the first−order conditions of producers subject to its production technology constraint under given output and input prices. The labor market is determined by the macroeconomic closure rule by balancing out total labor demand against total labor supply. Changes in the employment ratio affect the production output, and regional wage levels are linked to production costs in the regional labor market. In this model, based on the neoclassical closure rule, a full employment condition is applied in which wages are determined endogenously. It is assumed that regional labor input can be moved from one region to other in the short run model.

$$XD_i^r = \min(\frac{VA_i^r}{a_i^r}, \frac{IND_{1i}^r}{io_{1i}^r}, \dots, \frac{IND_{ji}^r}{io_{ji}^r}) \quad (3.1)$$

$$VA_i^r = A_i^r \cdot L_i^{r\,\alpha_i} \cdot K_i^{r\,1-\alpha_i} \quad (3.2)$$

$$L_i^r \cdot WA \cdot wdist_i^r = \alpha_i^r \cdot PVA_i^r \cdot VA_i^r \quad (3.3)$$

XD_i^r: Regional Gross Output of Domestically Produced Commodities

IND_{ji}^r: Regional Intermediate Inputs

VA_i^r: Regional Value−added

Arc−GIS Network Analysis.

L_i^r: Regional Labor Input

K_i^r: Regional Capital Stock

WA: Average Wage

$wdist_i^r$: Regional Wage Distribution Parameter

PVA_i^r: Regional Value-added

3.2.2. Price definition

All the prices of commodities are defined as either producer's price or consumer's price. In general, producer's price is used in the supply functions and consumer's price in the demand equations. The export price for domestic producers, defined as producer's price, is determined by world prices and the exchange rate adjusted with the rate of taxes and margins. The export price of commodity in domestic currency is derived from the product of world market price of exports (PWE) and the exchange rate. In the case of import price is revealed in a similar way, but its price presented at consumer's price based on domestic currency and world market price of imports (PWM). The activity price in each sector is derived by summing up the value-added price and the unit costs of intermediate inputs. The domestic prices of goods (PD_i) mean the price of domestic sales of domestic products. The composite good price (P_i) is a weighted average of the import price and the consumer's price of domestic sales.

In the context of regional basis, the commodities are composed of intraregional supplies, regional imports, and foreign imports with regard to the product origin of goods, and the regional products are spatially distributed to intraregional supplies, regional exports, and foreign exports in terms of the production destination. Commodity price is assumed to adjust towards a balance between supply and demand in factor inputs and commodity markets.

3.2.3. Export and Import

In the second stage, the intermediate demands are transformed into demands for domestic products and foreign imports using the Armington function. The total demands for the domestic products consist of intraregional supplies and regional exports, which are determined by their relative prices and spatial interaction between two regions at the bottom stage. The prices of imports and exports are determined exogenously, and the producers act as price takers. This condition is based on the small open economy assumption. The cost minimization from the Armington approach accounts for an optimal ratio of the foreign import to the domestic sale. With relative prices and different qualities, domestic sale is disaggregated into demands for two regional goods under the Cobb−Douglas function. In addition, profit maximization under the two−level Constant

Elasticity of Transformation (CET) function produces an optimal allocation of the gross output into the foreign exports and the domestic supplies. According to the concept of commodity equilibrium, domestic supply consists of intraregional supply and regional exports. The production volume depends on the relative price and the profit maximization of the producers rely on the amount of domestic demand and the elasticity of substitution.

$$\min PM_i^r \cdot M_i^r + PD_i^r \cdot XXD_i^r \tag{3.4}$$

$$\text{s.t}\, X_i^r = AC_i^r \cdot (\delta_i^r \cdot M_i^{-\rho c_i} + (1-\delta_i) \cdot XXD_i^{-\rho c_i})\hat{}(\frac{1}{\rho c_i}) \tag{3.5}$$

$$\frac{M_i^r}{XXD_i^r} = (\frac{\delta_i^r}{1-\delta_i^r} \cdot \frac{PD_i^r}{PM_i^r})^{\frac{1}{1+\rho c_i}} \tag{3.6}$$

$$\max PE_i \cdot E_i + PD_i^r \cdot XXD_i^r \tag{3.7}$$

$$\text{s.t}\, XD_i^r = AT_i \cdot (\gamma_i \cdot E_i^{\rho t_i} + (1-\gamma_i) \cdot XXD_i^{\rho t_i})\hat{}(\frac{1}{\rho t_i}) \tag{3.8}$$

$$\frac{E_i}{XXD_i^r} = (\frac{1-\gamma_i}{\gamma_i} \cdot \frac{PE_i}{PD_i})^{\frac{1}{\rho t_i - 1}} \tag{3.9}$$

XXD_i^r: Domestically Produced and Consumed Commodities

PM_i^r: Price of Import Commodity

PE_i: Price of Export Commodity

PD_i^r: Price of Domestic Commodity

M_i^r: Import

E_i: Export

X_i^r: Composite Commodity

3.2.4. Labor market

Labor demand can be derived from the first order condition for firm's profit maximization. Regional labor demand will depend on its product price, wages, and intermediate input prices. In the short run, the regional labor input is assumed to be homogeneous and moves among the regions, while capital stock cannot move from one region to others. The regional labor supply relies on the aggregate employment rate in each sector and the total population size of the region overall. The population is the sum of the natural increase of the population combined with the net gain (or loss) of migrant population. The latter is assumed to be in response to interregional differences between origin and destination regions in terms of average wage and unemployment rate, as well as the spatial distance between the regions.

3.2.5. Household income and Consumption

Households are the subjects of economic activity and affect not only consumption but also investment through savings. The total income of each household group in composed labor and capital income from providing production factors and receiving subsidies from government and transfer income from abroad. Whole consumption of household is assumed to be an equation of households' permanent income and transitory income from government. Labor income is determined by industry demand and average wage, and capital income is equal to the value−added after subtracting net production tax, employee compensation and depreciation. The disposable income for each household is described by the income after subtracting the direct tax and savings.

$$YH_r = YLC_r + YKC_r + YSUB_r + YFC_r \tag{3.10}$$

$$YD_r = YH_r - YTAX_r \tag{3.11}$$

$$YSAV_r = YD_r \cdot YSAVP_r \tag{3.12}$$

$$P_i \cdot PC_i = (YD_r - YSAV_r) \cdot PCES_i \tag{3.13}$$

YH_r: Household Income

YD_r: Disposable Income

YLC_r: Labor Income

YKC_r: Capital Income

$YSAV_r$: Household Savings

$YSAVP_r$: Marginal Propensity to Save

$PCES_r$: Marginal Propensity to Consume

$YSUB_r$: Government Subsidy

$YTAX_r$: Direct Tax

YFC_r: Transfer Income by the Rest of World (ROW)

P_i: Price of Commodity

PC_i: Private Consumption

3.2.6. Government Revenue and Expenditure

Government revenues derive from direct taxes from households and producers, indirect taxes, and tariffs. Government expenditures are divided into government consumption, subsidies for households, and government savings. The government current account saving is calculated as revenues minus current expenditures. The total savings are determined by summing depreciation, household savings, and government saving and minus foreign saving with exchange rate.

The total demand consists of intermediate and final demands such as consumption and investment expenditures of private and government sectors. Two levels of government system are specified in the model; two regional governments (including 16 provinces) and one national government. Government expenditures are composed of the consumption expenditures, subsidies to firms and households, and savings. Revenue sources include direct tax of household incomes, value-added, and foreign imports. Aggregate savings are sum of household savings, producer's savings of regional industries, private borrowings from abroad, and government savings, while determining total investments. There is one consolidated capital market without financial assets in the model, and the numeraire of the model is set as the consumer price index.

$$\text{GRV} = \sum_i ITAX_i + \sum_r YTAX_r + TARIFF \tag{3.14}$$

$$\text{GUSE} = \sum_i GC_i + \sum_r YSUB_r + GSAV \tag{3.15}$$

$$\text{SAVINGS} = \sum_i DEPR_i + \sum_r YSAV_r + GSAV - FSAV \cdot ER \tag{3.16}$$

GRV ：Government Revenue

GUSE ：Government Expenditure

$ITAX_i$: Indirect Tax

SAVINGS ：Savings (Investment)

$DEPR_i$: Depreciation

TARIFF ：Tariff

GC_i: Government Consumption

GSAV ：Government Savings

FSAV ：Foreign Savings

ER ：Exchange Rate

3.2.7. Commodity Market Equilibrium

In this model, demand composite goods are supplied with a combination of domestic supply and imports through the Armington function. Total demands for composite goods consist of intermediate consumptions and final consumptions. It can reflect the incomplete substitution between the two goods. In the process of minimizing the total cost, the appropriate demand for each good is determined, and it is generally estimated by the price ratio between foreign and domestic goods, domestic demand, and substitutional elasticity. This concept is applied equally to the country as well as the regional unit. The demand for intermediate goods and final goods by the region is composed of local supply goods and other local goods. The ratio of exports to total domestic goods or domestic goods is also determined by the Constant Elasticity of Transformation (CET) Function, which reflects the degree of imperfect elasticity between the two goods. How much domestic goods are supplied to the domestic market depends on the ratio between export and domestic supply prices, total supply, and resilience. Regional supplies are met by local supplies and exits to other regions. Theoretically, interregional trade (export and import size) can be estimated by Armington function and invariant elasticity function, but it is estimated by using interregional input output coefficient in this study.

$$X_i = AC_i[d_i M_i^{-\alpha_i} + (1-d_i)XS_i^{-\alpha_i}]^{-\frac{1}{\alpha_i}} \quad (3.17)$$

$$\frac{M_i}{XS_i} = [\frac{PS_i}{PM_i}\frac{d_i}{(1-d_i)}]^{\frac{1}{1+\alpha_i}} \quad (3.18)$$

$$XD_i = AT_i[q_i E_i^{r_i} + (1-q_i)XS_i^{r_i}]^{\frac{1}{r_i}} \quad (3.19)$$

$$\frac{E_i}{XS_i} = [\frac{PE_i}{PS_i}\frac{(1-q_i)}{q_i}]^{\frac{1}{r_i-1}} \quad (3.20)$$

E_i: Export Quantity

M_i : Import quantity

XS_i : Quantity of Domestic Demand (Supply)

PE_i: Price of Export Goods

PM_i : Price of Import Goods

PS_i : Price of Domestic Goods

AC_i: Efficiency Coefficient of Demand

d_i: Share Coefficient of Demand

α_i : Index of Demand Elasticity of Substitute

r_i : Index of Export Elasticity of Transformation

AT_i : Efficiency Coefficient of Supply

q_i: Share Coefficient of Supply

$r_i = \frac{1}{r_i - 1}$: Export Elasticity of Transformation

$\sigma_i = \frac{1}{1+\alpha_i}$: Import Elasticity of Substitution

Table 6. List of Major Equations of IRCGE Model

Output	Output = Leontief (Value added, Intermediate demand)
Value added	Value added = CD (Capital stock, Labor, LAND)
Supply	Output = CET (Foreign exports, Domestic supply)
Domestic supply	Domestic supply = CET (Regional exports, Intraregional supply)
Demand	Demand = Armington (Foreign imports, Domestic demand)
Labor demand	Labor demand = LD (Wage, Value added, Net price)
Labor supply	Labor supply = LS (Labor market participation rate, Population)
Population	Population = Natural growth of population + Net population inflows
Regional incomes	Regional incomes = Wage + Capital returns + Government subsidies
Migration	Migration = TODARO (Incomes and employment opportunities of origin and destination, Distance between origin and destination)
Consumption	Consumption by commodity = CC (Price, Incomes)
Private savings	Private savings = PS (Saving rate, Income)
Government revenues	Government revenues = Indirect tax + Direct tax + Tariff
Government expenditures	Government expenditures = Government current expenditure + Government savings + Government investment expenditure + Government subsidies
Labor market equilibrium	Labor demand = Labor supply
Capital market equilibrium	Private savings = Total investments
Commodity market equilibrium	Supply of commodities = Demand for commodities
Government	Government expenditures = Government revenues
Capital stock	Capital stock = Depreciated lagged capital stock + New investments

Source: The equations in the table is revised based on Kim(2014, 2017).

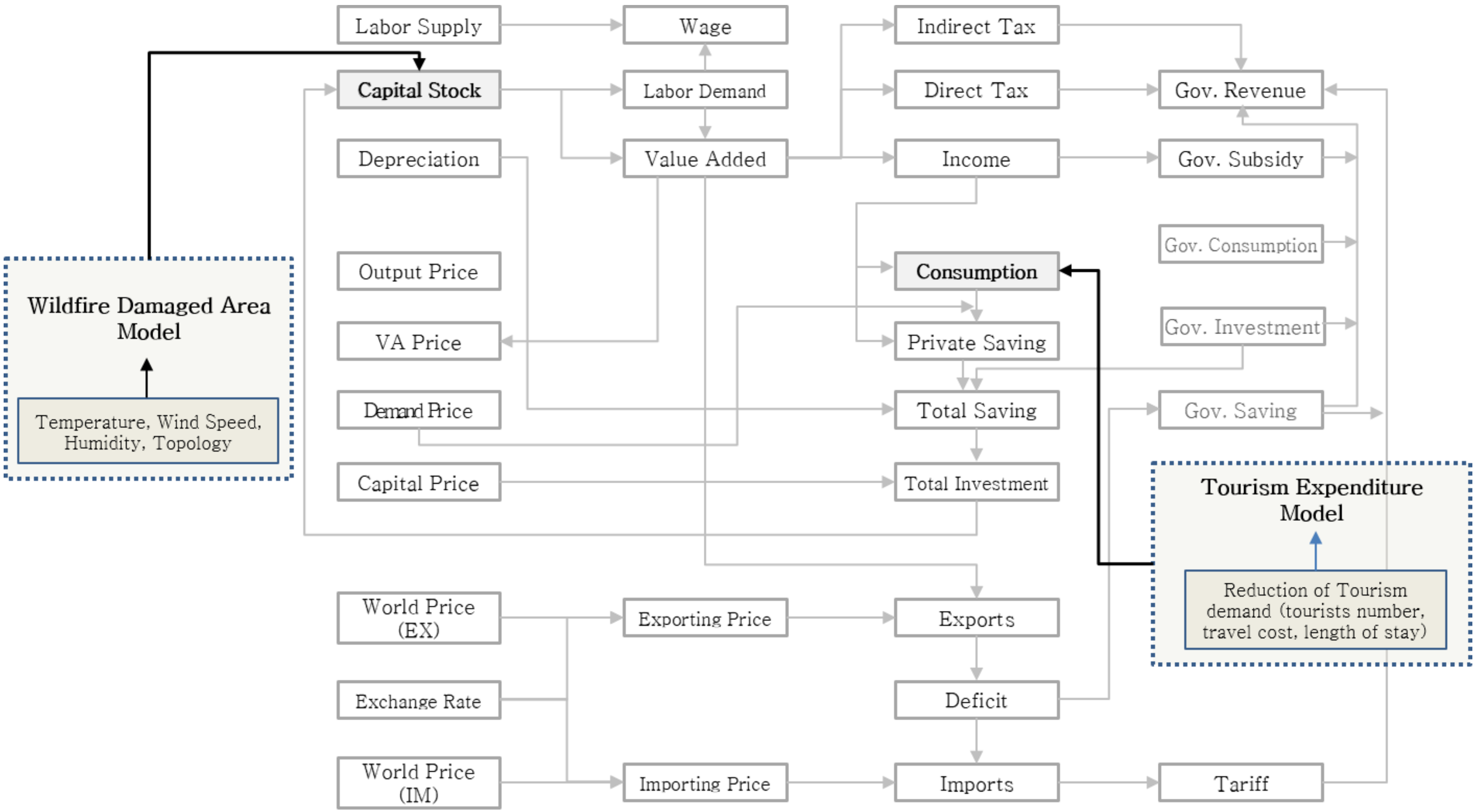

Figure 5. Structure of Inter Regional CGE (IRCGE) Model

The structure of the IRCGE model is shown in Figure 5. The simulations are conducted with econometric models and related variables presented in the IRCGE model. In the simulations, the loss of the wildfire area is entered into the capital stock and final demand of the forest industry in Gangwon province. Another losses of demand caused by wildfires derived from the decrease of tourism consumption expenditure. The regional economic effect is investigated by the shock variables in the model and highly depends on the regional and sectoral linkages and type of macroeconomic closure rules.

The SAM is calibrated as a data framework as a comprehensive and consistent general equilibrium data system for the development of the IRCGE model. The IRCGE model requires a comprehensive and disaggregated data system to explain the whole economy and policy experiments. The Social Accounting Matrix (SAM) is largely divided into production factor market, commodity product market, and foreign import & export market. The matrix is composed of household, firms, and government accounts for production, consumption, and savings. The SAM makes it possible to simulate various policies at the disaggregated level for economic agents based on each behavioral characteristics. The SAM consists of six accounts, which are factors, households, production activities, government, capital, and the rest of the world and is treated as an initial equilibrium for the IRCGE model. The statistical system of SAM integrates the regional input-output table and the national income accounts (Kim, 2014). The SAM focuses on production activities, distribution and expenditure relationships between economic agents in two different regions. The factor income and value-added from the production sectors are assigned to the household account, and the household spend them to consume commodity goods and services under the neoclassical economic mechanism. The investment sector consists of the depreciation of the production sectors, and household and government savings subtracting expenses for purchasing assets by the production sector (Park *et al.*, 2014). In this dissertation, the SAM is calibrated using the regional input-output table of Korea in 2013 and the national accounts data from the Bank of Korea. It consists of the production factors, a household, twelve producers, a government, an investment of each region and the ROW. The production sector consists of 12 industries and the government sector refers to the combination of the national and regional governments.

Table 7. A Simplified Inter Regional Social Accounting Matrix (IRSAM)

		Expenditures						
		Production Factors	Household	Government	Production Activities	Capital Account	Rest of World	Total
Receipts	Production Factors				Value added		Net factor income received from abroad	Incomes of the domestic factors of production
	Household	Allocation of value added to households	Transfers among households	Government transfers to households			Household incomes from abroad	Household incomes after transfer
	Government		Direct taxes on incomes		Indirect taxes on inputs		Government transfer incomes from abroad	Government incomes after transfer
	Production Activities		Household consumption expenditures	Government current expenditures	Intermediate consumption	Investment expenditures on domestic goods	Exports	Aggregate demand−gross output
	Capital Account		Household savings	Government savings			Net capital received from abroad	Aggregate savings
	Rest of World		Household expenditures on import goods	Debt servicing	Imports of raw materials	Imports of capital goods		imports
	Total	Incomes of the domestic factors of production	Total outlay of households	Total outlay of government	Total costs	Aggregate investment	Total foreign exchange receipts	

From the benchmark data, the CGE model can use the parameters to reproduce values and assess the effect of disaster damages. Kim (2008) suggested that the CGE model has two types of parameters: structural coefficients and behavior parameters. The structural coefficients are point estimates or non-elastic parameters, and the behavior parameters determine the behavior of agents. In this dissertation, the parameters are from three sources. The first set of parameters is from the SAM. Some of the shift or share parameters of the production belong to this set such as share parameters of production factors, import/export elasticity.

The second set of parameters is from previous studies. For instance, the alternative elasticity and the conversion elasticity of imports and exports are derived from Jeong (2008). Table 9 shows that the industrial substitution elasticity of import and transformation elasticity of export is recalculated by applied the ratio of imports in total supply and exports to total output from 2013 Interregional Input-Output table based on borrowing sectoral parameters from Jeong *et al.* (2003).

In addition to these two sets, econometric methods is used to estimate other parameters. To be specific, the parameters of forest product production were estimated using Leontief production function, Cobb-Douglas production function, Constant elasticity substitution function, Constant elasticity transformation function and Tourism expenditure function. The estimated or calibrated parameters enable to improve the model accuracy as reflecting the real economy and resulting in appropriate simulations. The equilibrium of supply and demand in the economy make it possible finding equilibrium condition by adjusting price mechanism based on the parameters in the model.

Table 8. Sectoral Elasticity of Substitution and Transformation

Industry	Substitution elasticity		Transformation elasticity	
	Gangwon	ROK	Gangwon	ROK
1. Forest Products	−0.082	−0.176	−0.803	−0.827
2. Wood and wood products	0.017	0.043	0.012	0.071
3. Pulp and paper products	0.000	−0.060	0.003	−1.551
4. Other manufacturing products and processing of timber	0.006	−2.769	0.029	−11.806
5. Retail and wholesale services	0.001	−0.688	0.000	−0.929
6. Transportation service	0.010	−3.725	0.004	−1.942
7. Restaurants and accommodation services	0.014	−3.123	0.021	−2.845
8. Cultural Services	0.002	−1.219	0.003	−1.232
9. Sports and entertainment services	0.011	14.349	0.005	5.667
10. Primary Industry	0.071	−3.366	0.118	−3.237
11. Manufacturing Industry	0.029	−0.679	0.061	−1.550
12. Service Industry	0.007	3.867	0.001	2.125

In the first simulation, estimated parameters of capital stock with land area in the production function, which are focused on the forest products (Model 1) and the forest manufacture industry (Model 2) respectively. It is applied into IRCGE model for calculating damage area by the wildfire as the input variable. The advantages of Cobb-Douglas production function are that it is relatively easier to estimate than other production functions and able to get the elasticity of the production factors[5]. If the production function in equation (3.21) and (3.23) are assumed to satisfy the homogeneity of degree one in factor inputs of the primary sector including additivity and symmetry conditions, such a restriction on the parameters are presented in equation (3.22) and (3.24). In particular, variable land of the Model 1 is used as a proxy variable for the capital stock and Model 2 is applied with the variable land as a part of capital stock because of the production features in forestry manufacturing sectors.

[5] The Cobb Douglas production function has a limitation on the assumption that the substitution elasticity is 1. The CES production function can estimate substitution elasticity, but it is difficult to estimate due to the data availability problem (Chung, 1994).

Model 1

$$lnVA_i = \beta_0 + \beta_1 lnL_i + \beta_2 lnK_i + \epsilon_i \tag{3.21}$$

It restricted to

$$\beta_1 + \beta_2 = 1 \tag{3.22}$$

VA_i : Aggregated value added of forest products industry

L_i : Total labor input of forest products industry

K_i : Forestry land areas as a proxy of capital input of forest products industry

Model 2

$$lnVA_i = \beta_0 + \beta_1 lnL_i + \beta_2 lnK_i + +\beta_3 lnLAND_i + \varepsilon_i \tag{3.23}$$

It restricted to

$$\beta_1 + \beta_2 + \beta_3 = 1 \tag{3.24}$$

VA_i : Aggregated value added of manufacturing of forest products industry

L_i : Total labor input of manufacturing of forest products industry

K_i : Total capital input of manufacturing of forest products industry

$LAND_i$: Production site area of the manufacturing corporate

The Model 1 (production function of forest products) has forestry area as a proxy of capital stock, number of employees in forest products sector, and road accessibility. The data is derived from the survey of mining and manufacturing industry in Korea. The estimation coefficients of Model 2 (production function of manufacturing forest products) are analyzed using the number of employees, capital stock, production site area, and road accessibility data. The spatial units of model 1 consist of 18 cities and counties in

Gangwon province during 2010−2015. The manufacturing production function is selected by three sectors in 33 manufacturing sectors that is wood and wood product manufacturing, pulp, paper and paper product manufacturing, and furniture manufacturing during 2000−2009. The descriptive statistics of variables in two models presented in Table 9.

Table 9. Descriptive Statistics of Variables for Model 1 and 2

Model 1 (forest products)				
Variable	Description	Mean	Median	S.D.
VA	Value added (unit: million US$)	0.020	0.012	0.019
L	Number of employees (unit: 1000 people)	1.953	1.500	2.283
K	Forest area as a proxy of capital stock(unit: 1000 ha)	74.557	66.229	35.488
Model 2 (manufacturing of forest products)				
Variable	Description	Mean	Median	S.D.
VA	Value added (unit: million US$)	0.034	0.007	0.095
L	Number of employees (unit: 1000 people)	0.353	0.127	0.762
K	Material fixed capital stock(unit: million US$)	0.058	0.006	0.184
LAND	Production site area (unit: m^2)	74.557	80.143	35.488

Table 10 presents the result of the production function estimation. The value added of forest products in the model 1 is increased by 0.586% when the area of the forest area rises by 1%. The land variable of manufacturing industry in model 2 contributed to value added rise by 0.078% followed by labor (0.669%), capital stock (0.252%) when each variable increased by 1%.

Table 10. Estimation of Production Function of forest products and Manufacturing forest products Industries

	Model 1		Model 2	
	Estimate (S.E)		Estimate (S.E)	
intercept	13.849***	(0.145)	1.399***	(0.121)
lnL	0.400***	(0.040)	0.396***	(0.026)
lnK	0.599***	(0.040)	0.562***	(0.029)
lnLAND	–	–	0.042**	(0.025)
Restrict	703.492***	(63.523)	27.994***	(10.833)
Adj R^2	0.609		0.902	
Sample size	1,100		1,098	

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level, value in parentheses indicates standard error of the coefficient.

3.3. Wildfire Damage Area Model

The wildfire damage area model is a method for estimating the burnt area caused by wildfires. This model is estimated by taking into account explanatory variables in the wildfire probability model and the wildfire diffusion model, which affecting the scale of wildfire damage. Generally, the sources of wildfire occurrence are classified into natural factors or human factors (Lee *et al.*, 2012; Woo, 2015). Due to the limitation of data, this study mainly considered natural factors such as maximum temperature, humidity, wind speed, slope of topography, and pine tree ratios.

In particular, since the weather data of the wildfire damage area model are large in uncertainty and volatility, it is necessary to assume the probability distribution for predicting the damage area using the measurement data in case of fire occurrence. The Gumbel probability distribution based on extreme value theory is used for predicting climate variations such as maximum temperature and wind speed (Lee, *et al.*, 2006). The amount of damage is estimated through the scenario analysis considering the climate change. This scenario of the climate change derived from the IPCC's RCP 8.5, which is a high emission scenario with no climate mitigation policies. It is caused by changes of maximum temperature, relative humidity, and average wind speed.

The analysis data were meteorological observations (maximum temperature, relative humidity, and average wind speed) provided by the Korea Meteorological Administration (KMA) and topographic features (slope and pine tree ratio) of the Korea Forest Service. The daily weather sources of Gangwon province were collected from based on one of disaster monitoring stations located in Goseong County in Gangwon province for 2013. The topographic data utilized to calculate the slope and pine tree ratio by grid zone in the spatial analysis tool of ArcGIS. To be specific, the slope in the grid zone is deliberated several processes. The contour layer is extracted using the TIN (Triangulated Irregular Network) on the digital topographic map of the forest, and the inclination is calculated by constructing a zone from the DEM (Digital Elevation Model) to the grid. The calculation method applied to the slope is the average maximum technique which combines the neighborhood algorithm and the maximum downhill Slope algorithm provided by ArcGIS10.1.

The Bayesian estimation method is used in the uncertain information due to the characteristics of forest fire data. In advance, posterior estimation is performed on the damage area after assuming Gumbel distribution as the prior distribution of wildfire damage.

Estimated wildfire damage area in this analysis through the model are dependent on daily database of climate factors, topographical factors per grid spatial unit, and regional tree type ratio. The Bayesian wildfire damage area model is in company with spatial heterogeneity of wildfires for the damaged areas, and transportation demand model at city and county level for trip restriction by the suppression works of wildfires.

The risk of forest fires in Korea was recorded in 1973, and the risk of forest fires is increasing with the accumulation of combustible materials such as leaves, shrubs, and the expansion of forest roads. The threat of forest fires and the problematic of fire enlargement are likely to be proportional to as the increase in fuel amount due to the prosperity of forests and the upsurge in evaporation amount in the dry seasons by the rising temperature. Korean large-scale wildfire damages are 32,895ha in 53 cases over the last 10 years, which is 1.0% of the total number of wildfires occurrence, but 88% of the area (Joint governmental relations in Korean Government, 2010). Table 11 shows the annual number of wildfire occurrence and burnt area in Gangwon province. It represents an irregular trend that is difficult to predict and even considering the climate changes. In addition, as the number of mountain climbers increased due to the implementation of the five-day workweek system since 2000, the incidence of wildfires increased further (National Emergency Management Agency, 2009). Korea is experiencing extreme climatic phenomena. Over the past 100 years (1912−2008), the average temperature in the six major cities has risen by 1.7 degrees, greatly exceeding the world average temperature of 0.74 degrees. In the future, it is expected to rise to one degree in 2020, four in 2050, and two in 2100.

Table 11. Annual Number of Wildfire Occurrence and Damage Area in Gangwon Province

	Number of wildfire occurrence	Burnt area (ha)
2000	141	24,210.0
2001	86	116.7
2002	52	241.8
2003	11	8.4
2004	57	757.9
2005	41	1,374.4
2006	30	12.2
2007	26	14.0
2008	25	13.5
2009	60	63.0
2010	46	93.1
2011	39	111.2
2012	44	16.2
2013	36	9.7
2014	73	20.0
2015	125	237.2
2016	91	50.7

In particular, Gangwon have cold and dry winds blowing from mainland of China in spring over the Taebaek mountain range cause the Fhn phenomenon and turn into high temperature and dry environment. The regions are located along the coast such as Goseong, Samcheok, Sokcho, Gangneung, and Donghae counties in Gangwon have higher temperatures and stronger winds than other regions, resulting in high risk of large wildfires. For instance, 2000 Gangneung large wildfire had the minimum humidity, extremely dry as 7 to 15% on the day, and the maximum instantaneous wind speed was 19 to 29.8m/s at that time (Lee, 2001).

The impacts of wildfire can be defined as changes in forest ecosystems in terms of physical, chemical, and biological aspects of forests (White *et al.*, 1996; Rogan and Yool, 2001). The wildfire damages is commonly influenced by variables such as climate, accumulated forest resources (fuel), and terrain. In Korea, wildfires damages increase in proportion to the amount of timber stocks, with 97% of the mountainous areas corresponding to 65% of the entire country, with absolute conditions called forestry (Korea Forest Service, 2001). The features of mountains including high slope, undulating topography, and percentage of coniferous forest contribute to increase the spatial expansion of wildfire damages and delay the suppression of wildfires (Kim *et al.*, 2014). Through the empirical case of wildfires, burning speed of wildfires on undulating slopes is 8 times faster than that of flat land due to factors such as topography and climate in Korea (Lee and Lee, 2006; National Emergency Management Agency, 2009). In addition, it is necessary to further research on the local economy effect of wildfires, especially large wildfires affected by climate changes are becoming frequent.

The recent irregular of wildfire occurrences and its damages illustrates the vulnerability of human health and property from extreme weather conditions. The magnitude of wildfire damage is influenced by climate change and also socio-economic developments in the wildfire region were the main cause as the rapid increase in damages (Botzen and van den Bergh, 2009). It is required to establish localized innovative adaptation policies to manage wildfire risks regarding households' perceptions of risk, investments in precautionary measures, and insurance purchases. A combination of investments in damage mitigation measures by households and prevention undertaken by the public sector is likely to result in well-diversified risk management strategies that enhance economic resilience to disasters (Botzen and van den Bergh, 2009).

The wildfire damage area is estimated as an input variable of newly developed IRCGE model in the dissertation. Many previous papers have suggested various fire damage assessment methods. Probabilistic models are mainly used with statistical descriptions related to wildfire damage using monitoring data besides the physical method (Nonomura *et al.*, 2007). McCaffrey (2006) suggested priority monitoring areas by selecting high risk areas after estimating the probability of occurrence of wildfires and its diffusion area. The result can contribute to save government budget to monitoring wildfire occurrences only focusing on high risk areas. However, probability model of wildfires is appropriate to evaluate the risk level of wildfire occurrence, but it is not suitable to estimate actual damaged area for this analysis. The methodology in the previous research on the wildfire damage analysis was mainly focused on direct cost analysis of the wildfire damage using cost method, econometric models, and IO analysis.

In order to estimate the damage area due to wildfires in Gangwon, the statistical distribution of wildfire losses due to extreme weather need to be assessed based on the Bayesian type model instead of the wildfire probability and diffusion models. The Bayesian model is used to estimate burned areas in the general fire risk assessment procedure in this dissertation. Bayesian analysis is a statistical paradigm that answers research questions about unknown parameters using probability statements. It is assumed that observed data sample (D) is fixed and model parameters θ are random. D is views as a result of a one-time experiment. A parameter is summarized by an entire distribution of values instead of one fixed value as in the classical frequentist analysis (Gelman *et al.*, 2014). The Bayesian approach is to estimate posterior probability for the extent of wildfire damage with assuming prior probability. Bayesian estimation of wildfire damage according to climatic conditions is assuming arbitrary prior distribution $(\theta \mid \mu)$ from the best knowledge, and then parameter for wildfire damage area is estimated according to posterior distribution $(\theta \mid Y, \mu)$. In the Bayesian approach, unlike the frequency-based approach, the parameter is treated as a random variable, and the kernel of the posterior density function $p(Y \mid \theta) \times \pi(\theta)$ is composed of the product of likelihood function and the pre-density function.

In the study of wildfire damage estimation, the Bayesian model is recently utilized for the fire study together with most popular logistic regression model, maximum entropy model, and the random forest model (Englin *et al.*, 2008: Dlamini, 2010; Mendes *et al.*, 2010; Mori and Johnson, 2013; Demet, 2014; Silva *et al.*, 2015; Jaafari *et al.*, 2017). Mori and Johnson (2013) argued that Bayesian models are suitable for simulation of the risk of wildfires, especially in small areas. The amount of wildfire damage varies greatly depending on local weather conditions including the climate change. The Bayesian approach is a robust method to infer uncertainty or variability of parameters in hierarchical models, such as when the data are auto-correlated and do not satisfy the criterion of randomness (McCarthy, 2007; Mori and Johnson, 2013).

The dependent variable(d_areat) is on the linear model of burnt area and assumed to follow a normal distribution, which is set to follow d_areat ~ Normal(0, r), where r is a hyper-parameter that was assumed to follow Normal(2, 5). To fit the model using Markov chain Monte Carlo (MCMC) simulation. It is performed six chains of 12,500 iterations with different initial values, discarded the first 2,500 and resulted in 10,000 iterations used for inference. The probability function is derived from Jang *et al*. (2017) in which the likelihood of the wildfire for Gangwon province depended on the highest temperature, effective humidity, relative humidity and the average wind speed as shown in the following equations. The spatial diffusion is determined by the Cosine (Cos) converted facing slope, the average wind speed and the area share of pine tree to the forest (Lee, 2005).

In equation (3.27), the explanatory variables in the Bayesian model are the maximum temperature, wind speed, and humidity of forest fire probability model (equation 3.25) and utilized the Cos converted facing slope and the area portion of pine tree in the spatial diffusion of wildfires model(see equation 3.26)[6]. The validity of the explanatory variables was confirmed in previous studies (Englin, 2008; Lee, 2005; Chen, 2014; Jang *et al.*, 2017). For instance, Chen(2014) identified important causal factors related to wildfire risks. Most significant factors are drought, high temperatures, and human actions which appear to enhance wildfire hazards. The data are specified on maximum temperature, effective humidity, relative humidity, and average wind speed from National Wildfire Survey in 2015. The effective humidity (EH) is the cumulative value of the relative humidity for 3 days including the relative one of the day and its coefficient is estimated 0.7 following by the wildfire probability model (Won et al, 2016).

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[6]Probability of Wildfires (Jang et al., 2017)

$$Prob_{Gangwon} = [1 + \exp\{-(1.932 + (0.109HT) - (0.047RH) - (0.057EH) + (0.646WS))\}]^{-1} \quad (3.25)$$

HT: The highest temperature (℃), EH: Effective humidity (%), RH: Relative humidity (%), WS: Average wind speed (m/sec)

Spatial Diffusion of Wildfires (Lee, 2005)

$$\text{Spatial Diffusion (ha)} = -134.87 - 322.55CS + 23.59WS + 143.49AP \quad (3.26)$$

CS: Cos converted facing slope, WS: Average wind speed (m/sec), AP: Area portion of pine tree (%)

The Bayesian wildfire damage area model for estimating burnt area of wildfires is as below.

$$d_{areat_i} = \beta_0 + \beta_1 temprt_i + \beta_2 windsped_i + \beta_3 humidity_i$$
$$+\beta_4 pinetree_i + \beta_5 cfs_i \quad (3.27)$$

where, d_areat_i is wildfire damaged area(ha), $temprt_i$ is highest temperature(℃), $windsped_i$ is average wind speed(m/s), $humidity_i$ is relative humidity (%), $pintree_i$ is ratio of pine tree in the area(%), and cfs_i is Cos converted facing slope (degree).

Wildfire damaged areas are estimated by using the Bayesian model as shown in equation (3.27). The maximum temperature, pine tree ratio, Cos converted facing slope and average wind speeds have a positive effect on the damaged area of wildfires, while humidity has a negative effect on it. The estimated probability or, technically, its posterior mean estimate is 0.332 of the highest temperature with a standard deviation 1.476 and Markov Chain Monte Carlo standard errors of 0.082 in Table 12. The damaged areas are extended by 0.332, 1.888, 1.250, and 1.938ha, respectively, when the maximum temperature, average wind speed, pine tree ratio, and cosine slope increased by one unit. On the other hand, if the relative humidity increases by 1%, the wildfire damage area decreases by −0.15ha.

Table 12. Estimates of Damaged Areas in Bayesian Normal Linear Model

	Variable	Mean Estimates	S.D.	MCSE	Median	Equal-tailed [95%Cred.Interval]	
Intercept	intercept	2.060	2.247	0.091	1.994	-2.374	6.510
Highest temperature(℃)	temprt	0.332	1.476	0.082	0.360	-2.540	3.264
Wind Speed(m/s)	windsped	1.888	2.299	0.114	1.836	-2.777	6.454
Relative Humidity(%)	humidity	-0.147	0.836	0.036	-0.138	-1.763	1.413
Pine tree ratio(%)	pinetree	1.250	2.023	0.105	1.237	-2.584	5.165
Slope (degree)	cfs	1.938	2.231	0.127	1.966	-2.518	6.332

* MCSE is Monte-Carlo standard error represents precision about posterior mean estimates.

Random-walk Metropolis-Hasting sampling is applied to capture prior distribution of damaged area of wildfire, which is a widely used posterior distribution sampling technique if the distribution is not established or the conjugated prior distribution. In statistics and in statistical physics, the Metropolis–Hastings algorithm is a Markov chain Monte Carlo (MCMC) method for obtaining a sequence of random samples from a probability distribution for which direct sampling is difficult. This sequence can be used to approximate the distribution (e.g., to generate a histogram), or to compute an integral (such as an expected value). Metropolis–Hastings and other MCMC algorithms are generally used for sampling from multi-dimensional distributions, especially when the number of dimensions is high (Bolstad, 2010).

Table 13. Check of MCMC Sampling Efficiency

Efficiency summaries MCMC sample size = 10,000

	Variable	ESS	Corr. time	Efficiency
Intercept	intercept	607.42	16.46	0.0607
Highest temperature(℃)	Temprt	325.91	30.68	0.0326
Wind Speed(m/s)	windsped	406.12	24.62	0.0406
Relative Humidity(%)	humidity	539.76	18.53	0.054
Pine tree ratio(%)	pinetree	371.53	26.92	0.0372
Slope (degree)	cfs	307.28	32.54	0.0307

Table 14. Test of Interval Hypothesis

Interval tests MCMC sample size = 10,000
prob1 : {d_areat:_cons} < 0.1

	Prob1	Mean	Std. Dev.	MCSE
Intercept	intercept	0.690	0.463	0.017
Highest temperature(℃)	temprt	0.330	0.470	0.020
Wind Speed(m/s)	windsped	0.675	0.468	0.019
Relative Humidity(%)	humidity	0.094	0.291	0.011
Pine tree ratio(%)	pinetree	0.546	0.498	0.022
Slope (degree)	cfs	0.674	0.469	0.022

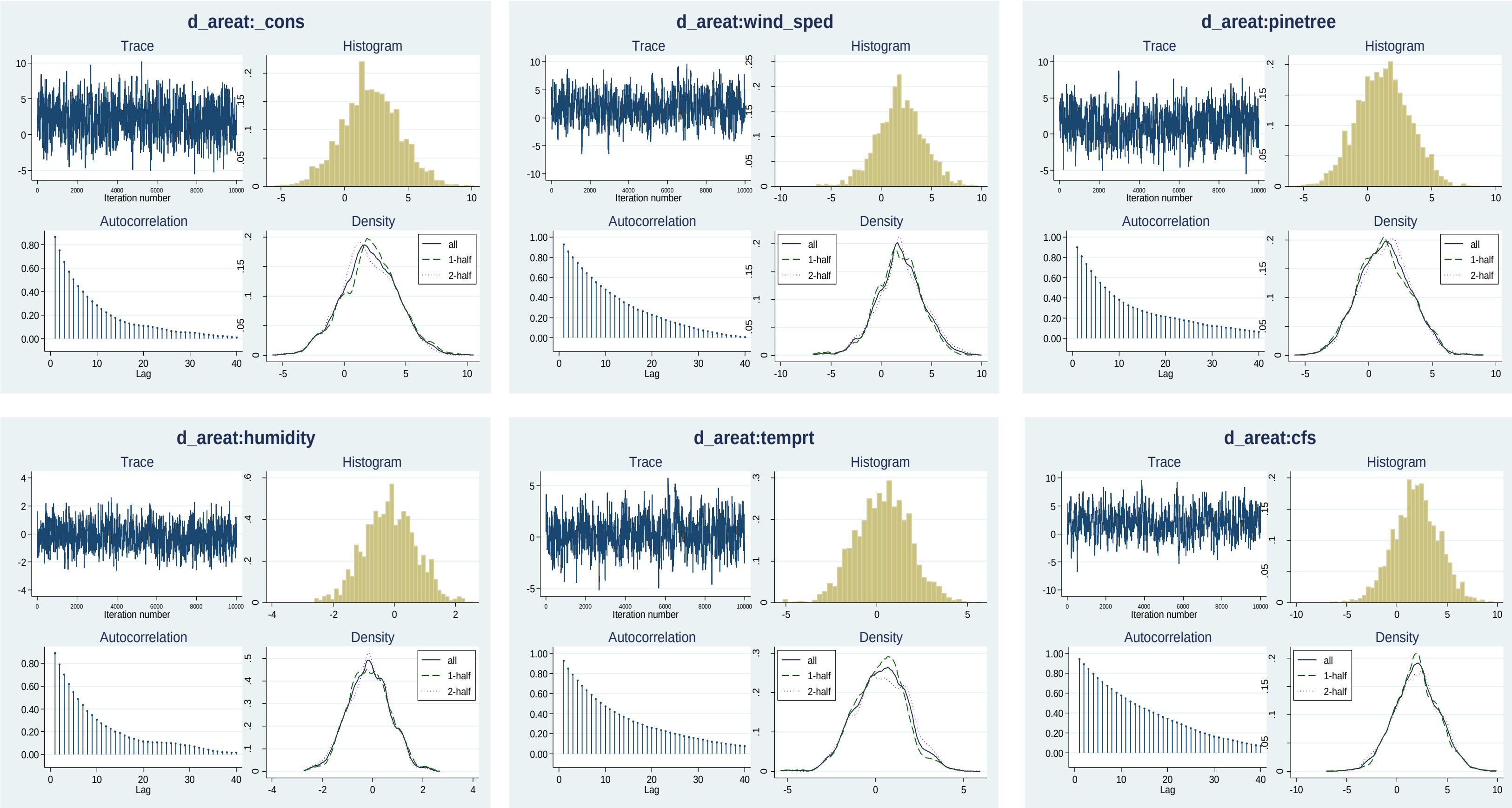

Figure 6. Diagnostics of MCMC Sampling

Basically, it is difficult to predict the damage area of wildfires because there are large standard deviations according to year, season, geographical feature and climate conditions. The range of climatic conditions is derived from upper limit to lower limit of maximum temperature, average wind speed and relative humidity distributions in the Goseong area using the MCMC. The each range assumed the Gumbel distribution of three climatic conditions to predict values of the upper limit. The validity of the wildfire damage area was calculated based on that 27 number of cases were selected and compared to the average damage area 27.82ha per year. When it is considering RCP8.5 scenario for the climate change, average damage area increased by 40.4%, compared to the burnt area under the case of without climate change.

Uncertainty in the climate change is largely divided into three categories: uncertainty due to the general circulation, uncertainty due to the CO2 scenario, and uncertainty due to the natural internal variability of climate (Kim *et al.*, 2014). Climate change can not be fully simulated, and climate prediction models have limitations that are inherently inaccurate (Giorgi and Mearns, 2002; Tebaldi and Knutti, 2007; Tebaldi *et al.*, 2004; Weigel *et al.*, 2008). One damaged area presents that applied number of cases from three different range values of climate conditions at Goseong, which are calculated in the wildfire damage area model in table 16.

Average wildfire damage area is 53.2ha and ranged from 45.8 ha to 65.3ha in the without climate change scenario. The largest damage shows 88.7ha as an upper limit under the case of climate change based on the ranged weather conditions in the table 15. In recent years, rising temperatures due to the climate change have affected to the risk of wildfires from certain times to throughout the year. At the same time, it greatly increased the risk of large wildfires in Gangwon province.

Table 15. Variation Range of Climate Conditions by MCMC at Goseong

Scenario	Range	Max Temp(℃)	Average Wind Speed(m/s)	Relative Humidity(%)
Without Climate Change	Upper limit	40.3	4.4	100.0
	Average	19.0	2.8	64.8
	Lower limit	4.9	1.5	35.0
With Climate Change (RCP8.5)	Upper limit	45.1	16.1	98.1
	Average	25.2	12.8	62.7
	Lower limit	10.4	9.6	37.1

Table 16. The 27 Cases of Wildfire Damaged Area based on Weather Variation by MCMC

(unit: ha)

Scenario / Cases	Without Climate Change			With Climate Change (RCP8.5)		
	Upper limit	Average	Lower limit	Upper limit	Average	Lower limit
1	62.7	57.9	55.3	87.0	82.6	80.0
2	60.9	56.3	53.7	81.7	77.5	74.9
3	59.0	54.7	51.9	76.5	72.4	69.8
4	65.3	60.8	57.8	88.7	84.5	82.0
5	60.9	56.3	53.7	81.7	77.5	74.9
6	61.6	57.6	54.3	78.2	74.3	71.6
7	65.3	60.8	57.8	88.7	84.5	82.0
8	63.4	59.2	56.0	83.5	79.4	76.8
9	63.4	59.2	56.0	83.5	79.4	76.8
10	60.2	56.0	53.9	84.8	80.8	78.6
11	58.4	54.4	52.3	79.5	75.7	73.4
12	56.5	52.8	50.6	74.3	70.6	68.3
13	57.7	53.2	50.8	83.1	78.9	76.4
14	62.8	58.9	57.0	86.5	82.7	80.7
15	59.1	55.7	53.5	76.0	72.6	70.5
16	55.8	51.6	49.2	77.8	73.8	71.3
17	60.9	57.3	55.3	81.3	77.7	75.6
18	59.1	55.7	53.5	76.0	72.6	70.5
19	60.3	57.0	55.3	84.3	81.0	79.2
20	57.7	54.1	51.8	82.6	79.0	77.0
21	55.2	51.3	48.3	80.9	77.1	74.6
22	58.4	55.4	53.9	79.1	75.9	74.1
23	55.9	52.6	50.6	77.4	74.0	72.0
24	53.3	49.7	47.1	75.6	72.0	69.8
25	56.5	53.8	52.3	73.8	70.8	69.0
26	54.0	50.9	49.2	72.1	68.9	66.9
27	51.4	48.1	45.8	70.4	67.0	64.8

The wildfire damage areas are directly linked to the losses of forest products, timber, landscape gardening, and so on. It means that all aspects are completely discontinued to use the forest land area. The amount of land assets per unit area was calculated by applying the forest land area ratio of Gangwon province to the total land assets in the country in table 17.

Table 17. The Land Asset per Forest Areas

	Land Asset (billion US$)	Forest Area (1,000 ha)	Land Asset per ha (1,000 US$)
Korea	5,923.09	6,335	935.04
Gangwon	1,285.31	1,372	937.06

In this dissertation, the losses of land assets are assessed including timber assets in table 18. The loss of land and timber assets caused by the Goseong wildfire damage depends on climate change scenario. It means that the losses of wildfire damages are presented as ranged value with upper limit and lower limit followed by the distribution of each climate source. The losses of land and timber assets consist of sum of the production losses in the forest sectors such as a reduction of capital stock as a factor input.

Table 18. The Loss of Land and Timber Assets by Goseong Wildfire

(unit: 1,000 US$)

	Without Climate Change	With Climate Change (RCP8.5)
Upper limit	122,426.1	166,321.9
Average	102,733.1	142,495.4
Lower limit	85,724.6	121,507.6

3.4. Transportation Demand Model

The transportation demand model generates the shortest travel time (minimum travel distance) between each city and county from a mathematical process of trip generation and distribution, and modal split with assignment. The characteristics of traffic demand have kind of the derived demand, diverse forms, and taking place over space, and have very strong dynamic volatility over time.

The shortest route algorithm in the network assignment results in a set of the shortest travel time (minimum travel distances), travel speeds, and travel demands on the links of the network using the EMME 4 program. Equation 3.28 is explained travel time of passengers from origin to destination considered of traffic volume, node and links.

$$T(OD) = \sum_{k=1}^{n} lt(OD)_k \qquad (l(OD) \in p(OD)) \tag{3.28}$$

T(OD): travel time from origin to destination

lt(OD): travel time of link l(OD)

l(OD): links in p(OD)

p(OD): the shortest line from origin to destination

O, D: origin and destination

n: the number of links in line p

Network consists of nodes, links, and traffic volume of links. The travel time savings are the most important form among road user benefits to be determined with the Volume to Delay Formula (VDF). A node accounts for an intersection, and a link presents a road or rail, which are connecting a node and another node. The node has coordinate values, and the link includes information such as a distance, a difference, a speed, and a capacity of the road section. Forecasting of traffic volume is based on a link allocation model that combines demand with supply and taking its value for each road link. At this time, the concept of a traffic zone called a centroid connector are introduced to connect the O/D and the network. As explained, the traffic demand is analyzed through this series of processes. When traffic fatalities occur due to the occurrence of wildfires, the driver is willing to take appropriate link and node to minimize travel times to maximize the utility level.

In the four−step transport model, the probability of travelers can select a particular mode (K) by the distribution of transporting mode in the logit model (equation 3.29).

$$\mathrm{P(K)} = \frac{e^{U_K}}{\sum_i^n e^{U_i}} \tag{3.29}$$

$U_K = utility\ level\ of\ mode\ K$

$U_i = utility\ level\ of\ mode\ i$

$n = number\ of\ mode$

Equation 3.30 is a utility function of transportation zone to zone for selecting transport mode m in the four−step transportation demand (cost) model.

$$U_{ijm} = \alpha_1 (Ttime)_{ijm} + \alpha_2 (Tcost)_{ijm} + (DUM)_m \tag{3.30}$$

U_{ijm} : $utiltiy\ function\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(Ttime)_{ijm}$: $total\ travel\ time\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(Tcost)_{ijm}$: $total\ travel\ cost\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(DUM)_m$: $Dummy\ of\ transport\ mode\ m$

Then, transit assignments are utilized the user balance principle from Wardrop (1952), which yields a balance of demand and supply. The travel time of the route used between origin and destination becomes less than or equal to the travel time of the route that is not used. An optimization algorithm of the link impedance (cost) function is used to derive the equilibrium state as shown below equation (3.31).

$$\mathrm{T} = T_0\left[1+\alpha\left(\frac{V}{C}\right)^{\beta}\right] + distance * weight \tag{3.31}$$

where, T and V is the travel time and flow, respectively on the link, T_0 is the free flow travel time, and C is the practical capacity, α and β are the model parameters, for which the value of α =0.15 minimum and $\beta = 4.0$ are typically used.

The shortest travel time (minimum travel distance) between each city and county is an input value for the accessibility which is defined as the spatial interaction or development potential contacts with activities (Kim *et al.*, 2004). The accessibility by city and county is derived from discounting the population at all destinations by the shortest travel time (minimum travel distance), while the population is regarded as a proxy variable for the opportunity level at the destination. The functional form is a kind of travel time decay function as a gravity type (Kim *et al,* 2004).

$$ACCPOP_i = \sum_{j=1}^{n} \frac{P_j}{d_{ij}^{\sigma}} \tag{3.32}$$

$ACCPOP_i$: Accessibility index of population of city and county i

p_i: Population size of city and county i

d_{ij}: Travel distance from city and county i to j

i, j: Origin node and destination node

σ : Travel distance parameter

As the result of analysis, the road accessibility on the network is decreased caused by the Goseong wildfire damage which is presented in Table 19. To be specific, road accessibility of Gangwon and ROK has been decreased by 2.36%, 0.12%, by respectively.

Table 19. Changes of Road Accessibility with the Wildfire

	BASE	Wildfire	Difference	% changes
Gangwon	1,459,875	1,425,353	34,522	2.36%
ROK	22,323,766	22,297,492	26,274	0.12%

3.5. Tourism Expenditure Model

In this chapter, the losses of tourist expenditure are estimated due to the increasing transport cost for the trip from the accessibility decrease after suffering the wildfire damage. This accident affects to grow the inefficiency of business, driving restrictions for specific area, canceling a trip, and selecting alternative travel destinations. As far as tourist expenditure is concerned in this chapter, it is necessary to build the regional tourism expenditure model to assess the losses of tourism expenditure of Gangwon province.

The domestic tourism expenditure has been studied as one of tourism demands, which is explained by supply and demand factors using the multivariate regression framework (Song and Li, 2008; Marrou and Paci, 2013). The tourism expenditure model was first developed by Stone (1954) with the assumption of consumer utility maximization under budget constraints. Each commodity group of tourists spending can be calculated as the proportional share of the spending by subtracted from total expenditure (Phlips, 1983). Pyo *et al.* (1991) developed a linear expenditure system to forecast tourism demand in domestic US with independent variables such as income, prices of commodity groups (transportation, lodging, food service, entertainment/recreation, others). This paper suggested income and price elasticities that enable to analyze the effects of income and price changes on tourism quantity demand adopting the data of business receipts related to tourism from 1972 to 1987 issued by the US Travel data Center 1989.

The analysis on regional tourism demand in a domestic territory increased mainly focused on Europe and US. Massidda and Etzo (2012) examined the domestic tourists demand across the Italian regions over the period 2004-2007 within a Generalized Method of Moments panel estimation framework. Regional tourism flows are also positively influenced by characteristics of the destination region like cultural expenditures, attractiveness, transport infrastructure and population density, confirming the crucial role played by the supply side factors. The negative impact of distance (-0.07) is also confirmed, but its magnitude is much smaller than in other studies. Garin-Muñoz (2009) analyzed the inflow of domestic and foreign tourists in a specific region, Galicia, during the period 1999-2006. Considering total nights spent, the estimated elasticities show that both domestic and foreign tourism flows are very sensitive to income in the origin markets and to prices. Deng and Athanasopoulos (2011) proposed a complex analysis of Australian domestic and international tourism flows using a dynamic spatial lag panel model. The model accounted for both temporal and origin–destination spatial dependence. It is also allowed to feature seasonal variation and asymmetry between capital–city and non–capital–city neighbors. Significant evidence of time–spatial correlation was found, along with positive effects of income and of time dummies controlling for two specific events, the Bali bombings and the Sidney Olympic Games. De la Mata and Llano–Verduras (2012) analyzed the domestic flows across the Spanish regions in two distinct years, 2001 and 2007, by using a Bayesian spatial autoregressive model. Although they found evidence of positive spatial autocorrelation, the spatial dependence affected in different ways to the origin and the destination regions. GDP is provided only for the destination regions, while the value added of the hotel industry and the beach length are included as explanatory features only for the origin. The results confirmed the negative influence of geographical distance (elasticity equal to −1.69).

Marrocu and Paci (2013) examined domestic tourism flows for the Italian provinces by applying origin–destination spatial interaction models and simultaneously accounting for both demand and supply side factors. Tourism is highly differentiated product and diversified destination places to meet the needs of increasingly varied mixes of tourists. The determinants considered include a set of both pull and push location characteristics, namely income, density, accessibility, a set of cultural, natural and recreational endowments and geographical distance. Yang *et al.* (2014) investigated the domestic tourism demand of urban and rural residents in China based on the data from the National Household Tourism Survey. Chinese domestic tourism demand is explained as a function of absolute income, relative income, domestic tourism price, and substitute price in this study. As a major contribution of this study, relative income was measured using the distance between individual income and average income over a city/province. This paper highlighted the effect of relative income on domestic tourism demand in some sub−regions of China by applying the multilevel model. More specially, regional differences between residents in different sub−regions and different patterns of determinants between urban and rural residents were identified and discussed.

Through the literature articles, spatial movements of domestic tourists need to be considered the regional characteristics of the origin−destinations and including the transportation and information service. Therefore, this dissertation is adopted independent variables: road accessibility, destination potential sources, tourist convenient facilities and attractions to estimate each influence on regional travel expenditure following the previous literature. Unfortunately, the regional tourism demand research for domestic Korea is insufficient because of a limit to the data based on origin−destination format. In this dissertation, we overcame the limitations of the data and created road accessibility variables by integrating the Korea Tourism Travel Surveys and the traffic network data 2015 from the Korea Transport Institute.

We defined the tourism industry five sectors based on the classification of Tourism Satellite Account in this dissertation. The tourism consumption expenditure in Gangwon destination accounted for 9.8% and 99.2% of the household consumption expenditure of Gangwon and the ROK, by respectively in the table 21. In the case of the ROK, Tourism expenditure in the ROK as a destination occupy 16.9% and 13.7% of total household spending for Gangwon and the ROK, respectively.

Table 20. Tourism Consumption Expenditure in Regional Tourism Industry

(unit: billion US$)

Region	Sector	Gangwon		ROK	
		Tourism	Others	Tourism	Others
Gangwon	S5	0.032364	0.297208	0.871476	0.007391
	S6	0.034618	0.317909	0.056327	0.000478
	S7	0.036751	0.337497	1.103291	0.009357
	S8	0.004618	0.042412	0.023616	0.000200
	S9	0.033707	0.309547	0.512098	0.004343
ROK	S5	0.285407	1.406987	8.726751	55.172043
	S6	0.026044	0.128393	2.557525	16.169115
	S7	0.167915	0.827781	6.167090	38.989418
	S8	0.004387	0.021628	0.344515	2.178085
	S9	0.032778	0.161585	2.213038	13.991210

Note: S5. Retail and wholesale services, S6. Transportation service, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services

The tourism expenditure function was developed with data of Korea Domestic Tourist Survey, regional statistics, and origin-destination information. The reduction of tourism expenditure in Gangwon is estimated shocks by changing the road accessibility from rising transportation cost. To be specific, the analytic database are derived from Korea Domestic Tourist Survey 2013 in Korea Culture and Tourism Institute (KCTI, http://www.tour.go.kr/) and the regional basis aggregated data from the regional statistics in the Korea Statistics, respectively. It is able to combine with these two data to design the Origin/Destination (OD) framework, and then develop the travel time distance through the spatial tool in ArcGIS software. The accessibility index is a weighted average of population of the node and link impedance (travel distance) between origin and destination generated from a gravity−type estimator as a proxy for transportation services in the tourism expenditure model(Kim *et al.*, 2004, 2017). The descriptive statistics of 18 destinations in Gangwon province and the 236 origin places in ROK are shown in Table 22.

Table 21. Descriptive Statistics of Variables in Tourism Demand Model for Gangwon

Variable (unit)	Obs	Mean	Std. Dev.	Min	Max
Tourism expenditure (million KRW)	653	852.00	3,040.00	−	72,200.00
Person inome(million KRW)	653	48.76	25.96	0.30	200.00
Age (year)	653	46.32	17.81	15.00	97.00
Travel frequency	653	2.02	2.33	1.00	11.00
Daily travel cost in previous year(KRW)	653	158,036.00	178,932.10	−	2,340,000.00
Employee numbers in Tourism sector (person)	653	1,208.73	1,050.20	213.00	4,030.00
Number of hotel room	653	551.16	429.38	−	1,172.00
Number of total firms	653	9,386.85	6,794.93	1,849.00	27,338.00
Number of culture legacy	653	45.76	36.49	7.00	124.00
Population of origin place	653	391,739.40	250,781.70	10,153.00	660,302.00
Index of road accessibility(Index)	653	2,782,076.00	1,723,990.00	1,139,715.00	7,311,430.00

The dependent variable of tourism expenditure model, tourism expenditure, was calculated as the product of tourist numbers, travel cost, and length of stay. Independent variables are included personal income, previous year's daily travel costs, number of establishments in a destination, population of origin places, number of culture legacy, and road accessibility, which have positive signs on tourism expenditure as shown in table 22. To be specific, tourism expenditures in Gangwon will be increased by 0.222%, 1.392%, 0.316%, and 0.030%, by respectively, when personal income, daily travel cost for previous year, number of firms in a destination, and road accessibility increase by 1% each.

On the other hand, the number of travel companies in the destination has mainly played a role of transmitting tourists to the outside of the region, thus showing a negative sign in the tourism expenditure model. The variable of travel frequency for the destination was consistent with previous research that repeated visitors tend to reduce their travel expenditures.

Tourist expenditure (TE) model

$$lnTE_i = \beta_0 + \beta_1 lnINC_i + \beta_2 AGE_i + \beta_3 AGE_i^2 + \beta_4 COUNT_i + \beta_5 lnTCOST_i^{t-1} + \beta_6 lnEMPLEI + \beta_7 lnHTLCP + \beta_8 lnNFIRM + \beta_9 lnCULTLG + \beta_{10} lnPOPi + \beta_{11} lnACC + \epsilon_i \quad (3.33)$$

Table 22. Estimates of Tourism Expenditure Model for Gangwon

Variable		Estimate	S.E
Intercept		−1.159*	1.729
Personal income (KRW)	lnINC	0.222***	0.064
Age(year)	AGE	0.055***	0.011
Age* Age	AGE^2	−0.001***	0.000
Travel frequency for the destination	COUNT	−0.012*	0.017
Daily travel cost for previous year	lnTCOST	1.392***	0.048
Number of employee in travel firms in destinations	lnEMPLEI	−0.203**	0.079
Number of hotel room in a destination	lnHTLCP	0.111**	0.045
Number of firms in a destination	lnNFIRM	0.316***	0.106
Number of culture legacy	lnCULTLG	0.170**	0.085
Population of origin places	lnPOPi	0.078**	0.035
Index of accessibility	lnACC	0.030*	0.095
Adjusted R−square		0.645	

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level, value in parentheses indicates standard error of the coefficient.

According to the 2013 Korea Domestic Tourism Survey, tourism spending accounts for 24.96% of total household spending, with a monetary value of 153.61 billion US $. Tourism expenditure amounted to 23.23 billion US$ for wholesale, transportation, lodging, food, culture, sports, entertainment service, and 11.67% of which is spent 2.71 billion US$ in Gangwon province.

It is assumed that any production and transportation activities are not allowed within a radius of 20 km of the wildfire damaged area for seven days. The damaged area can be calculated from the wildfire damage area model, which affect to the travel time distance on the national road network in the transport demand model. In the tourism expenditure model, the reduction of road accessibility by 2.42% in Gangwon affected to be decreased 5.78% in total tourism consumption expenditure in Gangwon, as its monetary currency value is 164.02 million US$.

Chapter 4. Simulation

4.1. Overview of Simulation

The study area is located in Gangwon province, where more than half of the large wildfires occur in Korea and the road traffic rate in Gangwon is relatively lower than other regions. In addition, Gangwon is well known tourist destination, especially for domestic tourist. Gangwon has high risk of wildfires because more than 80% in the total area is covered with mountain area in Gangwon. In other words, the Gangwon was appropriated as the study area on analyzing economic impact on the tourism and forest industry in particular. To be specific, the 2000 Goseong wildfire burned 23,794 ha, the largest wildfire in Korea since 2000, and can be strongly dependent on the topography including temperature, humidity and wind speed.

This chapter presented the process of experimental simulation through the IRCGE framework for estimating the economic effect of the wildfire damage in Korea. The calibrated IRCGE model is executed in comparative static simulations in the short run. Based on the wildfire damages on economic impacts of the regional or industrial aspect, it can be applied to policy instruments of the allocation of government budget, subsidy or grant organization, and tax reduction to minimize the wildfire damage. In this dissertation, the indirect impact is evaluated in terms of gross domestic production (GDP), gross regional production (GRP), and such macro-economic indicators.

The simulations are estimated regional economic effect of wildfire damages, which are divided into scenario 1(without climate change) and scenario 2 (with climate changes following the RCP8.5) based on the weather forecasting report from Korea Meteorological Administration 2012. This report argued that the climate change of Korean Peninsula is ongoing and it predicts the trend of global warming until the year of 2100. The high greenhouse gas emission scenario (RCP 8.5) is considered into changing values in the upper or lower limit of climate variables as the scenario of the climate change in Gangwon. Specifically, it is predicted a temperature rise of 0.62 degrees per 10 years according to the climate change scenario RCP8.5.

Baseline: No wildfires in Gangwon
Scenario 1 : Wildfires in Goseong county of Gangwon province without climate change
Scenario 2 : Wildfires in Goseong county of Gangwon province with the climate change of the high greenhouse gas emission (RCP8.5)

The damaged area of wildfires with no climate change in Gangwon is 65.3ha as the upper limit and it affects to decrease value added in forest sectors caused by decreasing capital stock in the forest products production model and forest manufacturing model. With considering the climate change, the wildfire damaged area ranged from 60.9ha to 88.7ha in RCP8.5 after applied positive or negative (±) standard deviation of each climate data. In addition, its average loss of land and timber asset in Gangwon is 937,000 US$ per ha and the final demand reduction of wildfires in forest industry amounted from 66.91ha to 70.84 million US$ in scenario 1 and from 62.69 to 83.12 million US$ in scenario 2 by increasing burnt area with the case of climate change. The climate change scenarios are predicted for the case with the climate change is higher than the case of without the climate change due to rising temperature and wind speed based on a forecasting of 2030 of the Korea National Weather Service.

Overall forest assets in Gangwon on the year of 2013 are 1,285.31 billion US$, accounting for 21.7% of the nation's total, including land and timber assets. It is included the residential and commercial building land, the attached land, the agricultural land, the forest land, the cultural entertainment land, and other land equivalent to the land assets in net capital stock of the Balance Sheet of the

Bank of Korea. The total amount of timber assets is distributed according to the ratio of the land assets to the total amount of land from the National Statistical Office. The classified timber assets are distributed according to the forest area by provinces.

4.2. Result of Impact Analysis by Wildfires

The wildfire experiment in this dissertation, it is supposed that the wildfire occurred in Gangwon province, which is located in the eastern area of the country. The location represent 21.6% of total forest area in Korea. Additionally, one of large wildfires has been damaged 23,448ha in Gangwon province for 2000 year. In the dissertation, the indirect impacts are measured in terms of gross domestic product (GDP) and gross regional product (GRP) under interindustrial mobility of labor and capital factors across regions. It is assumed that any production and transportation activities are not allowed within a 20 km radius of the damaged area.

For the analysis, 16 provinces are classified into two regions; one damaged Gangwon province and the rest of Korea (hereafter ROK). The industrial sectors are integrated into Forest sector, Tourism sector, Primary, Manufacturing, and Service sectors. When the wildfire happen at Goseong county in Gangwon province, there would be a sharp downturn in the national and regional economies similar to the expectation. The indirect impact on regional economies is the reduction of GRP, value added, Consumer Price Index (CPI), and so on. This analysis focused on indirect economic impact on regional changes of value-added caused by the wildfire. The economic impacts presented its loss value and the growth rate in the form of a range when it is considering the uncertainty of the climate condition. It means that the sign of positive or negative can be inconsistent and appeared together depending on the ranged value of the indirect economic effect.

The GDP could decreased from −0.039 to −0.087 billion US$ without the climate change case and from −0.051 to −0.535 billion US$ under the climate change. The Consumer Price Index (CPI) decreased from 0.01 to 0.030%p under the case of without climate change and by −0.11~0.11%p in the case of climate change, which is affected by the losses of the forest and tourism composite goods due to the wildfire. This would decline ranged from −0.069 to −0.153 billion US$ of GRP for Gangwon but increase from −0.027 to −0.065 billion US$ for ROK under the case of without the climate change. The climate change could lead to magnify the economic loss from −0.143 to −0.344 billion US$ for Gangwon and from −0.191 to 0.182 billion US$ under the climate change. In addition, the wildfire has a negative effect on the value−added in forest sector and tourism sector for Gangwon: the forest sector in the Gangwon by −12.10%~−17.43% and by −0.71~−0.85% in tourism sector under the case of without climate change. The negative effects on the GRP tend to become more severe in Gangwon than the ROK: the growth rate is 0.23~0.55%, which is much lower than that of the ROK by 0.01~−0.01%. The influence of the climate change for Gangwon are 1.5 to 2.2 times larger than value−added losses of the scenario under the without climate change.

However, somewhat interesting outcome is that the GRP of ROK could improve from 0.027 to 0.065 billion US$ without the climate change case and from −0.191 to 0.182 billion US$ under the climate change. That is, ROK is able to enjoy significant “reflexive benefits” by increasing the share in the domestic market for some time while Gangwon are experiencing value−added loss from the disaster. This should be noted that the economic benefits on the region should not be regarded as a positive effect of the wildfire in a sense that the increase in the GRP is generated through the sacrifice of the damaged region. It implies that it is necessary to establish regional coordination among local governments in order to obtain effective rehabilitation schemes to share the costs and benefits from the accidents. Taking into account inter−industry linkage structure embedded in the economic system, it would be worthwhile to implement sector−specific recovery activity plan to have the regional economic resilience to bounce back.

Table 23. Changes in GDP and GRP

1) Change in GDP, Value added, CPI, and Output (unit: billion US$, %)

	Without Climate Change		With Climate Change	
	Lower limit	Upper limit	Lower limit	Upper limit
Total GDP	−0.087	−0.039	−0.535	−0.051
VA of Gangwon	−0.153	−0.069	−0.344	−0.143
VA of ROK	0.027	0.065	−0.191	0.182
CPI	0.000	0.000	−0.001	0.001
Output of Gangwon	−0.225	−0.088	−0.580	−0.212
Output of ROK	−0.053	0.263	−3.591	1.500

2) Growth rate (baseline=100)

	Without Climate Change		With Climate Change	
	Lower limit	Upper limit	Lower limit	Upper limit
Total GDP	99.99	100.00	99.96	100.00
VA of Gangwon	99.45	99.75	98.77	99.49
VA of ROK	100.00	100.00	99.99	100.01
CPI	100.01	100.03	99.89	100.11
Output of Gangwon	99.59	99.84	98.93	99.61
Output of ROK	100.00	100.01	99.88	100.05

*Gangwon: Gangwon Province; ROK: The Rest of Korea
*The forest sector include S1. Forest Products, S2. Wood and wood products, S3. Pulp and paper products, S4. Other manufacturing products and processing of timber. The tourism sector consist of S5. Retail and wholesale services, S6. Transportation services, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services. Other sectors take in S10. Primary Industry, S11. Manufacturing Industry, and S12. Service Industry.

Table 24. Changes in Value-Added

1) Chang in Value-Added (unit: billion US$)

		Gangwon		ROK		Total	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Without Climate Change	Forest Sector	-0.087	-0.061	-0.010	0.002	-0.098	-0.058
	Tourism Sector	-0.045	-0.037	-0.017	0.004	-0.061	-0.034
	Primary Sector	-0.003	0.000	-0.002	0.000	-0.005	-0.001
	Manufacturing Sector	-0.003	0.002	-0.048	0.093	-0.051	0.095
	Service Sector	-0.015	0.032	-0.018	0.095	-0.033	0.126
	Total	-0.153	-0.064	-0.095	0.194	-0.248	0.129
With Climate Change	Forest Sector	-0.116	-0.087	-0.104	0.021	-0.220	-0.066
	Tourism Sector	-0.073	-0.045	-0.101	0.040	-0.174	-0.005
	Primary Sector	-0.003	-0.003	-0.039	0.010	-0.042	0.007
	Manufacturing Sector	-0.015	-0.005	-1.788	0.674	-1.802	0.669
	Service Sector	-0.022	-0.002	-0.530	1.809	-0.551	1.807
	Total	-0.228	-0.143	-2.562	2.554	-2.789	2.411

2) Growth Rate (baseline=100)

		Gangwon		ROK		Total	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Without Climate Change	Forest Sector	82.57	87.90	99.97	100.01	99.72	99.83
	Tourism Sector	99.15	99.29	99.99	100.00	99.97	99.98
	Primary Sector	99.88	99.98	99.99	100.00	99.98	100.00
	Manufacturing Sector	99.89	100.08	99.99	100.03	99.99	100.03
	Service Sector	99.91	100.19	100.00	100.01	100.00	100.02
	Total	99.45	99.77	99.99	100.01	99.98	100.01
With Climate Change	Forest Sector	76.89	82.61	99.69	100.06	99.36	99.81
	Tourism Sector	98.61	99.15	99.95	100.02	99.92	100.00
	Primary Sector	99.89	99.85	99.86	100.04	99.87	100.02
	Manufacturing Sector	99.49	99.83	99.51	100.18	99.51	100.18
	Service Sector	99.87	99.99	99.92	100.26	99.92	100.26
	Total	99.18	99.49	99.81	100.19	99.79	100.18

*Gangwon: Gangwon Province; ROK: The Rest of Korea

*The forest sector include S1. Forest Products, S2. Wood and wood products, S3. Pulp and paper products, S4. Other manufacturing products and processing of timber. The tourism sector consist of S5. Retail and wholesale services, S6. Transportation services, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services. Other sectors take in S10. Primary Industry, S11. Manufacturing Industry, and S12. Service Industry.

Chapter 5. Conclusions

5.1. Summary

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry. The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage model, transportation demand model, and tourism expenditure model. The IRCGE model is described two macro regions under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model estimated burnt areas considering high uncertainty based on data of temperature, wind speed, humidity from the Ministration of Korea Meteorology and wildfire statistics, forest type, slope features by spatial unit from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The estimated burnt area in the wildfire damage area model affected to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

In order to examine the validity of the developed IRCGE, a simulation on the Goseong wildfire was conducted for Gangwon province considering Intergovernmental Panel on Climate Change (IPCC)’s prospects for climate changes, the emission scenario of the Representative Concentration Pathways(RCP8.5). There is a suitable place to analyze the indirect impact on forest and tourism industry because it is a typical tourist destination and mountains covered more than 80% of the total area of the province. Markov Chain Monte Carlo method was adopted to estimate ranged burnt areas considering the high uncertainty of climate and topography due to the nature of wildfire, the change of transportation accessibility, and the loss of tourism expenditure.

The economic effects of Goseong wildfire were analyzed by using the experiment of the wildfires damage under the cases of without or with climate change. Gross Domestic Product (GDP) in Korea due to the wildfire damage decreased by −0.01% under the without climate change, −0.04% when considering climate change. The Gross Regional Product (GRP) of the Gangwon Province decreased from −0.25% to −0.55% (−0.069 ~ −0.153 billion US$) due to Goseong wildfire under the no climate change and from −0.51%

to −1.33% (−0.143~−0.344 billion US$) under the climate change (RCP 8.5). The value added of industrial changes in Gangwon province decreased from −12.10% to −17.43% in forest sector and from −0.71 to 0.85% in tourism sector due to the fire damage. The value added losses of the industry under the climate change will be about 1.5 to 2.2 times larger than the scenario without climate change. On the other hand, GRP in the rest of Korea (ROK) enjoyed reflex benefits from 0.027~0.06 billion US$ due to the wildfire damage in Gangwon Province, and value added changed within the range of −0.191 ~ 0.182 billion US$ in ROK under the climate change scenario.

This dissertation developed a framework for estimating economic effects with considering the climate change applicable to other natural or manmade disasters. The developed framework was applied to wildfire damage and confirmed its usefulness. The results of the analysis can be used as a basis for establishing the government budget for disaster prevention and magnitude of the subsidy considering prioritized monetary losses by each industry. In addition, it can be used to calculate the insurance premium for damage compensation.

5.2. Further Research

In terms of methodology, it is necessary to develop a quarterly model that is not an annual model in this study in order to improve the accuracy of the economic effect estimates, which enables to reflect seasonal variations in climate, production capacity and short-term disasters. For the quarterly IRCGE model, the coefficient of technology should be decomposed based on the initial data such as the input calculation table and the social accounting matrix. Also, it is necessary to introduce a dynamic model to analyze the economic effects of disasters considering the time required for long-term recovery depending on the damage level of the disaster. The dynamic model can overcome the disadvantages of the static model by applying the technology coefficient matrix to consider changes in production technology.

With regard to the policy, first, it is necessary to supplement the strategy of wildfire suppression to minimize the wildfire losses, to increase the scale of the disaster prevention budget, and to quickly prevent the spread of large wildfire. For example, the Ministry of Security and Emergency Management, which has improved the dualized wildfire evacuation structures, has established the first wild fire fighting action team, and regularized the wildfire monitoring workforce and raised the wage level. Second, it can be necessary to provide detour roads to improve transportation accessibility to wildfire damaged regions and also to increase business efficiency in wildfire areas and around regions. Most industries including manufacturing suffered from the increase of travel distance and then it can lead to a decline in value added and a negative impact on productivity. Third, in response to the decrease in tourism spending caused by the wildfire damage, local governments should minimize the damage through active tourism marketing policy to promote tourist visits and provide alternative transportation vehicles. Losses resulting from temporary closed parks and entertainment resources need to be presented compensation policies to support subsidies from the government.

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국문초록

Regional Indirect Impacts of Wildfire Damages on Outputs of Forest and Tourism Sectors

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본 연구의 목적은 예측이 어려운 재난의 경제적 효과 추정에 적용 가능한 미시-거시 연결된 분석틀인 지역간연산가능일반균형모형(Inter Regional Computable General Equilibrium Model: IRCGE)을 개발하는 것이다. 개발된 IRCGE모형은 우리나라 산림지역의 대표적 재난인 산불피해에 적용하여 그 유용성과 추정치의 타당성을 검토하였다. 분석대상지역은 국내 가장 큰 산불이 발생하였던 강원도 고성지역으로 산림이 80% 이상을 차지하고, 대표적인 관광목적지이므로 산림 및 관광산업의 경제적 간접효과를 동시에 분석 가능한 적지로 판단하였다. IRCGE모형은 일반 CGE모형에 기후변화 및 공간 특성을 고려한 산불피해면적모형, 산불진화로 인한 교통비용을 반영한 교통수요모형, 산불로 인한 관광수요 감소를 적용한 관광지출모형 등의 3개 미시모형을 연결한 분석틀이다. 먼저, 산불피해면적모형은 산림청의 산불통계와 기상청의 방재기상자료를 포함한 지형, 임상 등의 공간자료를 토대로 구축되었다. 교통수요모형은 국가교통네트워크자료를 토대로 통행발생, 통행분포, 수단선택, 통행배정의 4단계에 따라 산불지역 도로통제로 인한 254개 시군구별 도로접근성 변화를 분석하였다. 관광지출모형은 2013년 국민여행실태조사를 토대로 산불피해로 인한 강원도 관광지출액의 변화를 추정하였다.

IRCGE모형을 이용한 고성산불피해의 경제적 효과 시뮬레이션은 기후변화 이전과 이후의 2가지 시나리오로 구분하여 산불피해면적 범위자료를 토대로 분석하였다. 먼저, 산불피해로 인한 우리나라 국가총생산(GDP)은 -0.01%에서 기후변화 고려 시 -0.04%까지 감소하였다. 고

성산불로 인하여 강원의 지역총생산(GRP)는 −0.25~−0.55%에 해당하는 690억원~1530억원이 감소하였고, 기후변화(RCP8.5)를 고려하면 −0.51~−1.33%인 1430억원~3440억원으로 피해수준이 크게 증가하였다. 산불피해로 인한 소비자물가지수(CPI)는 −0.01%p~−0.030%p가 감소하였고, 기후변화 시나리오에서는 −0.11%p~0.11%p의 변화를 보였다. 강원도 산림업과 관광업의 부가가치는 산불피해로 인하여 −12.10%~−17.43%와 −0.71~0.85%가 각각 감소하였다. 기후변화를 고려한 해당 산업의 부가가치 감소는 기후변화없는 시나리오의 약 1.5~2.2배 증가하였다. 한편, 기타지역의 GRP는 강원의 산불피해로 인한 270억원~600억원의 반사이익을 누렸고, 기타지역 기후변화 시나리오에서 부(−)의 1,910억원에서 정(+)의 1,820억원의 범위에서 부가가치 변화가 나타났다.

본 연구의 기여는 다양한 재난에 적용가능한 경제적 효과추정 분석틀을 개발한 것이다. 개발한 분석틀은 산불피해에 적용하여 그 유용성을 확인하였다. 개발된 미시−거시 연결모형에 다양한 재난을 분석한 미시모형을 추가하는 방식으로 이용할 수 있다. 기존 연구는 재난의 직접효과 추정에 집중되어 지역 및 산업간 간접효과 연구가 미흡한 상황이었다. 본 연구는 재난의 간접효과를 분석하여 연관산업의 부가가치 손실과 다른 지역의 간접 피해를 확인할 수 있었다. 분석결과는 산업별 재정지출의 우선순위 결정에 활용할 수 있다. 추가적으로 이는 산불방재예산, 보조금 규모 수립에 근거자료로 활용이 가능하며, 피해보상을 위한 보험금 산정에 이용할 수 있다.

향후 연구과제는 방법론과 정책적 측면으로 구분하여 살펴보았다. 먼저, 방법론적 측면에서 기후의 계절성, 생산능력의 변동 및 단기 재난을 반영하여 경제적 효과 추정치의 정확성을 제고하기 위한 분기모형을 개발할 필요가 있다. 분기 IRCGE모형을 위하여 투입산출표와 사회계정행렬 등의 초기자료를 시간을 기준으로 기술계수를 분해할 수 있다. 또한, 재난의 피해수준에 따라 복구에 필요한 기간을 고려한 재난의 경제적 효과를 분석하기 위하여 동태모형을 도입할 필요가 있다. 동태모형은 생산기술의 변화를 고려하기 위하여 기술계수행렬을 적용하여 정태모형의 단점을 극복할 수 있다. 정책적 측면은, 산불피해최소화를 위한 산불진화 및 방재 예산편성, 산불발생지역의 사업 효율성을 제고하기 위한 교통접근성 보완, 관광지출액 감소에 대응한 지방정부의 관광마케팅정책 추진과 대체 운송수단의 활용방안 등을 연구할 필요가 있다.

주요어: 지역경제효과, 재난, 산불, 관광지출, 지역간연산가능일반균형모형
학번: 2011−30335

경제학박사 학위논문

Regional Indirect Impacts of Wildfire Damages on Outputs of Forest and Tourism Sectors

산불피해가 산림 및 관광산업에 미치는 지역경제효과 분석

2018년 2월

서울대학교 대학원

농경제사회학부 지역정보전공

권 영 현

Regional Indirect Impacts of Wildfire Damages on Outputs of Forest and Tourism Sectors

지도 교수 김 의 준

이 논문을 경제학박사 학위논문으로 제출함
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서울대학교 대학원
농경제사회학부 지역정보전공
권 영 현

권영현의 경제학박사 학위논문을 인준함
2018년 2월

위 원 장 ______________________ (인)

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Abstract

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry. The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage model, transportation demand model, and tourism expenditure model. The IRCGE model is described two macro regions under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model estimated burnt areas considering high uncertainty based on data of temperature, wind speed, humidity from the Ministration of Korea Meteorology and wildfire statistics, forest type, slope features by spatial unit from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The estimated burnt area in the wildfire damage area model affected to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

In order to examine the validity of the developed IRCGE, a simulation on the Goseong wildfire was conducted for Gangwon province considering Intergovernmental Panel on Climate Change (IPCC)'s prospects for climate changes, the emission scenario of the Representative Concentration Pathways(RCP8.5). There is a suitable place to analyze the indirect impact on forest and tourism industry because it is a typical tourist destination and mountains covered more than 80% of the total area of the province. Markov Chain Monte Carlo method was adopted to estimate ranged burnt areas considering the high uncertainty of climate and topography due to the nature of wildfire, the change of transportation accessibility, and the loss of tourism expenditure.

The economic effects of Goseong wildfire were analyzed by using the experiment of the wildfires damage under the cases of without or with climate change. Gross Domestic Product (GDP) in

Korea due to the wildfire damage decreased by −0.01% under the without climate change, −0.04% when considering climate change. The Gross Regional Product (GRP) of the Gangwon Province decreased from −0.25% to −0.55% (−0.069 ~ −0.153 billion US$) due to Goseong wildfire under the no climate change and from −0.51% to −1.33% (−0.143~−0.344 billion US$) under the climate change (RCP 8.5). The value added of industrial changes in Gangwon province decreased from −12.10% to −17.43% in forest sector and from −0.71 to 0.85% in tourism sector due to the fire damage. The value added losses of the industry under the climate change will be about 1.5 to 2.2 times larger than the scenario without climate change. On the other hand, GRP in the rest of Korea (ROK) enjoyed reflex benefits from 0.027~0.06 billion US$ due to the wildfire damage in Gangwon Province, and value added changed within the range of −0.191 ~ 0.182 billion US$ in ROK under the climate change scenario.

This dissertation developed a framework for estimating economic effects with considering the climate change applicable to other natural or manmade disasters. The developed framework was applied to wildfire damage and confirmed its usefulness. The results of the analysis can be used as a basis for establishing the government budget for disaster prevention and magnitude of the subsidy considering prioritized monetary losses by each industry. In addition, it can be used to calculate the insurance premium for damage compensation.

In the further research, it can be extended to develop a quarterly model to improve the accuracy of the economic estimates or dynamic model to consider the long-term recovery depending on the magnitude of the disaster. With regard to the policy, it need to be increasing the scale of the disaster prevention budget in response to the economic losses, providing a detour plan to improve transportation accessibility to damaged regions, and aggressive tourism marketing policy to promote tourist destinations.

Keyword: Economic impact, Disasters, Wildfires, Tourism Expenditure, Inter Regional Computable General Equilibrium Model

Student Number: 2011-30335

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Chapter 1. Introduction

1.1. Research Background and Purpose

The losses of disasters are increasing due to the unexpected abnormal weather and the rise of outdoor recreation activities. Many natural disasters, such as earthquakes and volcano eruptions, and social disasters, such as wildfires, car accidents and terrors, have occurred to affect regional economies. As an example, the massive earthquake above a 7.0−magnitude struck Haiti on 12^{th} of January, 2010. This resulted more than 230,000 people were killed, and its direct economic damage was estimated up to 13.9 billion US$ (Cavallo *et al.*, 2010). Similarly, the most powerful typhoon Maemi hit the Korean peninsula on 12^{th} of September 2003. According to the Fox News (2003), the property damage was estimated at 1.3 billion US$, with 5,000 houses destroyed or damaged and 20 major companies shut down on the southeastern coast[1]. Korea’s economy growth rate was only 3.5% due to the typhoon in 2003. The wildfire is belonging to the social disaster in Korea, which is caused by humans, while the damage is determined

[1] http://www.foxnews.com/story/2003/09/15/typhoon−maemi−kills−6−in−south−korea.html

by climate and geographical conditions. The wildfire damage and its resulting loss is growing as accelerating fire severity and intensity through the case of California in the United States (Doerr and Santin, 2016). The wildfire is one of the most risky threats to concern about industrial production losses, and the reduction of travel demand. For instance, direct impacts of the 2017 wildfire season on Montana's visitor economy, the state lost up to 0.8 million visitors due to last summer's fires and smoke, resulting in a loss of 240.5 million US$ in visitor spending and translating to a 6.8% loss in expected annual spending from the Institute for Tourism and Recreation Research (Sage and Nickerson, 2017).

Economic outputs from disaster can be classified into direct and indirect ones, Direct and indirect effects are sometimes referred to as primary and secondary (or higher-order) effects, respectively. The former includes physical damages or the consequences such as business interruption and unemployment, while the latter is defined as the consequence of interactions between transactions across sectors (Cochrane, 2004; Rose, 2004; Ding *et al.* 2011). In particular, Rose *et al.* (1997) estimated regional economic impact of an earthquake into divided by direct and indirect effects of electricity lifeline disruptions. Ryu and Cho (2010) estimated the indirect impact of the Rusa typhoon which reduced 1.18% of GDP in Korea. Many direct impacts of natural or social disasters had been conducted to estimate economic output. Meanwhile, studies on the indirect impacts of disasters has been found in a few literatures (Rose *et al.*, 1997; Kim *et al.,* 2002; Ryu and Cho, 2010; Brounrn and Derwall, 2010; Strobl, 2012; Koks and Thissen 2016). The researches on indirect impacts of disasters were relatively lacking compared to that on direct impacts. Accordingly, it would be necessary to measure the indirect effects of disasters using quantitative tools.

In Korea, natural disasters such as heavy rains, typhoons, and heavy snow had caused many damages according to the Statistics Korea. The average annual losses with respect to dead or missing for the period 2000–2016 are 49 persons, and the average property loss is 1,190.9 million US$ (constant 2016). Among Korea's disasters, burnt areas of wildfire damages have been increased due to the occurrence of 33 large scale wildfires since year 2000. As the benchmark wildfire, 2000 Goseong wildfire in Gangwon province burned the forest areas 23,674 ha and 2005 Goseong wildfire destroyed Naksan temple which is well-known cultural heritage and over 1,400 years old. However, previous papers have mainly focused on assessing direct impacts of wildfires, which implied underestimated the damage scale for not considering indirect impacts caused by wildfire disasters. Still, indirect impact analysis is insufficient because the analytic method has not fully developed yet to investigate the inter-regional and inter-industrial effects. To address this problem, it is required to develop analytic framework to estimate indirect economic losses due to the various disasters.

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect economic impacts of wildfire damage on forest and tourism industry. It can be applied to analyze the indirect economic impacts of wildfires using the Inter Regional Computable General Equilibrium (hereafter IRCGE) model. The framework is based on a stylized interregional CGE model at two macro-regional level in Korea which linked to wildfire damaged area model, tourism expenditure model and transportation demand model at a city and county level. The IRCGE model with micro modules developed in this study utilized to the analysis of indirect effects on several types of natural disasters and spatial units. Climate change had a stronger signal in the wildfires including California's. Taking the climate change into consideration, it can be utilized different database such as spatial data from the climate observations and topographical data and economic statistical areas such as a city or county level in the wildfire sites. In the study, the IRCGE model is developed for two macro regions and 12 industrial sectors on the base year of 2013. It is applied to the simulation of the wildfire in

Gangwon province of Korea where represents large wildfire area in Korea, to measure indirect impacts. The expected result show advanced method to assess indirect economic losses and its utilization of various natural disasters and policy implication of budget scale, industrial efficiency, and investment of production factors. Figure 1 presents the structure of the dissertation with specifications of motivation, literature review, methodology, simulations, and summary with further research agenda.

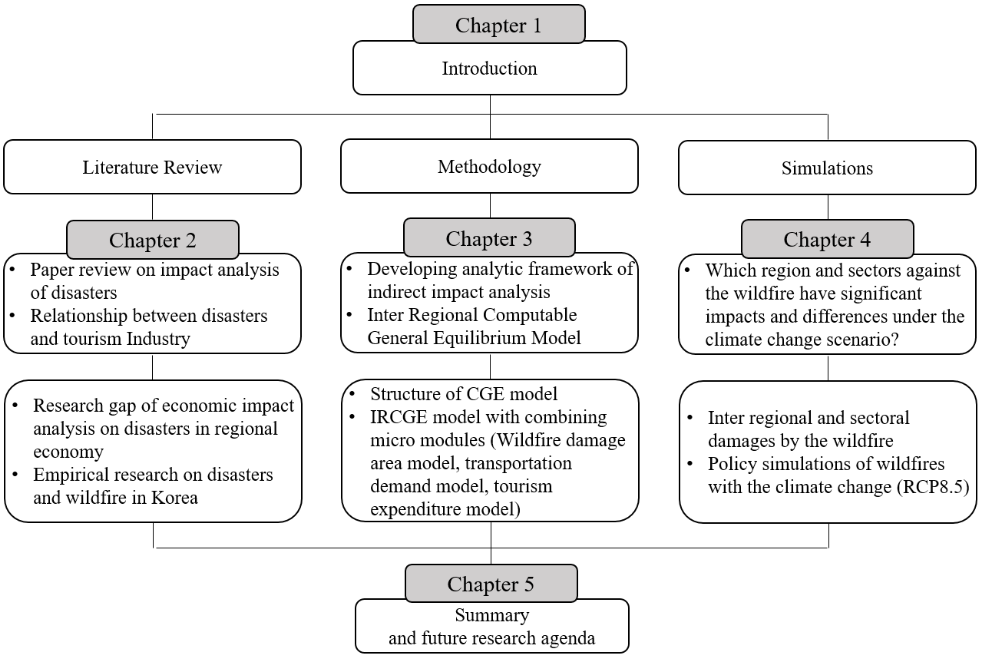

Figure 1. Structure of the Dissertation

1.2. Organization

This dissertation consists of five chapters. Chapter 1 describes the research background and the purpose of the dissertation. Chapter 2 discusses literature reviews on economic impact of wildfires, natural or manmade disasters, and tourism industrial losses of wildfires. Chapter 3 develops the IRCGE model for economic impact analysis of wildfire damages. Chapter 4 analyzes regional economic growth and value added changes through the simulations of the climate change on wildfires. Chapter 5 concludes the results and discusses policy implications for outputs of forest and tourism sectors.

Chapter 2. Literature Review

This chapter focuses on the definition and the types of disasters and then reviews previous papers on the impact of disaster on the economy and the tourism industry. There are many types of disasters, which affects the economic performance and the tourism industry directly or indirectly with various causes and magnitudes of disasters.

2.1. Definition and Typology of Disaster

There are several definitions of a disaster and its definition used seems dependent upon the discipline using the term (Turner and Pedgeon, 1997; PDM, 2002; Denis, 1995; Keller and AI−madhari, 1996; Aini *et al.*, 2001; Shaluf *et al.*, 2003). A disaster is different to a crisis in the traditional meaning of the word. A crisis is a situation in which important decisions involving threat and opportunity have to be made in a particular short time. Rather, disasters involve management procedures that must be maintained and management problems coped with under conditions of major technical emergency involving threats of injury and loss of life (Turner and Pedgeon, 1997; Richardson, 1994). To be specific, Turner and Pedgeon (1997) pointed out that no definition of "disaster" is accepted universally. Parker (1992) proposed that the definition of disaster is an unusual natural or manmade event, including an event caused by failure of technological system, which temporarily overwhelms the response capacity of human communities, groups of individuals or natural environments and causes massive damage, economic loss, disruption, injury, and loss of life. Hood and Jackson (1992) classified the disaster into three types: natural disaster, manmade disaster (socio-technical disaster), and hybrid disaster. Different terms have been used to describe the types of disasters, however, the natural and manmade disasters cover all types of disasters (Schaluf *et al.*, 2003).

Disasters defined as a natural event, manmade event, or both (Shaluf *et al.*, 2003). Natural disaster is unplanned and socially disruptive event with sudden and severe disruptive effects. Man-made disaster occurs due to interaction between human, organizational, and technological (HOT) factors and regulatory, infrastructure, and preparedness (RIP) factors. The impacts of man-made disaster sometimes transcend geographical boundaries and can even have trans-generational effects (Three Mile Island nuclear power plant disaster, Bhopal gas disaster, and Chernobyl nuclear power plant disaster). Disaster could be of a sudden impact disaster (e.g. air/road/rail accident) is usually of short duration and has a limited direct effect on local community; a high–impact disaster (e.g. flood) has a great direct effect on community over a longer period (Shaluf *et al.*, 2003). Disaster causes large scale damage to human life, physical environment and has large economic, social cost. Most disasters arise not because of a single factor but due to accumulated unnoticed events.

In Korea, disasters are defined as social disasters and natural disasters (Korea Ministry of the Interior and Safety, 2017). Social disasters are various kinds of accidents that can cause damage to lives and property. They include traffic accidents, collapses, explosions, fires, wildfires, cyber terrorism, infectious diseases, and AI. Natural disasters include storms, floods, heavy rain, strong winds, heat waves, lightning, heavy snow, droughts, earthquakes, yellow dust, cold waves, and thawing. To be specific, a disaster means a situation in which the living environment changes or damages human lives or property, so that human survival and property can not be preserved (Song, 2013). Also, a disaster can be defined as a situation in which the crisis is amplified, causing serious damage and threats to life or property, resulting in paralysis of various systems of society (Kim, 2005).

On the other hand, the types of disasters defined in the fundamental law on Disaster and Safety Management are as follows. As of 2017, the fundamental law classifies disasters into natural disasters, social disasters, and overseas disasters (revised on 26th July 2017) according to the Office of Legislation in Korea government. This is inconsistent with the disaster classification system in the field and national safety management plans and requires a clear conceptualization.

Table 1. The Types of Disasters Defined in the Fundamental Law in Korea

classification	List of disasters
Natural disaster	Storm, flood, heavy rain, strong wind, storm, flood, heavy snow, lightning, drought, earthquake, yellow sand, algal blooms, tidal water, volcanic activity, asteroids A collision or collision of a natural space object such as a meteoroid, or other natural phenomena
Social disaster	Damages caused by fire, collapse, explosion, traffic accidents (including air and water accidents), chemical, biological, and radiological accidents, environmental pollution accidents, and damages caused by the paralysis of national-based systems such as energy, telecommunications, transportation, finance, medical care, water supply, infectious disease or spread of livestock infectious diseases
Overseas disaster	Disasters that need to be dealt with at the government level as a disaster that could damage the lives, bodies and property of the Korean people outside the territory of the Republic of Korea

Source: Fundamental law on disaster and safety management in Korea (2017.7) and revised by the author.

In Korea, the study of tourism effects on disasters is at an early stage and have most likely being studied in terms of disaster management. Yoo (2014) defined that a disaster refers to an emergency state that can lead to a bad situation. The disaster is closely related to the crisis, and the disaster in the tourism sector is dealing with in the crisis management. Because disaster and crisis are two different events, however, they are related events where the crisis is more comprehensive than the disaster (Shaluf *et al.*, 2003). Yoo (2011) classified the disaster of the tourism industry into direct disaster and indirect disaster. The former includes tourism-related disputes, natural disasters, tourist-related disasters, and damage to tourists due to terrorism. The latter embrace impact of terrorism and military actions, economic crisis, and epidemics.

Table 2. Disaster Type and Contents in Tourism Industry

classification	Contents of disaster
Direct disasters	Tourism-related disputes, natural disasters, tourist-related disasters, and damage to tourists due to terrorism
Indirect disasters	impact of terrorism and military actions, economic crisis, and epidemics

In short, the wildfires covered in this study are natural disasters and manmade disasters. Wildfires belong to social disaster according to the fundamental law in Korea. In terms of characteristics of wildfires, the spread of wildfires and the magnitude of damage depends heavily on the natural environment including weather conditions and geographical features, although people cause wildfires.

2.2. Economic Impact of Disasters on Economy

This section reviewed previous papers on the impacts of natural disasters and man-made disasters. There have been numerous attempts to measure the regional economic impact of natural or man-made disasters. As discussed in Greenberg *et al.,* (2007) and Okuyama (2007), Input-Output (IO) model, the CGE model and other econometric models have been widely used in analyzing the economic impact of disasters.

Greenberg *et al.* (2007) classified impacts of disasters into with regard to the types of impacts, geographical scale, temporal scale, and ability to measure key policy consequences[2]. As the IO based

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[2] **Ability to Measure Costs and Benefits:**

1) Direct impacts—changes in business as a direct consequence of the event, and investments to mitigate, recover, and redevelop.
2) Indirect impacts—changes in sales of suppliers to directly affected businesses throughout the lifecycle, including preparedness-related investments prior to the event, impacts of suffering the event, and recovering from it.
3) Induced impacts—shift in sales due to changes in residential income.

Geographical Scale:

1) Local/county—the area directly hit by the event.
2) Regional/multicounty—surrounding area that suffers and/or benefits from the event and preparedness or recovery investments.
3) State—the host state(s) of the event.
4) National—the United States. International—nations that are impacted negatively or positively by the event.

Temporal Scale:

1) Short-term aftermath (initially monthly, then quarterly for two years).
2) Intermediate (initially quarterly, then annually for two to five years).
3) Long-term (annually for five or more years).

Ability to Measure Key Policy Consequences:

1) Investments in mitigative measures (e.g., upgrading bridges, dams, electric power transformers)
2) Investments in resiliency (e.g., education about alternative methods of production, changing schedules, use of alternative resources, etc.).
3) Impact on disadvantaged (e.g., isolated poor, immobile, and otherwise impaired).

model, Ryu and Cho (2010) estimated the indirect economic damages due to typhoons and heavy rains of Korea, and developed an 'event matrix,' which is designed to calculate new input-output structure after the outbreak of disasters. Rose *et al.* (1997) estimated the regional economic losses from earthquake-damaged electric utility lifelines in the New Madrid Seismic Zone of Tennessee with the IO and linear programming models. The potential production loss over the recovery period could amount to as much as 7% of GRP of the state. They showed how losses could be reduced by reallocating electricity resources and optimizing their recovery sequences through linear programming. Okuyama (2004) applied Miyazawa's extended input-output framework to estimate the spatial impacts of the Great Hanshin Earthquake of 1995 in Japan and its recovery process and the sequential inter-industry model (SIM) to investigate the dynamic process of the impact paths of the disaster. The SIM framework was originally developed to analyze inter-industry production in a dynamic economic environment such as large construction projects where the effects on production and employment are transitory. Gordon *et al.* (1998) also applied Southern California Planning Model, the IO based model to estimate business interruption costs of the 1994 Northridge earthquake, and found that business interruption accounted for 25-30% of the full costs of the earthquake.

Using multi regional input output (MRIO) model, in den Baumen *et al.* (2015) estimated the total indirect loss of production possibilities in national and global economy due to the 2013 flood in Germany. Direct losses of production are reduced by €3.1 billion in Bayern of Germany, other regions in Germany were investigated in the model. Economies outside Germany lost €33.8 million of their production possibilities due to reduced export of German commodities. Most severely indirectly affected by losses in production are the real estate service sector, transport equipment production, and other business services in Bayern. When it comes to reducing damages and disruption from disasters, secondary effects of disaster are taken into account and supply chain restrictions from other partner economies are involved with recovery of production possibilities in the risk management.

A transportation network was integrated with the IO model such as Cho *et al.* (2001) and Sohn *et al.* (2003) to analyze the economic impact of the earthquake on transportation network for the Midwest states. The modeling system of Sohn *et al.* (2003) included a transportation network loss function, a final demand loss function, and an integrated commodity flow model. The paper showed that the economic significance was not always determined by not only the level of disruption but also the volume of flow on the link, relative location (topology) on the highway network, and the strength of the economic activities near the network link. Cho *et al.* (2001) developed an integrated and operational model of losses due to the earthquake impacts on transportation and industrial capacity, and showed how these losses affected the metropolitan economy. The model could trace the effects of an earthquake on the Los Angeles economy, including its impact on the transportation services delivered by the highway network. It also incorporated bridge and other structure performance models, transportation network models, spatial allocation models, and the IO models into a composited operational system. They found that the spatial distribution of these losses were sensitive to changes in network costs by transportation structure losses. Kim *et al.* (2002) estimated earthquake impacts on transportation cost using input-output analysis integrated with transportation demand model based on the U.S. interstate highway system. The regional impacts of transportation disruptions caused by the earthquake was calculated in three scenarios, one of three evaluated the reduction of overall shipment cost 186 billion ton mile/year and average 10.82 miles. The results provide a basis fro making policy decisions to mitigate unexpected disasters and for planning to construct new highway network sections to strengthen the existing network. Koks and Thissen (2016) considered production technologies and constraints of supply side of transportation demand in the integrated recursive dynamic multiregional supply-use model and investigated economic impacts caused by three floods of Rotterdam in Netherlands. Although abundant studies have developed models to estimate the economic impacts from disasters, they asserted that more research focuses on assessing the indirect losses outside the affected region in more detail as well. Baghersad and Zobel (2015) provided a new linear programming model, based on Leontief's input-output model, to investigate the economic consequences of production capacity bottlenecks caused by disasters. An important contribution of the paper is the incorporation of industry sectors' preferences in allocating limited products/services between final domestic demand, foreign final demand, and intermediate industries. This provides support for estimating some of the indirect economic impacts of disasters when the electricity sector of Singapore is disrupted. An extension of the model is provided recovery operations within disrupted sectors, from the standpoint of evaluating the performance of the economy during the transition period after a disaster. The results of 12 different scenarios showed that the total average inoperability and total inoperability of the entire economy decrease with decreasing initial loss and increasing recovery within the electricity sector. This implies that improving the robustness of the electricity sector can have a stronger impact on the total average inoperability of the economy than decreasing the recovery time.

The CGE is another popular analytic framework measuring economic impact of disasters and well-documented approach include supply side effects and price flexibility due to the non-linearity. Bosello *et al.* (2007) used the CGE model to measure the amount of land and capital loss due to sea level rise in the coastal regions. The GDP and the energy consumption would fall down without the coastal protection, but could increase in the regions with substantial dike building in spite of a reduction in the utility level with the coastal protection. Tatano (2008) presented an analytical framework to estimate the economic losses incurred due to transportation network disruption after a catastrophic earthquake. The Spatial CGE model was designed to capture properties involving time and integration with the transportation network, and was applied to estimate the transport-related loss arising from the Niigata-Chuetsu earthquake. The simulation found that a spillover pattern of economic losses arising from the earthquake over regions with respect to the intra- and interregional trade. This paper discussed that countermeasures were needed to reduce negative spillovers to the unaffected regions as well as the adoption of mitigation policies for the reduction of damage to houses and facilities. Rose *et al.* (2005) analyzed the economic impact of a disruption of water services in the Portland Metro economy. It showed how indirect economic losses depended on water shortages, the extent of pre-event mitigation, and post event inherent and adaptive resilience.

Recently, it is proposed incorporated micro models with Input output or CGE model to get detailed estimates of economy-wide disaster losses. Husby and Koks (2017) suggested estimating the impact of disasters specified on household migration, which can be a transmission way of disasters to other regions and industries through combining Input output model or CGE model with ABMs. A main advantage of these models is their capability to capture the ripple effects, whereby the impacts of a disaster are transmitted to regions and sectors that are not directly affected by the event. They emphasized that the literature of disaster impact analysis contains no examples of studies attempting to hard link IO or CGEs with ABMs. An example of a soft-linked model CGE-ABM was Husby (2016) who applied an ABM of opinion dynamics to analyze the impact of public concern of disaster losses predicted by a spatial CGE model. Increasing public concern reduces the utility flow from amenities in the disaster struck region, making this region less attractive as a place of residence.

In addition to the most commonly used IO and CGE models, the economic effects of disasters were analyzed by means of econometric models, cost analysis, and synthesis control method. As it is discussed in Richard *et al.* (1984), Hong *et al.* (1996), and Strobl (2012), econometric models were utilized for investigating economic losses combined with several specified models such as transportation model, supply side model, and longitudinal model. Richard *et al.* (1984) developed a regional econometric model that was mainly focused on supply-side factors such as capital investment, migration, and transportation in the model structure. It identified how regions received different economic impacts from the natural disasters in terms of the degree of spatial disaggregation. They argued that the reconstruction was a key factor on the long-run growth and recovery path of regions in a sense that the income gains from the post-disaster period could offset income losses.

In the aftermath of the disaster, post-natural disaster in the long-run might benefit from a process of "creative destruction" (Skidmore and Toya, 2002; Cuaresma *et al.*, 2008). It is argued that interactions with income variables indicate that the level of development of the country has an effect on the elasticity of R&D

spillovers to catastrophic risk, with richer countries eventually experiencing creative destruction after a disaster (Coe and Helpman, 1995; Coe *et al.*, 1997; Cuaresma, 2008). Hong *et al.* (1996) calculated monetary losses due to the natural disaster of the nuclear power plant, although it was less relevant to the economic impact analysis. They estimated economic cost incurred by accidents in the nuclear power plants, while the overall costs were disaggregated into replacement power cost, capital investment cost, plant repair cost, early decommissioning cost, health cost, evacuation cost, relocation cost, agricultural product disposal cost, and decontamination cost. Strobl (2012) investigated the macroeconomic impact of hurricanes in developing regions, which are Central American and Caribbean areas. The average hurricane strike caused the growth rate in GDP to fall by at least 0.83 percentage points in the region using wind field model and econometric panel model.

Analysis of post– disaster effects on the regional economy has been widely conducted through econometric models. Belasen and Dai (2014) investigated the impact of hurricanes in Florida on county level taxable sales revenues using the econometric model. Within six months after a hurricane strikes a county, revenues declined as much as 17%, whereas revenues in neighboring counties increased by upward of 17% over that same time frame. Particular focus is given to tourism-related sectors within the regional economy.

Lastly, they showed that along the pathways of hurricanes, initially hit counties face a more severe burden, ranging as high as a 33% immediate decline in taxable revenues in one month for coastal counties. Agnolucci *et al.* (2017) estimated the causal impact of GDP on domestic material consumption (DMC) applying the number of storm occurrences as an instrument for GDP. Some material prices affected in the short term but this effect disappears two years after a storm occurs. The outcome addressed new evidence that increasing the GDP growth rate causes an increase in the DMC growth rate for Western Europe based on a panel dataset of 32 European countries from 2000 to 2014. Lis and Nickel (2010) assessed the impact of large scale extreme weather events on changes in public budgets and their implications based on a panel data set for 138 countries and from 1985 until 2007. Extreme weather events comprise the following disasters: drought, extreme temperature, flood, mass movement dry, mass movement wet, storm, wildfire. Budgetary impact of disasters ranges between 0.23% and 1.4% of GDP depending on country group using the econometric model. The fiscal policy can be a crucial instrument on reducing disaster damage and its recovery but none of these studies examined the impact of change on public finances before this paper.

There are utilized synthetic control method for capturing long term economic impact by post disasters including hurricanes and earthquakes. Coffman (2012) measured the long−term economic impact by the Hurricane Iniki 1992 for Kauai’ s economy. The damage was estimated US$ 7.4 billion for 2008 but has yet to recover, 18 years after the disaster. Barone and Mocetti (2014) examined the impact of two large−scale earthquakes that occurred in two different Italian regions in 1976 and 1980 through the synthetic control approach. The short−term effects were negligible in both regions, though they became negative if we simulate the GDP that would have been observed in absence of financial aid.

In the long−term, the findings indicated a positive effect in one case and a negative effect in the other, largely reflecting divergent patterns of the TFP. DuPont and Noy(2015) also used synthetic control method to reinvestigate 1995 Earthquake in Japan even 13 years after the quake. A decline in per capita GDP for 2008 was yen 400,000 per person lower (12% decrease) than it would have been had the earthquake not occurred. Importantly, the adverse long term impact is identified in a rich region of a high income country and with the backing of a deep−pocketed fiscal authority.

With changes in GDP caused by disasters, Padli *et al.* (2010) employed cross−sectional analysis to investigate a relationship between economic condition and the economic impact of natural disasters. The major independent variables were GDP per capita, the government consumption ratio to GDP, the years of schooling attainment, the land area and the population size. Cerqua and Pietro (2017) investigated effects of 2009 L'Auila earthquake on educational outcomes in developed countries using the synthetic control method. This event killed 309 people, injured more than 1,500 individuals, and caused widespread damage and destruction. The potential decline in the university enrolment following the disaster could have considerable detrimental economic effects given the important role of students in providing jobs, rental income and demand for local goods and services. With this in mind, the analysis showed that the subsequent enrolment at the local university in Germany had no statistically significant effect on first−year in the three academic years after the disaster. The natural disaster, however, caused a compositional change in the first−year student population, with a substantial change in the number of students aged 21 or above.

The man−made disaster research is relatively inferior to the natural disaster and has focused on the effects of stock market, taxable sales in regional economy due to terrors and riots. Brounrn and Derwall (2010) estimated the price effects of the 9/11 terror on international stock markets, using a multivariate dummy regression model. Compare to the price impact of a different set of unexpected natural disasters, it is found that the effect of terrors have greater economic and statistical importance than one of natural disasters. The immediate price reaction to the major terror attacks that have occurred since 1990 averages −0.34%, which translates into a negative annual price impact of over 134%. However, these findings are severely weakened when the 9/11 attacks are excluded from the sample. Baade *et al.* (2007) examined taxable sales in the Los Angeles and Miami metropolitan areas to find evidence of the short- and long-run effects of the Rodney King riots 1992 and Hurricane Andrew 1992 on their respective economies using the intervention analysis. The comparison of these two events shows that the man-made disaster, King riots, had a long-term negative effect on Los Angeles' economy while the natural disaster, Hurricane Andrew, had a short-term positive effect on the Miami economy.

Table 3. Impact Analysis of Disasters

Author	Type of Disasters	Model	Impacts / Key Issues
Richard *et al.* (1984)	Earthquake	Econometric model	Long run and short run impacts
Hong *et al.* (1996)	Nuclear plant disruption	Cost analysis	Cost analysis
Rose *et al.* (1997)	Earthquake	Input Output model and Linear programming	Reduction in GRP (7%)
Gorden *et al.* (1998)	Earthquake	Input Output model	Cost of business interruption
Cho *et al.* (2001)	Earthquake	Input Output model	Integration of network model, spatial allocation model and IO model
Kim *et al.* (2002)	Earthquake	Input Output model	IO model combined transportation model
Sohn *et al.* (2003)	Earthquake	Input Output model	Network effects on transportation
Okuyama (2004)	Earthquake	Sequential inter-industry model	Impacts on inter-regional and inter-industrial sectors
Rose *et al.* (2005)	Disruption in water service	CGE model	Impacts of water service disruptions
Baade *et al.* (2007)	Hybrid disaster	Intervention analysis on ARIMA model	Taxable sales dropped 1.29%p in the city during the Rodney king riots
Bosello *et al.* (2007)	Sea level rise	CGE model	Impacts on GDP and energy consumptions
Tatano (2008)	Earthquake	Spatial CGE model	Direct and indirect spillover effect on regional economies
Ryu and Cho (2010)	Typhoon and heavy Rain	Input Output model	Reduction in GDP (1.18%)
Padli *et al.* (2010)	Natural disaster	Econometric model	Linkage between economic condition and impacts
Brounrn and Derwall (2010)	Terrorist attack	Econometric model	Negative price effects on financial markets (−0.34%)

Table 3. (Continued)

Author	Type of Disasters	Model	Impacts / Key Issues
Brounrn and Derwall (2010)	Terrorist attack	Econometric model	Negative price effects on financial markets (−0.34%)
Strobl (2012)	Hurricane	Econometric model	Average hurricane strike caused output to fall by at least 0.83 %p in the developing region
Barone and Mocetti (2014)	Earthquake	Synthesis Control method	Financial aid might either increase technical efficiency
Belasen and Dai (2014)	Hurricanes	Econometric model	Reduction of taxable sales revenues 17%
Baade *et al.* (2007)	The Rodney King riots and Hurricane Andrew	Intervention analysis	The King riots had a long−term negative effect on LA' economy while Hurricane Andrew had a short−term positive effect on the Miami economy.
Lis and Nickel (2010)	Extreme weather events	Econometric Analysis	Impact of climate change on public finances 0.23%~1.4% of GDP
In den Baumen *et al.* (2015)	Flood	MRIO model	Indirect loss of production €6.2 billion
Baghersad and Zobel (2015)	Disasters	New linear programming model with IO system	Indirect economic impacts of disasters
Koks and Thissen (2016)	Floods	IO model	Supply driven regional IO model with transport disruption
Klomp (2016)	1,000 natural disasters	Econometric model	The amount of damage caused by a single meteorological or geophysical event is on average about 2.5 times larger than for a flood or major drought

Table 3. (Continued)

Author	Type of Disasters	Model	Impacts / Key Issues
Cerqua and Pietro (2017)	Earthquake	Synthetic control method	Increase of number of students aged 21 or above after the disaster
Agnolucci *et al.* (2017)	Storm	Econometric Analysis	Increases of domestic material consumption
Husby and Koks (2017)	Disasters	IO, CGE model with ABMs	Suggesting combining micro model with IO or CGE model

* This table is revised from Kim and Kwon(2016) in the book chapter of 『Quantitative Regional economic and Environmental Analysis for Sustainability in Korea』.

The disaster causes an instantaneous destruction of capital stock in the neoclassical growth system. The reduction of production factors such as capital, labor, and land due to disasters can cause economic damage and reduce economic growth in developing analytic frameworks. Post-disaster economy converges towards its long-run, steady-state equilibrium through faster capital accumulation. Therefore, it can be found that decrease of the GDP in the short run while no effects in the long run. However, this is clearly an oversimplification since it does not capture other channels through which the disaster might impact on the production function, on the inputs and on their use. In more detail, more traditional neo-classical growth models, like the Solow model, predict that the reduction of the capital-labor ratio drives countries temporarily away from their long run growth path, while the endogenous growth models provide less clear-cut predictions. For example, models based on Schumpeter's creative destruction theory may even predict higher growth rates as a result of natural disasters since these shocks can work as an accelerator for upgrading the destroyed capital stock (Klomp and Valckx, 2014; Loayza *et al.*, 2012; Cavallo *et al.*, 2013).

On the other hand, West and Lenze (1994), Klomp (2016) have pointed out, there are several difficulties in assessing the economic impact of the natural disasters because the majority of all disasters happen in different spatial units, where macroeconomic research is hampered due to the unreliable economic data. First of all, the event size is uncertain and unknown, and is not classified into industrial sectors as proposed in the IO and CGE models. These might cause a double-counting problem to measure benefits and costs of the disasters. Klomp (2016) exemplified that based on the estimates of EM-DAT (2013) the amount of damage caused by a single meteorological or geophysical event is on average about 2.5 times larger than for a flood or major drought. It would be difficult to regard the disasters as exclusive supply or demand events, and to expect the exact behavioral patterns of households and firms after the outbreak of disasters. The final outcomes of the analysis tend to be very sensitive to initial conditions and assumption underlined in the model and research design.

This study focused on the trend that the risk of large scale wildfires, damaged areas are above 100 ha in Korea, has increased sharply since 2000 (Lee and Lee, 2011). Looking at the 33 large-scale wildfires since 2000, Gangwon province has 17 wildfires occurred according to the Chosun Newspaper in Korea[3]. More than 50% of the large wildfires in Korea have been concentrated in Gangwon province, where depends heavily on the tourism industry in the regional economy, therefore it was decided to be the study area in this research for analyzing economic impacts of the wildfire.

There are previous papers on impact analysis of wildfires and mostly focused on estimating direct economic effects of wildfire losses. Cost approach of suppression has been a primary method for the economic analysis of the wildfire (Rahn, 2009). Mercer *et al.* (2000) examined an economic impact of catastrophic wildfires and efficacy of fuel reduction in Florida with spatial and econometric models. The loss by the 1998 Florida wildfires was estimated as 622-880 million US$ including costs of timberland owners (345-605 million US$), the tourism industry (138 million US$), and the resources diverted to fighting the fires (100 million US$). Kunji *et al.* (2002) reviewed the effect of the wildfire on air quality and health

[3]http://news.chosun.com/site/data/html_dir/2017/05/19/2017051901911.html

in Indonesia. More than 90% of respondent had respiratory symptoms, and elderly individuals suffered a serious deterioration of overall health. Between September 1997 and November 1997 in Indonesia, there were 527 hazed-related deaths, 0.30 million cases of asthma, 58,095 cases of bronchitis, and 1.45 million cases of acute respiratory infection reported.

Multivariate analysis showed that severity of respiratory problems relied on gender, history of asthma, and frequency of wearing a mask. The wildfire and the trans-boundary haze resulting from the fires affected several neighboring countries for a period of about four months, having a significant impact on health, daily life, transportation and air traffic (Kreimer, 2001). Rahn (2009) estimated the overall economic impact of wildfires on regional economies in San Diego. The total economic impact of the 2003 wildfire in San Diego County was approximately 2.45 billion US$ or $6,500 per acre. The total suppression cost was less than 2% of the entire economic impact, which was a relatively negligible cost in contrast to the overall loss.

In recent years, there have been an increasing number of cases in economic effects analysis of wildfires for specific fields in the economy: studies on the effects of wildfire on housing price, labor market, medical cost, and climate changes. Most frequently used method are econometric model or input output model in the study following the cost analysis. However, the analysis on indirect effects of tourism industry caused by wildfires are still insufficient and have focused on direct effects, that is, calculating wildfire damages only.

Moseley *et al.* (2012) analyzed the effects of large wildfires in California during 2004–2008 on labor markets and how wildfire suppression spending may mediate these effects. Local employment and wages in a county increased during the wildfire; the economic impact of the suppression effort outweighed the economic disruption from wildfires in the short term. The wildfires caused a longer–term instability in local labor markets by amplifying seasonal variation in the employment in tourism and natural resource sectors. Kiel and Matheson (2015) analyzed housing price effect of canyon forest fire in Colorado 2010 captured by home owner's perceptions about the risk of living in forested area subject to wildfires. The sale price of housing expected to be declined 21.9% caused by wildfire through the difference–in–difference approach. Kochi *et al.* (2016) investigated economic cost of wildfire smoke exposure as counting medical cost in hospital admissions at the period of 2007 through time–series count model and negative binomial model. The total medical cost were estimated over 3.4 million US$ associated wildfires in Southern California.

In the context of global climate change, Melvin *et al.* (2017) focused potential economic implications from changes of wildfire by climate, which is the burned area and its respond cost along to the RCP8.5 and RCP4.5 scenario using Alaskan Frame−based Ecosystem Code (ALFRESCO) model. Estimated cumulative response costs were of 1.2−2.1 billion US$ with averaged burned 46.7 million ha for RCP8.45 and 1.1−2.0 billion US$ with 42.1 million ha for RCP4.5 between 2006and 2100 across Alaska.

The analysis of the economic effects of wildfires in Korea is considerably insufficient in comparison with the large scale damage of wildfires. With regard to the methodology of wildfire effects analysis, there were recently used input−output model, cost analysis, and contingent valuation method (CVM) similar to that of overseas studies. Lee *et al.* (2017) analyzed the local economic effects of wildfire restoration grants from the government. In detail, it was analyzed a ripple effect of government aid for 2000 the east coast wildfire restoration through the input−output analysis. Direct production inducement effect was higher than indirect production inducement effect except for construction sector. In addition, The economic effects of production, employment, and income in three damaged regions affected by forest fires were compared and its efficiency of government aid. Woo *et al.* (2001) estimate overall timber losses of the east coast wildfire 2000 in Gangwon province in Korea using cost analysis. Not including economic impact of the wildfire, total timber losses were calculated 96.5 million US$ and among them pine trees were recognized the most vulnerable type as occupied 69% of total estimated amount.

Exceptionally, it has been studied in terms of loss of value of forests caused by wildfires. Ko *et al.* (2016) estimated the value of one mountain using CVM method consuming the forest will be disappeared by wildfires. They asserted the importance of Seowoo-bong in Jeju island as natural resources for utilizing recreational, historical, iconological, and scenic value in regional economy.

Table 4. Impact Analysis of Wildfires

Author	Country / Region	Method	Impacts
Malanson and Westman (1991)	USA / California	Computer simulation model	Interactive effects of CO2-induced climate on a drought-deciduous shrub land in California
Mercer *et al.* (2000)	USA / Florida	Spatial and Econometric Analysis	Economic losses of 1864$ per acre by 1998 Florida Wildfires
Kunji *et al.* (2002)	Indonesia	Econometric Analysis	Change in mortality by 1997 Indonesian wildfire smoke
Fried *et al.* (2004)	USA / California	Cost analysis	Increased burned area by climate changes
Rahn (2009)	USA / California	Cost analysis	Cost of 2.45 billion US$ by 2003 wildfires in San Diego County
Moseley *et al.* (2012)	USA/ California	Econometric Analysis	Increases in local employment and wages during large wildfires of 2008 California.
Duffield *et al.* (2013)	USA / Yellowstone National Park	Input Output Analysis	Losses for recreational use at US$108.29 per ha and regional economic impacts at 159 million US$ in Great Yellowstone Area for the 1986-2011
Kiel and Matheson (2015)	USA / Colorado	Econometric Analysis	Housing sale prices declined 21.9% wildfire in Colorado, 2010
Kochi *et al.* (2016)	USA / California	Econometric Analysis	Medical costs caused by wildfire smoke exposure were over 3.4 million US$ from the wildfires in Southern California 2007
Melvin *et al.* (2017)	USA/ Alaska	Cost analysis	Burned cost 1.2-2.1 billion US$ for RCP8.5 and 1.1-2.0 billion US$ for RCP4.5

Upon the analytic database used, previous papers on wildfires have focused on the changes of forests appearance due to wildfires and its damage scale analysis on the forest trees and crops. However, the application of the spatial micro data which has a great influence on the occurrence and spread of wildfires was insufficient. The spatial micro data have the advantage of accurately analyzing the probability of occurrence of wildfires and the spatial diffusion area. Diffusion and damage areas of wildfires vary depending on the conditions of environmental factors, including the characteristics of local wildfires, are important guidelines for disaster prevention and suppression. The research based on spatial microdata can provide information to help prevent wildfires from spreading early and contribute to reducing damage from wildfires.

On the other hand, previous studies on the calculation of wildfire damage tend to focus mainly on forest timber loss, partly included wildfire suppression budgets and recovery costs. In addition to the primary forest products loss, which has concentrated on previous research, it is necessary to consider secondary damages to the regional economy, such as the suspension of industrial production activities such as agriculture, forestry and tourism service, the reduction of visitor demand, congestion of transport traffic from the road control. Furthermore, indirect damages caused by large-scale wildfires can have a negative impact on the related industries, leading to long-term economic recession in the developing region, which could be beyond direct cost of forest damages. It is required to use spatial micro data for examining regional economic impacts of wildfires for the accuracy, because indirect damage analysis can be sensitive to the damaged area of wildfires. Assessment of the economic effects of developing areas based on the calculation of the damaged area of wildfires can be used to increase the economic understanding of the wildfire disaster prevention and to estimate the investment amount of the government budget.

2.3. Economic Impact of Disasters on Tourism Industry

Disasters resulting from natural and human-made hazards are frequent occurrences throughout the world (International Federation of Red Cross and Red Crescent Societies, 2006). Tourism destinations located in high-risk disaster regions face greater challenges in developing a tourism economy (Tsai *et al.*, 2016). Prideaux (2003) recognized the next three types of disaster focused on tourism activities: (1) several types of disasters (e.g. earthquakes, typhoons, floods, droughts, and wildfires); (2) sudden climate change in a long term perspective; and (3) global epidemics caused by a new types of influenza or undiscovered diseases, for such events give rise to the most frequent and serious losses at tourism industry.

The unexpected damages in previous papers resulting from tsunamis, floods, typhoons, earthquakes, often disrupt tourism businesses in destination economies. In comparison with most other industries, tourism is highly reliant on the natural environment and weather conditions (Bode *et al.*, 2003). The impacts of tourism industry caused by disasters may have both positive and negative consequences (Ap and Crompton, 1998; Mathieson and Wall, 1982).

With regard to the analytic method, Econometric model, IO model, and CGE model mainly have applied to investigate the economic effects of disasters on tourism behavior, tourism industry, and regional economy.

Disasters have tremendous impacts on tourism industry, as discovered by hurricane Katrina in 2005, the South−Asia tsunami in 2004 and severe acute respiratory syndrome (SARS) in 2003 (Tsai *et al.* 2016). The analysis of hurricane impacts on tourism investigated in Woosnam and Kim (2014), Belasen and Dai (2004), Kim and Marcouiller (2015) that showed tourism visitor volumes, revenue decline, tourism−based economy within the context of social vulnerability and resiliency. To be specific, Woosnam and Kim (2014) considered impacts of hurricanes in the southeastern United States containing coastal national parks based on two longitudinal data methods such as panel logit and autoregressive integrated moving average model. This paper focused on the relationship between the duration, intensity, and damage of hurricanes; existing climate conditions; and tourism demand on park visitation during hurricane and tourism seasons. With regard to the response of tourism economies to disaster damages, the park that encountered stronger catastrophes can be closed for a longer period in order to reconstruct facilities or natural/cultural resources damaged by storms.

Another hurricane damages, Belasen and Dai (2004) examined the impact of hurricanes in Florida on taxable sales revenues using an econometric model. Revenues declined by 17% for six months after a strike of the hurricane and tourism sector in Florida is the largest source of revenue. However, it was not possible to analyze the impact on the tourism sector due to data limitations. Kim and Marcouiller (2015) developed a conceptual model of disaster loss factors to estimate the vulnerability and resiliency of 10 tourism based regional economies including US national parks or seashores affected by several hurricanes over 26-year period through a negative binomial panel regression and a difference-in-difference model. Both direct and indirect economic effects investigated to regional economy affected by disasters in tourism-based economy and disaster-prone areas.

The storm triggered a major flood in Charente-Maritime, which had a number of impacts: oyster farms (a major employer in the area) were destroyed, the tourism sector suffered, and productivity of agricultural land (including wine production) was affected by salty sea water (Lumbroso and Vinet 2011; Genovese and Przyluski 2013). Yeoman *et al.* (2007) considered the impact of oil and energy price rises on Scottish tourism industry using CGE model, as transport and oil have been recognized the most influential factor of tourism growth. Therefore, there are selected key variables such as oil forecasts, security of supply, cost of production, world demand, alternative forms of energy including renewables and nuclear power. The triggers can be considered as unexpected disasters, political instability, and economic shocks for oil price fluctuations. As oil price rises, international expenditure drops by 37% and 27% in two different scenarios, which are energy inflation, paying for climate change respectively because the tourist can be burdened transportation cost for long distance travel by airplane. In terms of inflation caused by increasing oil prices, consumer price index (CPI) affected to the threat of stag-inflation which leads to a reduction in disposable income and discretionary spending because of slow value added growth and rising inflation.

There was no significant impact on tourism industry in the short term, but long term impact of rising oil prices came on Scottish tourism. Guo *et al.* (2017) focused on economic impacts of visitor spending for coastal economy, where is highly sensitive to natural and human disasters and changes in economic conditions. Using IMPLAN input-output model, Survey Sampling International (SSI) presented approximately 16.4% million travelers visited Alabama and Mississippi Gulf Coast in 2013 and the average per visitor spending was $730.11. In total , sales revenue $17.6 billion was estimated and it can be transferred value added $7.4 billion, labor income $5.9 billion, and 200,000 full and part−time job in the five coastal counties.

The wildfire is one of the most risky threats we need to be concerned about industrial production losses, travel demand declines, and places images of tourist destination and resources. According to the 2017 wildfire damage of Montana tourism industry, its direct impacts was estimated on the Montana's visitor economy during the wildfire season using the cost analysis. The entire state lost up to 800,000 visitors due to last summer's fires and smoke, resulting in a loss of US$240.5 million in visitor spending and translating to a 6.8 percent loss in expected annual spending from the Institute for Tourism and Recreation Research (Sage and Nickerson, 2017). Pyke *et al.* (2016) focused on the direct impact of 2013 bushfire in North East Victoria, Australia due to the fire and post−fire flooding. During the burnt for 55 days in early 2013, visitor spending losses were approximately $1.5 million based on the visitor survey with personal average expenditure of $184 per day. To minimize the economic effects of fire events, they asserted that the tourism planning and improved stakeholder communications are necessary to be emerged as key priorities and revealed adaptations through the destination sustainability framework (DSF) in the paper.

There are still recognized as shortage of research investigating impact analysis on tourism industries after disasters including wildfires. In addition to disasters on tourism destinations, increasing losses of tangible and intangible cultural heritage as tourism resources during these disasters need to pay attention to the protection policy (Marrion, 2016). More attention can be given to indirect effect of disasters on the region and its neighboring regions regarding to sectoral linkages to minimize overall effects by disasters and to prepare recovery management.

2.4. Implication of Literature Review

The literature review is summarized in the following three sections. Firstly, the frequency of disasters increases with the climate change, and the scale of damage is also growing. In previous papers, there are discussed with major disasters such as a hurricane, storm, earthquake, flood in the natural disaster and also a terror, wildfire, nuclear plant disruption in the human-made disaster. The analytic method of economic indirect impact analysis are repeatedly used Input-output model, CGE model. Direct losses of disasters have been mainly investigated through the econometric model and Cost analysis. In analysis of economic effects on disasters, double counting problems arise due to the uncertainty and unknown characteristics of disasters. Additionally, the magnitude of disaster damages is likely to be increased by an average of 2.5 times depending on climate conditions and terrain features. The final output of disaster impacts are sensitively changed depending on the initial damage conditions. The idea suggested by Husby and Koks (2017) need to be advanced to improve disaster damages as combining with micro models based on CGE model considering both side of demand and supply changes.

Secondly, the economic effects of wildfires were mainly conducted in the United States, where wildfires are large and frequent. Input output model, Econometric model, Cost analysis are mainly utilized in the analysis of regional economic effects. Mostly, direct damages to timber losses were mainly estimated, however, analysis of indirect economic effects were insufficient. In addition, analysis of regional economic effects on the damage of wildfires caused by climate change was limited.

Third, impacts of disasters on tourism have largely been examined with emphasis on economic damages and recovery policies. However, there are shortage of impact analysis caused by wildfires on tourism industry and tourism destinations. Similar to the disaster impacts on the general economy, analysis of wildfire impacts on tourism have applied by the cost analysis, econometric model, input output model, and CGE model. With regard to the wildfire on tourism industry, it is necessary to capture indirect impacts on regional or sectoral spillover from the unexpected events. The overall losses of wildfires need to be analyzed from the long term perspective. At the same time, secondary wildfire damages such as flooding and its smoke can be significant on property loss and human health not only for neighboring areas but also for linked industries including service sectors.

Chapter 3. Methodology

This chapter introduces the outline of the whole methodology and explains the CGE model structure, wildfire damage area model, transportation demand model, and tourism expenditure model as the micro modules.

3.1. Overview of Analytic Framework

The main objective of this study is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry of Korea. Figure 2 presents the structure of this dissertation with specification of analysis methodology corresponding to the main object. Among various disasters in Korea, this dissertation focuses on the wildfire as increasing risk of forest resources and its growing burnt areas in Korea after 2000. Mountainous areas with natural or cultural heritages have been widely used as the tourist attractions, particularly, climbing or hiking mountain is the most popular activity in outdoor recreations in Korea.

The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage area model, transportation demand model, and tourism expenditure model. The

IRCGE model is described two macro regional economy under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model predicts wildfire losses with high uncertainty and complexity based on database of temperature, wind speed, and humidity from the Ministration of Korea Meteorology. And wildfire statistics of forest type and slope features by spatial unit are from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The dependent variable is explained by personal income, previous year's daily travel costs, number of establishments in a destination, population of origin places, number of culture legacy, and road accessibility. The estimated burnt area in the wildfire damage area model affects to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

To estimate the indirect economic impact of wildfires on the regional economy and sectoral effects, the analytic framework is applied after connecting stylized IRCGE model with three sub-modules. The three modules are consisted of as follows in detail.

First, the wildfire burnt area is calculated in the wildfire damage area model by converting into land assets and timber assets based on statistics in Bank of Korea on the base year of 2013. The amount of wildfire damages is directly linked to reduce the capital stock in production factor inputs and final demand losses of timber for landscape gardening in IRCGE model. It resulted in losses of the gross regional production (GRP). Second, this dissertation assumed that certain radius of wildfires restricts passage of people and vehicles across the roads. Accordingly, they need to detour to other roads while paying additional transportation costs. These changes in transportation accessibility increase the production cost to be included in the production function. Finally, the rising transportation costs in personal travel budget can affect to decrease tourist numbers, as tourists choose alternative destinations considering the risk aversion behavior of tourists instead of the prescheduled destination.

The losses of capital stock in the production, final demand, and tourism destination revenues will be the inputs as the shock variables into the IRCGE model. The damages generated in the region spread positive or negative effects on other regions beyond the border through the economic linkages in the production, consumption, and price mechanism. This analysis process explores regional economic impacts on Gangwon and the rest of Korea (ROK) caused by wildfire of the Gangwon province. The impacts will be included production, income, consumption, and value added changes of industrial sectors of the two regions of Korea through the IRCGE framework.

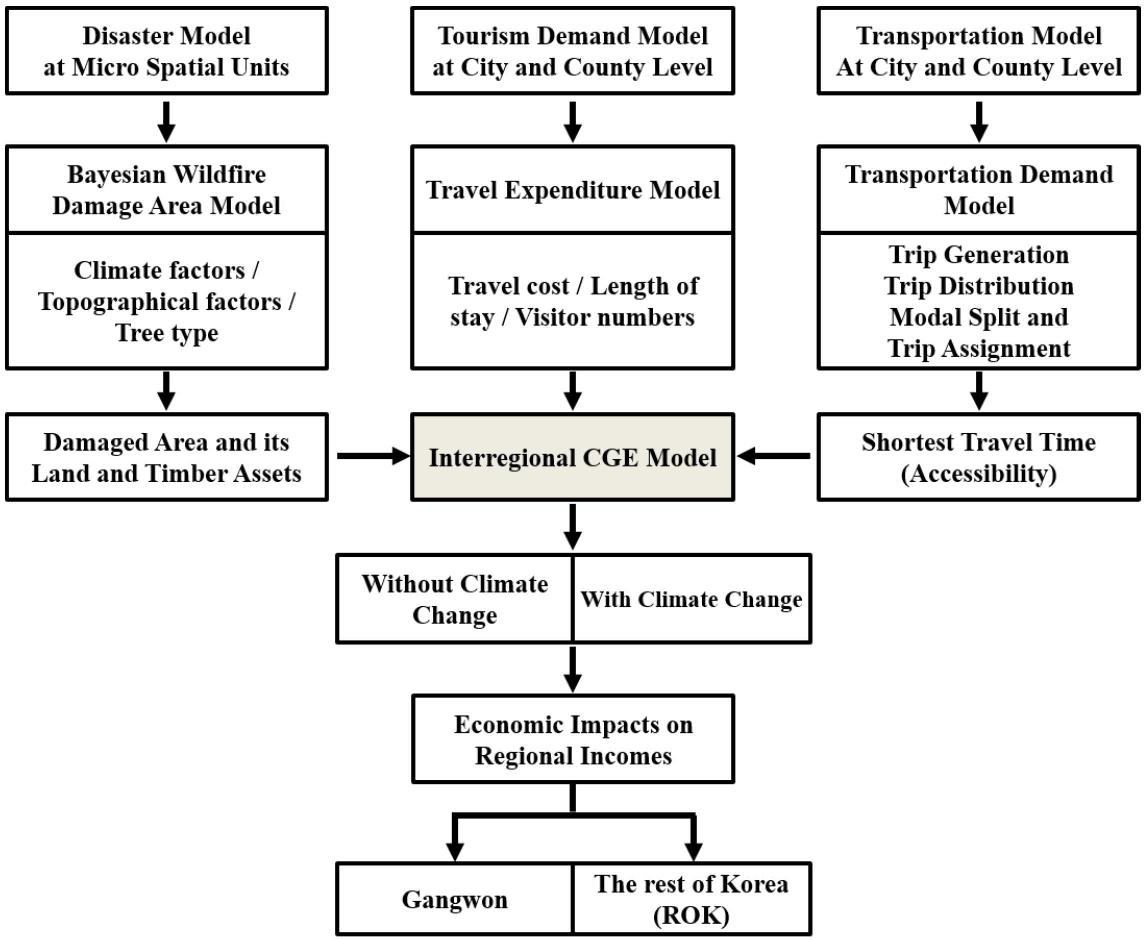

Figure 2. Structure of IRCGE Model for Economic Analysis of Wildfires

3.2 Computable General Equilibrium (CGE) Model

The Computable General Equilibrium (CGE) model indicates an economic system that describes the process of balancing the equilibrium state between demand and supply by flexible price adjustments. The economic agents in the model consist of the household, producers, and government. It is assumed that markets of production factors and commodities are perfectly competitive and all the agents are price takers.

Specifically, the commodities are produced by the producers with the factor input to maximize its profit, which are assumed subject to its production technology constraint under given output and input prices. The factor income is created by the producers and paid back to the provider of the factors such as the household. The household spends received factor income to purchase the commodities. In the commodity market, the produced commodity is consumed by the household for maximizing its utility subject to the household budget constraint. Their optimization problems are only dependent on the relative prices of given commodity and factors. Market demand and supply of any commodity are continuous, non-negative, and homogeneous of degree zero. The market-clearing condition for commodities ensures equality of its demand and supply quantities and that of factors indicating that the total demand for each factor must be equal to its given endowments. Solving the system of simultaneous equations of the household, producers, and market clearing conditions, the price of one commodity or one factor need to be fixed as a numeraire. Then, all other prices are expressed as relative prices in CGE model excepting the fixed one numeraire.

The theoretical basis of CGE modelling is Walras' Law. As early as in 1874, Walras (1954) showed that equilibrium conditions in different markets in an economy are not independent and general equilibrium is available at any set of prices. Arrow and Debreu (1954), Debreu (1954), and Arrow and Hahn (1971) turned Walrasian general equilibrium theory into the Arrow-Debreu framework. The framework forms the foundation for CGE modelling based on following four types of equations as explained. (1) The equations for equilibrium conditions for each market to ensure that supply equals demand for each good and services. (2) The equations for income-expenditure identities to ensure the balance of each account. (3) The equations for behavioral relationships to describe economic agents' reactions to changes in prices and incomes. (4) The equations for production function to determine the output for each sector and how production factors can be allocated.

The predecessor of CGE modelling is Input−Output (IO) analysis. Considering inter−industry linkage, IO analysis is based on Walrasian general equilibrium theory and highly relies on the IO table. The IO analysis was popular in 1950s to 1980s because of its ability to estimate the aggregate as well as sectoral level economic impacts and to trace the linkages between industries. However, shortcomings of IO analysis is widely criticized by CGE modelers (Briassoulis, 1991; Johnson, 1999; Blake, 2000; Dwyer et al., 2004, 2006). There is a strict and unrealistic assumption in IO analysis including assuming fixed IO ratios like as mechanical production, rigid and lacking explanatory power. Thus, a fixed technical coefficient in IO model does not reflect the production technology at certain time. Another assumption of IO analysis is that there are no constraints on the capacity of production activities in an industry to meet additional demands, which is of course unrealistic in any economy. It means that there are not considered of price effect and substitutions between production factors.

The CGE model can remove the limitations of the IO model. The CGE model is more realistic, flexible, and comprehensive general equilibrium model with the advent and development of computer technology. Although the initial CGE model was criticized as unrealistic assuming perfect competition, it developed complexity by developing imperfect competition and dynamic CGE models (Dixon *et al.*, 1982; Harris, 1984; Palstev, 2000).

To begin with three basic elements of CGE model, there are composed of theoretical foundation of CGE model, numerical specification of parameters in the model, and economic effects analysis of executing policy experiment. There are four key features of the CGE model (Kim, 2000). It is a multi-sectoral model that considers the mutual relationship between sectors. Therefore, the model enables examination of the dynamic impact of external shock. Second, it allows simulation studies to be conducted because it includes the concept of optimality, such as maximizing the profit of producers. Third, it is a macro-micro system based on microeconomic and macroeconomic theory. Thus, the result of a shock does not show contradictions. Fourth, quantity and price are determined in the process of eliminating excess demand.

The Inter Regional CGE model used in this dissertation specifies regional production, consumption, saving (investment), government revenue (expenditure), foreign trade, and labor mobility in the regional economy. The model structure follows the neoclassical elasticity approach of Robinson (1989) to simultaneously determine prices and quantities on one hand, and to limit the degree of substitution in sectoral supply and demand on the other hand. Unlike the IO analysis, IRCGE model is considered of all economic agents such as the producer, household and government, each producer and household is assumed to be a price-taker, choosing an optimal set of factor inputs and commodity demands under the maximization principle of constrained profit and private utility, respectively. In the process of IRCGE model, the internalized the commodity quantity, its price and consumption level determined by the households' income. The market clearing price operates to get the profit maximization of firms and utility maximization of households according to the neoclassical economic theory.

The difference of IRCGE model in this dissertation compared to previous one is specialized on micro-simulation modules for estimating wildfire damages and this model can be applied to various unexpected disasters in the future. The model is a linked system of a stylized IRCGE model for regional economic analysis at a region level with three micro modules: a wildfire damage area module, transportation demand module, and tourism demand module at a city and county level or a lower spatial level. In particular, a bottom-up approach is applied to calculation of the value-added at the macro region level which are the sum of those to be specified with econometric production functions at city and county level.

The IRCGE model estimates the indirect economic impacts of the wildfire on outputs of forest and tourism sectors in Korea. The IRCGE model is developed for two macro regions and 12 industrial sectors on a base year of 2013, and is applied to the experimental simulation for the wildfire damages in Gangwon province to measure the loss of regional income. The two regions in the model are Gangwon and the rest of Korea(ROK). 12 Industrial sectors are divided into four forest sectors, five tourism sectors, and the other three sectors in the table 5. To be specific, the forest industry is defined as the sectors that have a high input ratio of timber and forest products based on sales of the Interregional 2013 Input-Out table composed of 82 sectors from the Bank of Korea. In fact, forest sectors are damaged directly from the wildfire. In the model, the forest sectors are as follows: (1) Forest products, (2) Timber and wood products, (3) Pulp and paper product, and (4) Other manufacturing products and processing of timber. The tourism industry consists of five different sectors such as (5) wholesale and retail services, (6) transportation services, (7) food and accommodation services, (8) culture service, (9) sports and entertainment services sector according to the classification of Tourism Satellite Accounts (TSA:RMF, 2008). The rest three sectors are classified into (10) Primary industry, (11) Manufacturing industry, and (12) Service industry.

Table 5. Industrial Classification of 12 Sectors for IRCGE model

Classification	Sub-Sector
Forest sectors	1. Forest Products
	2. Wood and wood products
	3. Pulp and paper products
	4. Other manufacturing products and processing of timber
Tourism sectors	5. Retail and wholesale services
	6. Transportation services
	7. Restaurants and accommodation services
	8. Cultural Services
	9. Sports and entertainment services
General sectors	10. Primary Industry
	11. Manufacturing Industry
	12. Service Industry

The study area of this dissertation is designated as Gangwon province in Korea. Gangwon Province is covered by mountainous areas with more than 80% in total land areas. In addition, the region has the highest risk of wildfires occurrence in more than half of Korea's large wildfires after 2000. Gangwon is an interior position with less accessibility to road transportation network than other regions, an indicating having difficulty to suppress wildfires. Therefore, wildfires of Gangwon easily spread with strong wind, steep slope of mountains, and abundant timber fuel. Figure 3 shows the location of the wildfire in Goseong County, Gangwon Province. The damaged areas of the Goseong wildfire are determined by conditions of climate and terrain, and the area will change according to the climate change scenarios.

The IRCGE model explains demand, supply, and its equilibrium conditions under the macroeconomic closure rule. The supply sector of the IRCGE model consists of production function, labor demand, export and import, and demand sector includes household income, household consumption, and the government accounts. The macroeconomic closure rules were applied by labor fixed or wage fixed in the simulations.

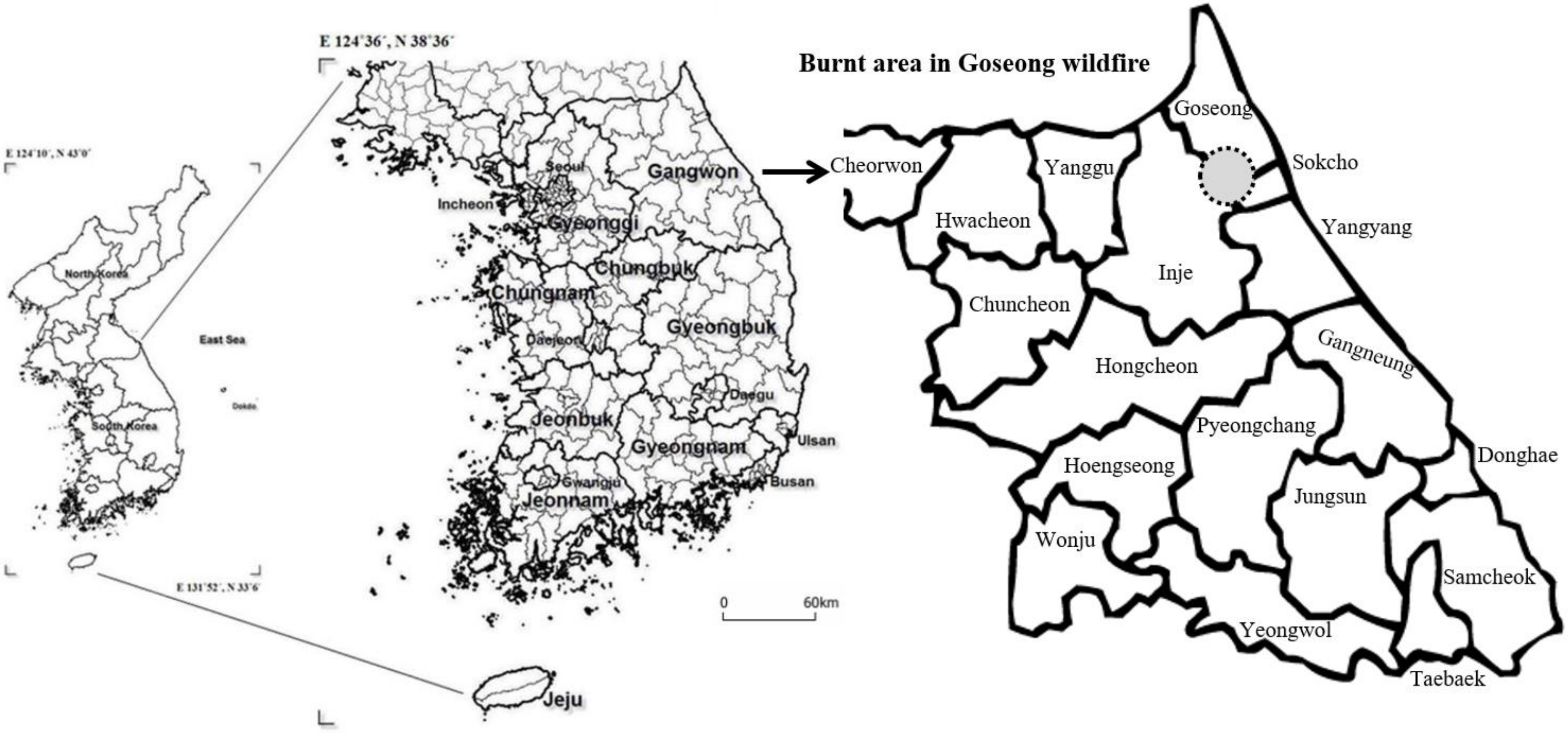

Figure 3. Study area of Gangwon Province and Burnt Area of Goseong Wildfire in Gangwon

The IRCGE model is based on the conceptual framework of the real SAMs, is highly disaggregated with 12 production sectors (goods) and one household group in each region, one representative government, and rest of the world. The two regional commodities are disaggregated into intraregional demands, regional imports, and foreign imports in terms of the product origin and intraregional supplies, regional exports, and foreign exports in terms of the product destination, which are introduced to allow the model to capture imperfect substitution between domestic goods and goods in the rest of world (ROW). The prices of commodity and factor input are adjusted to balance between supply and demand in the market. The structure of IRCGE model is designed to present two regional economies in Korea based on a year of 2013 as a short-run model.

The IRCGE model primarily relies on the basic assumptions of standard microeconomics as its foundations. The household is supposed to maximize its utility subject to its budget constraint, while the producers maximize their profits subject to given constraints on production technology. The household and all the producers are assumed to be price takers which means the markets are perfectly competitive. In the IRCGE model, the production activities are disaggregated into three categories: forest, tourism, and general sectors. And each production activity i is assumed to produce only one corresponding commodity i. It is explained the flows of goods and factors at each stage where they are combined for either production or consumption in the CGE model. The flows are presented from the bottom to the top in Figure 4.

(1) Labor and capital can be aggregated into the composite factor through the composite factor production function

(2) The composite factor is combined with the intermediate inputs of commodities to produce the gross domestic output using the gross domestic output production function (Leontief)

(3) The gross domestic output is transformed into the exports and domestic good using the gross domestic output transformation function such as Constant elasticity of transformation (CET) function

(4) The domestic good is combined with the imports to produce the composite good with the composite good production function such as Armington function

(5) The composite good is distributed among household consumption, government consumption, investment, and intermediate uses in composite good market equilibrium

(6) Household utility is generated by consumption of private expenditure as the utility function indicates.

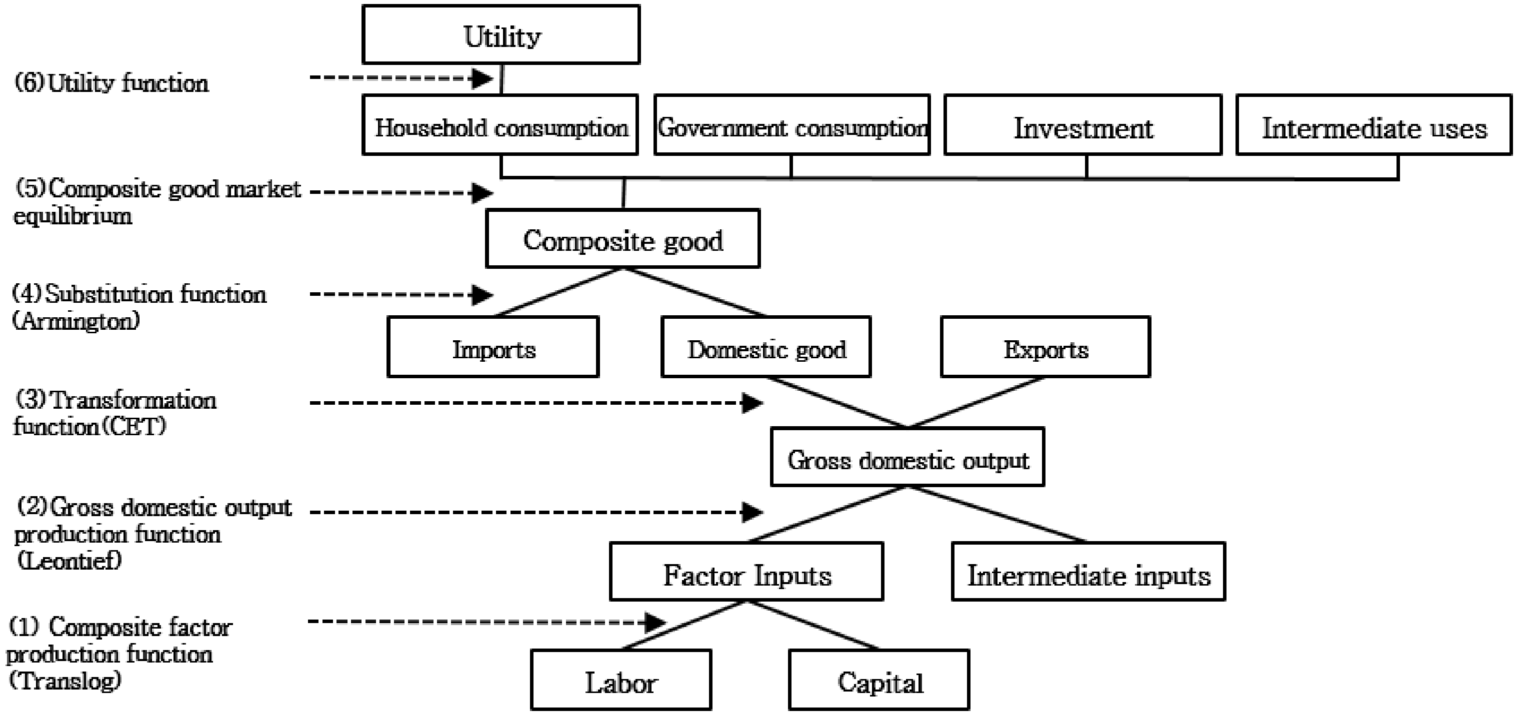

Figure 4. Overall Structure of CGE model

3.2.1. Production

In the next section dealing with the real sectors in the model, a simplified version of IRCGE model is presented starting with the supply part including key equations. The supply part in the IRCGE model consist of production function, labor demand, export, and import. To begin with production, the IRCGE model accounts for the economic behavior of producers and consumers on the real side economy based on the approach of neoclassical elasticity (Robinson, 1989). The production structure of IRCGE model is composed of three stages (Kim and Kwon, 2016; Kim *et al.*, 2004, 2017).

In the first step, the gross output by region and sector is established by the Leontief production function of value added and intermediate inputs. The intermediate input is derived from interregional input−output coefficients, and the value−added at macro regional level is simply the sum of those of cities and counties through the production function. These are specified with spatial econometric production function of labor and capital inputs with the forest area variable, and an external factor such as accessibility variable[4]. It is assumed that the producer select the optimal size of

[4] The accessibility index is defined as a weighted average of population of the node and link impedances (travel distance) generated from a gravity−type estimator as a proxy for transportation services in the production function (Kim et al., 2004, 2017). The travel time is calibrated by the shortest inter−zone travel time using road network among 254 cities and counties in Korea with the aid of

the production factors under the maximization principle of constrained profit. The regional labor demand is derived from the value−added maximization of the first−order conditions of producers subject to its production technology constraint under given output and input prices. The labor market is determined by the macroeconomic closure rule by balancing out total labor demand against total labor supply. Changes in the employment ratio affect the production output, and regional wage levels are linked to production costs in the regional labor market. In this model, based on the neoclassical closure rule, a full employment condition is applied in which wages are determined endogenously. It is assumed that regional labor input can be moved from one region to other in the short run model.

$$XD_i^r = \min\left(\frac{VA_i^r}{a_i^r}, \frac{IND_{1i}^r}{io_{1i}^r}, \dots, \frac{IND_{ji}^r}{io_{ji}^r}\right) \tag{3.1}$$

$$VA_i^r = A_i^r \cdot L_i^{r\,\alpha_i} \cdot K_i^{r\,1-\alpha_i} \tag{3.2}$$

$$L_i^r \cdot WA \cdot wdist_i^r = \alpha_i^r \cdot PVA_i^r \cdot VA_i^r \tag{3.3}$$

XD_i^r: Regional Gross Output of Domestically Produced Commodities

IND_{ji}^r: Regional Intermediate Inputs

VA_i^r: Regional Value−added

Arc−GIS Network Analysis.

L_i^r: Regional Labor Input

K_i^r: Regional Capital Stock

WA: Average Wage

$wdist_i^r$: Regional Wage Distribution Parameter

PVA_i^r: Regional Value-added

3.2.2. Price definition

All the prices of commodities are defined as either producer's price or consumer's price. In general, producer's price is used in the supply functions and consumer's price in the demand equations. The export price for domestic producers, defined as producer's price, is determined by world prices and the exchange rate adjusted with the rate of taxes and margins. The export price of commodity in domestic currency is derived from the product of world market price of exports (PWE) and the exchange rate. In the case of import price is revealed in a similar way, but its price presented at consumer's price based on domestic currency and world market price of imports (PWM). The activity price in each sector is derived by summing up the value-added price and the unit costs of intermediate inputs. The domestic prices of goods (PD_i) mean the price of domestic sales of domestic products. The composite good price (P_i) is a weighted average of the import price and the consumer's price of domestic sales.

In the context of regional basis, the commodities are composed of intraregional supplies, regional imports, and foreign imports with regard to the product origin of goods, and the regional products are spatially distributed to intraregional supplies, regional exports, and foreign exports in terms of the production destination. Commodity price is assumed to adjust towards a balance between supply and demand in factor inputs and commodity markets.

3.2.3. Export and Import

In the second stage, the intermediate demands are transformed into demands for domestic products and foreign imports using the Armington function. The total demands for the domestic products consist of intraregional supplies and regional exports, which are determined by their relative prices and spatial interaction between two regions at the bottom stage. The prices of imports and exports are determined exogenously, and the producers act as price takers. This condition is based on the small open economy assumption. The cost minimization from the Armington approach accounts for an optimal ratio of the foreign import to the domestic sale. With relative prices and different qualities, domestic sale is disaggregated into demands for two regional goods under the Cobb-Douglas function. In addition, profit maximization under the two-level Constant

Elasticity of Transformation (CET) function produces an optimal allocation of the gross output into the foreign exports and the domestic supplies. According to the concept of commodity equilibrium, domestic supply consists of intraregional supply and regional exports. The production volume depends on the relative price and the profit maximization of the producers rely on the amount of domestic demand and the elasticity of substitution.

$$\min PM_i^r \cdot M_i^r + PD_i^r \cdot XXD_i^r \tag{3.4}$$

$$\text{s.t}\, X_i^r = AC_i^r \cdot (\delta_i^r \cdot M_i^{-\rho c_i} + (1-\delta_i) \cdot XXD_i^{-\rho c_i})\hat{}(\frac{1}{\rho c_i}) \tag{3.5}$$

$$\frac{M_i^r}{XXD_i^r} = (\frac{\delta_i^r}{1-\delta_i^r} \cdot \frac{PD_i^r}{PM_i^r})^{\frac{1}{1+\rho c_i}} \tag{3.6}$$

$$\max PE_i \cdot E_i + PD_i^r \cdot XXD_i^r \tag{3.7}$$

$$\text{s.t}\, XD_i^r = AT_i \cdot (\gamma_i \cdot E_i^{\rho t_i} + (1-\gamma_i) \cdot XXD_i^{\rho t_i})\hat{}(\frac{1}{\rho t_i}) \tag{3.8}$$

$$\frac{E_i}{XXD_i^r} = (\frac{1-\gamma_i}{\gamma_i} \cdot \frac{PE_i}{PD_i})^{\frac{1}{\rho t_i - 1}} \tag{3.9}$$

XXD_i^r: Domestically Produced and Consumed Commodities

PM_i^r: Price of Import Commodity

PE_i: Price of Export Commodity

PD_i^r: Price of Domestic Commodity

M_i^r: Import

E_i: Export

X_i^r: Composite Commodity

3.2.4. Labor market

Labor demand can be derived from the first order condition for firm's profit maximization. Regional labor demand will depend on its product price, wages, and intermediate input prices. In the short run, the regional labor input is assumed to be homogeneous and moves among the regions, while capital stock cannot move from one region to others. The regional labor supply relies on the aggregate employment rate in each sector and the total population size of the region overall. The population is the sum of the natural increase of the population combined with the net gain (or loss) of migrant population. The latter is assumed to be in response to interregional differences between origin and destination regions in terms of average wage and unemployment rate, as well as the spatial distance between the regions.

3.2.5. Household income and Consumption

Households are the subjects of economic activity and affect not only consumption but also investment through savings. The total income of each household group in composed labor and capital income from providing production factors and receiving subsidies from government and transfer income from abroad. Whole consumption of household is assumed to be an equation of households' permanent income and transitory income from government. Labor income is determined by industry demand and average wage, and capital income is equal to the value-added after subtracting net production tax, employee compensation and depreciation. The disposable income for each household is described by the income after subtracting the direct tax and savings.

$$YH_r = YLC_r + YKC_r + YSUB_r + YFC_r \tag{3.10}$$

$$YD_r = YH_r - YTAX_r \tag{3.11}$$

$$YSAV_r = YD_r \cdot YSAVP_r \tag{3.12}$$

$$P_i \cdot PC_i = (YD_r - YSAV_r) \cdot PCES_i \tag{3.13}$$

YH_r: Household Income

YD_r: Disposable Income

YLC_r: Labor Income

YKC_r: Capital Income

$YSAV_r$: Household Savings

$YSAVP_r$: Marginal Propensity to Save

$PCES_r$: Marginal Propensity to Consume

$YSUB_r$: Government Subsidy

$YTAX_r$: Direct Tax

YFC_r: Transfer Income by the Rest of World (ROW)

P_i: Price of Commodity

PC_i: Private Consumption

3.2.6. Government Revenue and Expenditure

Government revenues derive from direct taxes from households and producers, indirect taxes, and tariffs. Government expenditures are divided into government consumption, subsidies for households, and government savings. The government current account saving is calculated as revenues minus current expenditures. The total savings are determined by summing depreciation, household savings, and government saving and minus foreign saving with exchange rate.

The total demand consists of intermediate and final demands such as consumption and investment expenditures of private and government sectors. Two levels of government system are specified in the model; two regional governments (including 16 provinces) and one national government. Government expenditures are composed of the consumption expenditures, subsidies to firms and households, and savings. Revenue sources include direct tax of household incomes, value-added, and foreign imports. Aggregate savings are sum of household savings, producer's savings of regional industries, private borrowings from abroad, and government savings, while determining total investments. There is one consolidated capital market without financial assets in the model, and the numeraire of the model is set as the consumer price index.

$$\text{GRV} = \sum_i ITAX_i + \sum_r YTAX_r + TARIFF \quad (3.14)$$

$$\text{GUSE} = \sum_i GC_i + \sum_r YSUB_r + GSAV \quad (3.15)$$

$$\text{SAVINGS} = \sum_i DEPR_i + \sum_r YSAV_r + GSAV - FSAV \cdot ER \quad (3.16)$$

GRV : Government Revenue

GUSE : Government Expenditure

$ITAX_i$: Indirect Tax

SAVINGS : Savings (Investment)

$DEPR_i$: Depreciation

TARIFF : Tariff

GC_i: Government Consumption

GSAV : Government Savings

FSAV : Foreign Savings

ER : Exchange Rate

3.2.7. Commodity Market Equilibrium

In this model, demand composite goods are supplied with a combination of domestic supply and imports through the Armington function. Total demands for composite goods consist of intermediate consumptions and final consumptions. It can reflect the incomplete substitution between the two goods. In the process of minimizing the total cost, the appropriate demand for each good is determined, and it is generally estimated by the price ratio between foreign and domestic goods, domestic demand, and substitutional elasticity. This concept is applied equally to the country as well as the regional unit. The demand for intermediate goods and final goods by the region is composed of local supply goods and other local goods. The ratio of exports to total domestic goods or domestic goods is also determined by the Constant Elasticity of Transformation (CET) Function, which reflects the degree of imperfect elasticity between the two goods. How much domestic goods are supplied to the domestic market depends on the ratio between export and domestic supply prices, total supply, and resilience. Regional supplies are met by local supplies and exits to other regions. Theoretically, interregional trade (export and import size) can be estimated by Armington function and invariant elasticity function, but it is estimated by using interregional input output coefficient in this study.

$$X_i = AC_i[d_i M_i^{-\alpha_i} + (1-d_i)XS_i^{-\alpha_i}]^{-\frac{1}{\alpha_i}} \tag{3.17}$$

$$\frac{M_i}{XS_i} = [\frac{PS_i}{PM_i}\frac{d_i}{(1-d_i)}]^{\frac{1}{1+\alpha_i}} \tag{3.18}$$

$$XD_i = AT_i[q_i E_i^{r_i} + (1-q_i)XS_i^{r_i}]^{\frac{1}{r_i}} \tag{3.19}$$

$$\frac{E_i}{XS_i} = [\frac{PE_i}{PS_i}\frac{(1-q_i)}{q_i}]^{\frac{1}{r_i-1}} \tag{3.20}$$

E_i: Export Quantity

M_i : Import quantity

XS_i : Quantity of Domestic Demand (Supply)

PE_i: Price of Export Goods

PM_i : Price of Import Goods

PS_i : Price of Domestic Goods

AC_i: Efficiency Coefficient of Demand

d_i: Share Coefficient of Demand

α_i : Index of Demand Elasticity of Substitute

r_i : Index of Export Elasticity of Transformation

AT_i : Efficiency Coefficient of Supply

q_i: Share Coefficient of Supply

$r_i = \frac{1}{r_i-1}$: Export Elasticity of Transformation

$\sigma_i = \frac{1}{1+\alpha_i}$: Import Elasticity of Substitution

Table 6. List of Major Equations of IRCGE Model

Output	Output = Leontief (Value added, Intermediate demand)
Value added	Value added = CD (Capital stock, Labor, LAND)
Supply	Output = CET (Foreign exports, Domestic supply)
Domestic supply	Domestic supply = CET (Regional exports, Intraregional supply)
Demand	Demand = Armington (Foreign imports, Domestic demand)
Labor demand	Labor demand = LD (Wage, Value added, Net price)
Labor supply	Labor supply = LS (Labor market participation rate, Population)
Population	Population = Natural growth of population + Net population inflows
Regional incomes	Regional incomes = Wage + Capital returns + Government subsidies
Migration	Migration = TODARO (Incomes and employment opportunities of origin and destination, Distance between origin and destination)
Consumption	Consumption by commodity = CC (Price, Incomes)
Private savings	Private savings = PS (Saving rate, Income)
Government revenues	Government revenues = Indirect tax + Direct tax + Tariff
Government expenditures	Government expenditures = Government current expenditure + Government savings + Government investment expenditure + Government subsidies
Labor market equilibrium	Labor demand = Labor supply
Capital market equilibrium	Private savings = Total investments
Commodity market equilibrium	Supply of commodities = Demand for commodities
Government	Government expenditures = Government revenues
Capital stock	Capital stock = Depreciated lagged capital stock + New investments

Source: The equations in the table is revised based on Kim(2014, 2017).

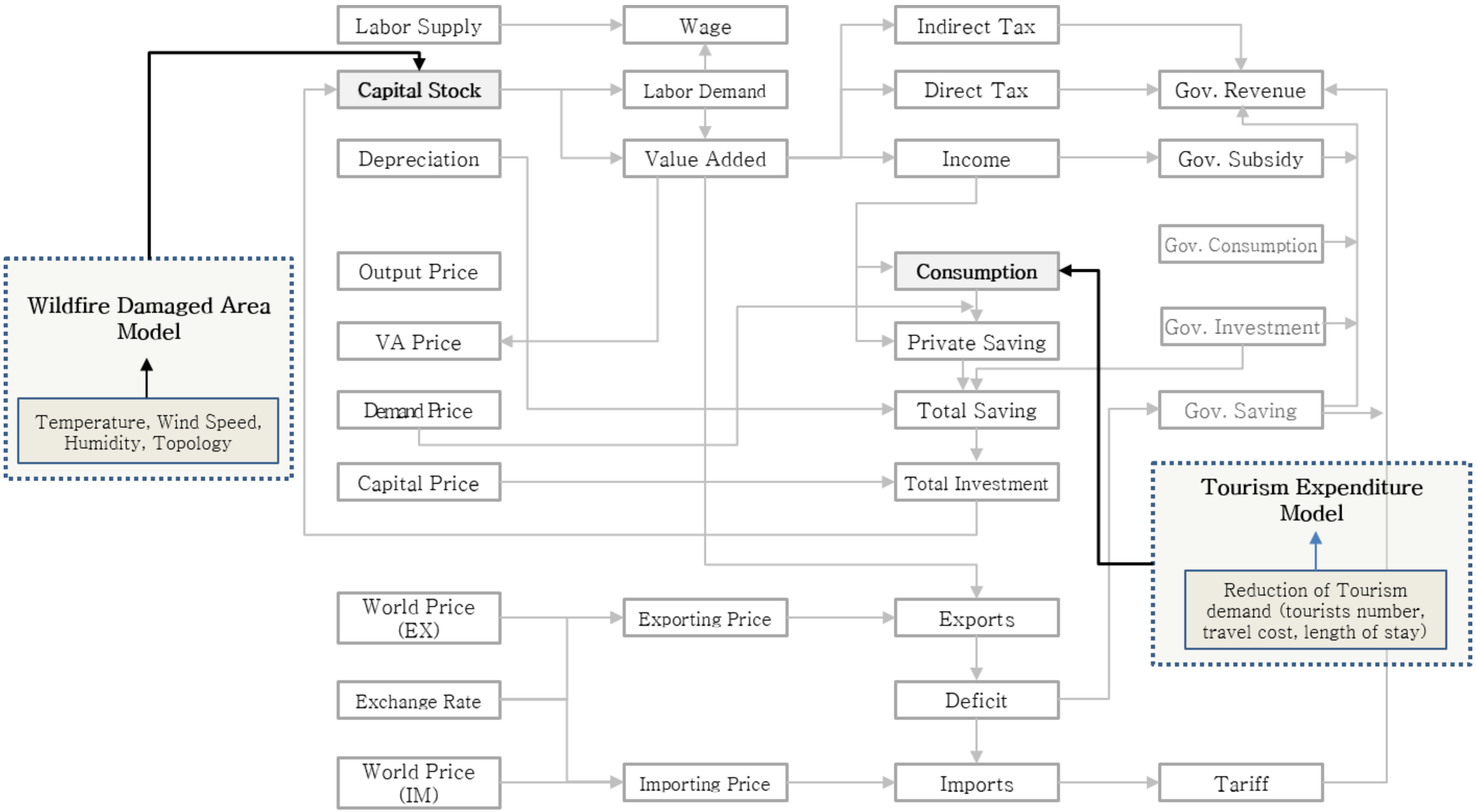

Figure 5. Structure of Inter Regional CGE (IRCGE) Model

The structure of the IRCGE model is shown in Figure 5. The simulations are conducted with econometric models and related variables presented in the IRCGE model. In the simulations, the loss of the wildfire area is entered into the capital stock and final demand of the forest industry in Gangwon province. Another losses of demand caused by wildfires derived from the decrease of tourism consumption expenditure. The regional economic effect is investigated by the shock variables in the model and highly depends on the regional and sectoral linkages and type of macroeconomic closure rules.

The SAM is calibrated as a data framework as a comprehensive and consistent general equilibrium data system for the development of the IRCGE model. The IRCGE model requires a comprehensive and disaggregated data system to explain the whole economy and policy experiments. The Social Accounting Matrix (SAM) is largely divided into production factor market, commodity product market, and foreign import & export market. The matrix is composed of household, firms, and government accounts for production, consumption, and savings. The SAM makes it possible to simulate various policies at the disaggregated level for economic agents based on each behavioral characteristics. The SAM consists of six accounts, which are factors, households, production activities, government, capital, and the rest of the world and is treated as an initial equilibrium for the IRCGE model. The statistical system of SAM integrates the regional input-output table and the national income accounts (Kim, 2014). The SAM focuses on production activities, distribution and expenditure relationships between economic agents in two different regions. The factor income and value-added from the production sectors are assigned to the household account, and the household spend them to consume commodity goods and services under the neoclassical economic mechanism. The investment sector consists of the depreciation of the production sectors, and household and government savings subtracting expenses for purchasing assets by the production sector (Park *et al.*, 2014). In this dissertation, the SAM is calibrated using the regional input-output table of Korea in 2013 and the national accounts data from the Bank of Korea. It consists of the production factors, a household, twelve producers, a government, an investment of each region and the ROW. The production sector consists of 12 industries and the government sector refers to the combination of the national and regional governments.

Table 7. A Simplified Inter Regional Social Accounting Matrix (IRSAM)

		Expenditures						
		Production Factors	Household	Government	Production Activities	Capital Account	Rest of World	Total
Receipts	Production Factors				Value added		Net factor income received from abroad	Incomes of the domestic factors of production
	Household	Allocation of value added to households	Transfers among households	Government transfers to households			Household incomes from abroad	Household incomes after transfer
	Government		Direct taxes on incomes		Indirect taxes on inputs		Government transfer incomes from abroad	Government incomes after transfer
	Production Activities		Household consumption expenditures	Government current expenditures	Intermediate consumption	Investment expenditures on domestic goods	Exports	Aggregate demand−gross output
	Capital Account		Household savings	Government savings			Net capital received from abroad	Aggregate savings
	Rest of World		Household expenditures on import goods	Debt servicing	Imports of raw materials	Imports of capital goods		imports
	Total	Incomes of the domestic factors of production	Total outlay of households	Total outlay of government	Total costs	Aggregate investment	Total foreign exchange receipts	

From the benchmark data, the CGE model can use the parameters to reproduce values and assess the effect of disaster damages. Kim (2008) suggested that the CGE model has two types of parameters: structural coefficients and behavior parameters. The structural coefficients are point estimates or non-elastic parameters, and the behavior parameters determine the behavior of agents. In this dissertation, the parameters are from three sources. The first set of parameters is from the SAM. Some of the shift or share parameters of the production belong to this set such as share parameters of production factors, import/export elasticity.

The second set of parameters is from previous studies. For instance, the alternative elasticity and the conversion elasticity of imports and exports are derived from Jeong (2008). Table 9 shows that the industrial substitution elasticity of import and transformation elasticity of export is recalculated by applied the ratio of imports in total supply and exports to total output from 2013 Interregional Input-Output table based on borrowing sectoral parameters from Jeong *et al.* (2003).

In addition to these two sets, econometric methods is used to estimate other parameters. To be specific, the parameters of forest product production were estimated using Leontief production function, Cobb-Douglas production function, Constant elasticity substitution function, Constant elasticity transformation function and Tourism expenditure function. The estimated or calibrated parameters enable to improve the model accuracy as reflecting the real economy and resulting in appropriate simulations. The equilibrium of supply and demand in the economy make it possible finding equilibrium condition by adjusting price mechanism based on the parameters in the model.

Table 8. Sectoral Elasticity of Substitution and Transformation

Industry	Substitution elasticity		Transformation elasticity	
	Gangwon	ROK	Gangwon	ROK
1. Forest Products	−0.082	−0.176	−0.803	−0.827
2. Wood and wood products	0.017	0.043	0.012	0.071
3. Pulp and paper products	0.000	−0.060	0.003	−1.551
4. Other manufacturing products and processing of timber	0.006	−2.769	0.029	−11.806
5. Retail and wholesale services	0.001	−0.688	0.000	−0.929
6. Transportation service	0.010	−3.725	0.004	−1.942
7. Restaurants and accommodation services	0.014	−3.123	0.021	−2.845
8. Cultural Services	0.002	−1.219	0.003	−1.232
9. Sports and entertainment services	0.011	14.349	0.005	5.667
10. Primary Industry	0.071	−3.366	0.118	−3.237
11. Manufacturing Industry	0.029	−0.679	0.061	−1.550
12. Service Industry	0.007	3.867	0.001	2.125

In the first simulation, estimated parameters of capital stock with land area in the production function, which are focused on the forest products (Model 1) and the forest manufacture industry (Model 2) respectively. It is applied into IRCGE model for calculating damage area by the wildfire as the input variable. The advantages of Cobb-Douglas production function are that it is relatively easier to estimate than other production functions and able to get the elasticity of the production factors[5]. If the production function in equation (3.21) and (3.23) are assumed to satisfy the homogeneity of degree one in factor inputs of the primary sector including additivity and symmetry conditions, such a restriction on the parameters are presented in equation (3.22) and (3.24). In particular, variable land of the Model 1 is used as a proxy variable for the capital stock and Model 2 is applied with the variable land as a part of capital stock because of the production features in forestry manufacturing sectors.

[5] The Cobb Douglas production function has a limitation on the assumption that the substitution elasticity is 1. The CES production function can estimate substitution elasticity, but it is difficult to estimate due to the data availability problem (Chung, 1994).

Model 1

$$lnVA_i = \beta_0 + \beta_1 lnL_i + \beta_2 lnK_i + \epsilon_i \tag{3.21}$$

It restricted to

$$\beta_1 + \beta_2 = 1 \tag{3.22}$$

VA_i : Aggregated value added of forest products industry

L_i : Total labor input of forest products industry

K_i : Forestry land areas as a proxy of capital input of forest products industry

Model 2

$$lnVA_i = \beta_0 + \beta_1 lnL_i + \beta_2 lnK_i + +\beta_3 lnLAND_i + \varepsilon_i \tag{3.23}$$

It restricted to

$$\beta_1 + \beta_2 + \beta_3 = 1 \tag{3.24}$$

VA_i : Aggregated value added of manufacturing of forest products industry

L_i : Total labor input of manufacturing of forest products industry

K_i : Total capital input of manufacturing of forest products industry

$LAND_i$: Production site area of the manufacturing corporate

The Model 1 (production function of forest products) has forestry area as a proxy of capital stock, number of employees in forest products sector, and road accessibility. The data is derived from the survey of mining and manufacturing industry in Korea. The estimation coefficients of Model 2 (production function of manufacturing forest products) are analyzed using the number of employees, capital stock, production site area, and road accessibility data. The spatial units of model 1 consist of 18 cities and counties in

Gangwon province during 2010–2015. The manufacturing production function is selected by three sectors in 33 manufacturing sectors that is wood and wood product manufacturing, pulp, paper and paper product manufacturing, and furniture manufacturing during 2000–2009. The descriptive statistics of variables in two models presented in Table 9.

Table 9. Descriptive Statistics of Variables for Model 1 and 2

Model 1 (forest products)				
Variable	Description	Mean	Median	S.D.
VA	Value added (unit: million US$)	0.020	0.012	0.019
L	Number of employees (unit: 1000 people)	1.953	1.500	2.283
K	Forest area as a proxy of capital stock(unit: 1000 ha)	74.557	66.229	35.488
Model 2 (manufacturing of forest products)				
Variable	Description	Mean	Median	S.D.
VA	Value added (unit: million US$)	0.034	0.007	0.095
L	Number of employees (unit: 1000 people)	0.353	0.127	0.762
K	Material fixed capital stock(unit: million US$)	0.058	0.006	0.184
LAND	Production site area (unit: m^2)	74.557	80.143	35.488

Table 10 presents the result of the production function estimation. The value added of forest products in the model 1 is increased by 0.586% when the area of the forest area rises by 1%. The land variable of manufacturing industry in model 2 contributed to value added rise by 0.078% followed by labor (0.669%), capital stock (0.252%) when each variable increased by 1%.

Table 10. Estimation of Production Function of forest products and Manufacturing forest products Industries

	Model 1	Model 2
	Estimate (S.E)	Estimate (S.E)
intercept	13.849*** (0.145)	1.399*** (0.121)
lnL	0.400*** (0.040)	0.396*** (0.026)
lnK	0.599*** (0.040)	0.562*** (0.029)
lnLAND	– –	0.042** (0.025)
Restrict	703.492*** (63.523)	27.994*** (10.833)
Adj R^2	0.609	0.902
Sample size	1,100	1,098

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level, value in parentheses indicates standard error of the coefficient.

3.3. Wildfire Damage Area Model

The wildfire damage area model is a method for estimating the burnt area caused by wildfires. This model is estimated by taking into account explanatory variables in the wildfire probability model and the wildfire diffusion model, which affecting the scale of wildfire damage. Generally, the sources of wildfire occurrence are classified into natural factors or human factors (Lee *et al.*, 2012; Woo, 2015). Due to the limitation of data, this study mainly considered natural factors such as maximum temperature, humidity, wind speed, slope of topography, and pine tree ratios.

In particular, since the weather data of the wildfire damage area model are large in uncertainty and volatility, it is necessary to assume the probability distribution for predicting the damage area using the measurement data in case of fire occurrence. The Gumbel probability distribution based on extreme value theory is used for predicting climate variations such as maximum temperature and wind speed (Lee, *et al.*, 2006). The amount of damage is estimated through the scenario analysis considering the climate change. This scenario of the climate change derived from the IPCC's RCP 8.5, which is a high emission scenario with no climate mitigation policies. It is caused by changes of maximum temperature, relative humidity, and average wind speed.

The analysis data were meteorological observations (maximum temperature, relative humidity, and average wind speed) provided by the Korea Meteorological Administration (KMA) and topographic features (slope and pine tree ratio) of the Korea Forest Service. The daily weather sources of Gangwon province were collected from based on one of disaster monitoring stations located in Goseong County in Gangwon province for 2013. The topographic data utilized to calculate the slope and pine tree ratio by grid zone in the spatial analysis tool of ArcGIS. To be specific, the slope in the grid zone is deliberated several processes. The contour layer is extracted using the TIN (Triangulated Irregular Network) on the digital topographic map of the forest, and the inclination is calculated by constructing a zone from the DEM (Digital Elevation Model) to the grid. The calculation method applied to the slope is the average maximum technique which combines the neighborhood algorithm and the maximum downhill Slope algorithm provided by ArcGIS10.1.

The Bayesian estimation method is used in the uncertain information due to the characteristics of forest fire data. In advance, posterior estimation is performed on the damage area after assuming Gumbel distribution as the prior distribution of wildfire damage.

Estimated wildfire damage area in this analysis through the model are dependent on daily database of climate factors, topographical factors per grid spatial unit, and regional tree type ratio. The Bayesian wildfire damage area model is in company with spatial heterogeneity of wildfires for the damaged areas, and transportation demand model at city and county level for trip restriction by the suppression works of wildfires.

The risk of forest fires in Korea was recorded in 1973, and the risk of forest fires is increasing with the accumulation of combustible materials such as leaves, shrubs, and the expansion of forest roads. The threat of forest fires and the problematic of fire enlargement are likely to be proportional to as the increase in fuel amount due to the prosperity of forests and the upsurge in evaporation amount in the dry seasons by the rising temperature. Korean large-scale wildfire damages are 32,895ha in 53 cases over the last 10 years, which is 1.0% of the total number of wildfires occurrence, but 88% of the area (Joint governmental relations in Korean Government, 2010). Table 11 shows the annual number of wildfire occurrence and burnt area in Gangwon province. It represents an irregular trend that is difficult to predict and even considering the climate changes. In addition, as the number of mountain climbers increased due to the implementation of the five-day workweek system since 2000, the incidence of wildfires increased further (National Emergency Management Agency, 2009). Korea is experiencing extreme climatic phenomena. Over the past 100 years (1912–2008), the average temperature in the six major cities has risen by 1.7 degrees, greatly exceeding the world average temperature of 0.74 degrees. In the future, it is expected to rise to one degree in 2020, four in 2050, and two in 2100.

Table 11. Annual Number of Wildfire Occurrence and Damage Area in Gangwon Province

	Number of wildfire occurrence	Burnt area (ha)
2000	141	24,210.0
2001	86	116.7
2002	52	241.8
2003	11	8.4
2004	57	757.9
2005	41	1,374.4
2006	30	12.2
2007	26	14.0
2008	25	13.5
2009	60	63.0
2010	46	93.1
2011	39	111.2
2012	44	16.2
2013	36	9.7
2014	73	20.0
2015	125	237.2
2016	91	50.7

In particular, Gangwon have cold and dry winds blowing from mainland of China in spring over the Taebaek mountain range cause the Fhn phenomenon and turn into high temperature and dry environment. The regions are located along the coast such as Goseong, Samcheok, Sokcho, Gangneung, and Donghae counties in Gangwon have higher temperatures and stronger winds than other regions, resulting in high risk of large wildfires. For instance, 2000 Gangneung large wildfire had the minimum humidity, extremely dry as 7 to 15% on the day, and the maximum instantaneous wind speed was 19 to 29.8m/s at that time (Lee, 2001).

The impacts of wildfire can be defined as changes in forest ecosystems in terms of physical, chemical, and biological aspects of forests (White *et al.*, 1996; Rogan and Yool, 2001). The wildfire damages is commonly influenced by variables such as climate, accumulated forest resources (fuel), and terrain. In Korea, wildfires damages increase in proportion to the amount of timber stocks, with 97% of the mountainous areas corresponding to 65% of the entire country, with absolute conditions called forestry (Korea Forest Service, 2001). The features of mountains including high slope, undulating topography, and percentage of coniferous forest contribute to increase the spatial expansion of wildfire damages and delay the suppression of wildfires (Kim *et al.*, 2014). Through the empirical case of wildfires, burning speed of wildfires on undulating slopes is 8 times faster than that of flat land due to factors such as topography and climate in Korea (Lee and Lee, 2006; National Emergency Management Agency, 2009). In addition, it is necessary to further research on the local economy effect of wildfires, especially large wildfires affected by climate changes are becoming frequent.

The recent irregular of wildfire occurrences and its damages illustrates the vulnerability of human health and property from extreme weather conditions. The magnitude of wildfire damage is influenced by climate change and also socio-economic developments in the wildfire region were the main cause as the rapid increase in damages (Botzen and van den Bergh, 2009). It is required to establish localized innovative adaptation policies to manage wildfire risks regarding households' perceptions of risk, investments in precautionary measures, and insurance purchases. A combination of investments in damage mitigation measures by households and prevention undertaken by the public sector is likely to result in well-diversified risk management strategies that enhance economic resilience to disasters (Botzen and van den Bergh, 2009).

The wildfire damage area is estimated as an input variable of newly developed IRCGE model in the dissertation. Many previous papers have suggested various fire damage assessment methods. Probabilistic models are mainly used with statistical descriptions related to wildfire damage using monitoring data besides the physical method (Nonomura *et al.*, 2007). McCaffrey (2006) suggested priority monitoring areas by selecting high risk areas after estimating the probability of occurrence of wildfires and its diffusion area. The result can contribute to save government budget to monitoring wildfire occurrences only focusing on high risk areas. However, probability model of wildfires is appropriate to evaluate the risk level of wildfire occurrence, but it is not suitable to estimate actual damaged area for this analysis. The methodology in the previous research on the wildfire damage analysis was mainly focused on direct cost analysis of the wildfire damage using cost method, econometric models, and IO analysis.

In order to estimate the damage area due to wildfires in Gangwon, the statistical distribution of wildfire losses due to extreme weather need to be assessed based on the Bayesian type model instead of the wildfire probability and diffusion models. The Bayesian model is used to estimate burned areas in the general fire risk assessment procedure in this dissertation. Bayesian analysis is a statistical paradigm that answers research questions about unknown parameters using probability statements. It is assumed that observed data sample (D) is fixed and model parameters θ are random. D is views as a result of a one-time experiment. A parameter is summarized by an entire distribution of values instead of one fixed value as in the classical frequentist analysis (Gelman *et al.*, 2014). The Bayesian approach is to estimate posterior probability for the extent of wildfire damage with assuming prior probability. Bayesian estimation of wildfire damage according to climatic conditions is assuming arbitrary prior distribution ($\theta \mid \mu$) from the best knowledge, and then parameter for wildfire damage area is estimated according to posterior distribution ($\theta \mid Y, \mu$). In the Bayesian approach, unlike the frequency-based approach, the parameter is treated as a random variable, and the kernel of the posterior density function $p(Y \mid \theta) \times \pi(\theta)$ is composed of the product of likelihood function and the pre-density function.

In the study of wildfire damage estimation, the Bayesian model is recently utilized for the fire study together with most popular logistic regression model, maximum entropy model, and the random forest model (Englin *et al.*, 2008: Dlamini, 2010; Mendes *et al.*, 2010; Mori and Johnson, 2013; Demet, 2014; Silva *et al.*, 2015; Jaafari *et al.*, 2017). Mori and Johnson (2013) argued that Bayesian models are suitable for simulation of the risk of wildfires, especially in small areas. The amount of wildfire damage varies greatly depending on local weather conditions including the climate change. The Bayesian approach is a robust method to infer uncertainty or variability of parameters in hierarchical models, such as when the data are auto-correlated and do not satisfy the criterion of randomness (McCarthy, 2007; Mori and Johnson, 2013).

The dependent variable(d_areat) is on the linear model of burnt area and assumed to follow a normal distribution, which is set to follow d_areat ~ Normal(0, r), where r is a hyper-parameter that was assumed to follow Normal(2, 5). To fit the model using Markov chain Monte Carlo (MCMC) simulation. It is performed six chains of 12,500 iterations with different initial values, discarded the first 2,500 and resulted in 10,000 iterations used for inference. The probability function is derived from Jang *et al.* (2017) in which the likelihood of the wildfire for Gangwon province depended on the highest temperature, effective humidity, relative humidity and the average wind speed as shown in the following equations. The spatial diffusion is determined by the Cosine (Cos) converted facing slope, the average wind speed and the area share of pine tree to the forest (Lee, 2005).

In equation (3.27), the explanatory variables in the Bayesian model are the maximum temperature, wind speed, and humidity of forest fire probability model (equation 3.25) and utilized the Cos converted facing slope and the area portion of pine tree in the spatial diffusion of wildfires model(see equation 3.26)[6]. The validity of the explanatory variables was confirmed in previous studies (Englin, 2008; Lee, 2005; Chen, 2014; Jang *et al.*, 2017). For instance, Chen(2014) identified important causal factors related to wildfire risks. Most significant factors are drought, high temperatures, and human actions which appear to enhance wildfire hazards. The data are specified on maximum temperature, effective humidity, relative humidity, and average wind speed from National Wildfire Survey in 2015. The effective humidity (EH) is the cumulative value of the relative humidity for 3 days including the relative one of the day and its coefficient is estimated 0.7 following by the wildfire probability model (Won et al, 2016).

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[6] Probability of Wildfires (Jang et al., 2017)

$$Prob_{Gangwon} = [1 + \exp\{-(1.932 + (0.109HT) - (0.047RH) - (0.057EH) + (0.646WS))\}]^{-1} \quad (3.25)$$

HT: The highest temperature (℃), EH: Effective humidity (%), RH: Relative humidity (%), WS: Average wind speed (m/sec)

Spatial Diffusion of Wildfires (Lee, 2005)

$$\text{Spatial Diffusion (ha)} = -134.87 - 322.55CS + 23.59WS + 143.49AP \quad (3.26)$$

CS: Cos converted facing slope, WS: Average wind speed (m/sec), AP: Area portion of pine tree (%)

The Bayesian wildfire damage area model for estimating burnt area of wildfires is as below.

$$d_{areat_i} = \beta_0 + \beta_1 temprt_i + \beta_2 windsped_i + \beta_3 humidity_i$$

$$+\beta_4 pinetree_i + \beta_5 cfs_i \tag{3.27}$$

where, d_areat_i is wildfire damaged area(ha), $temprt_i$ is highest temperature(℃), $windsped_i$ is average wind speed(m/s), $humidity_i$ is relative humidity (%), $pintree_i$ is ratio of pine tree in the area(%), and cfs_i is Cos converted facing slope (degree).

Wildfire damaged areas are estimated by using the Bayesian model as shown in equation (3.27). The maximum temperature, pine tree ratio, Cos converted facing slope and average wind speeds have a positive effect on the damaged area of wildfires, while humidity has a negative effect on it. The estimated probability or, technically, its posterior mean estimate is 0.332 of the highest temperature with a standard deviation 1.476 and Markov Chain Monte Carlo standard errors of 0.082 in Table 12. The damaged areas are extended by 0.332, 1.888, 1.250, and 1.938ha, respectively, when the maximum temperature, average wind speed, pine tree ratio, and cosine slope increased by one unit. On the other hand, if the relative humidity increases by 1%, the wildfire damage area decreases by −0.15ha.

Table 12. Estimates of Damaged Areas in Bayesian Normal Linear Model

	Variable	Mean Estimates	S.D.	MCSE	Median	Equal-tailed [95%Cred.Interval]	
Intercept	intercept	2.060	2.247	0.091	1.994	−2.374	6.510
Highest temperature(℃)	temprt	0.332	1.476	0.082	0.360	−2.540	3.264
Wind Speed(m/s)	windsped	1.888	2.299	0.114	1.836	−2.777	6.454
Relative Humidity(%)	humidity	−0.147	0.836	0.036	−0.138	−1.763	1.413
Pine tree ratio(%)	pinetree	1.250	2.023	0.105	1.237	−2.584	5.165
Slope (degree)	cfs	1.938	2.231	0.127	1.966	−2.518	6.332

* MCSE is Monte-Carlo standard error represents precision about posterior mean estimates.

Random-walk Metropolis-Hasting sampling is applied to capture prior distribution of damaged area of wildfire, which is a widely used posterior distribution sampling technique if the distribution is not established or the conjugated prior distribution. In statistics and in statistical physics, the Metropolis–Hastings algorithm is a Markov chain Monte Carlo (MCMC) method for obtaining a sequence of random samples from a probability distribution for which direct sampling is difficult. This sequence can be used to approximate the distribution (e.g., to generate a histogram), or to compute an integral (such as an expected value). Metropolis–Hastings and other MCMC algorithms are generally used for sampling from multi-dimensional distributions, especially when the number of dimensions is high (Bolstad, 2010).

Table 13. Check of MCMC Sampling Efficiency

Efficiency summaries MCMC sample size = 10,000

	Variable	ESS	Corr. time	Efficiency
Intercept	intercept	607.42	16.46	0.0607
Highest temperature(℃)	Temprt	325.91	30.68	0.0326
Wind Speed(m/s)	windsped	406.12	24.62	0.0406
Relative Humidity(%)	humidity	539.76	18.53	0.054
Pine tree ratio(%)	pinetree	371.53	26.92	0.0372
Slope (degree)	cfs	307.28	32.54	0.0307

Table 14. Test of Interval Hypothesis

Interval tests MCMC sample size = 10,000
prob1 : {d_areat:_cons} < 0.1

	Prob1	Mean	Std. Dev.	MCSE
Intercept	intercept	0.690	0.463	0.017
Highest temperature(℃)	temprt	0.330	0.470	0.020
Wind Speed(m/s)	windsped	0.675	0.468	0.019
Relative Humidity(%)	humidity	0.094	0.291	0.011
Pine tree ratio(%)	pinetree	0.546	0.498	0.022
Slope (degree)	cfs	0.674	0.469	0.022

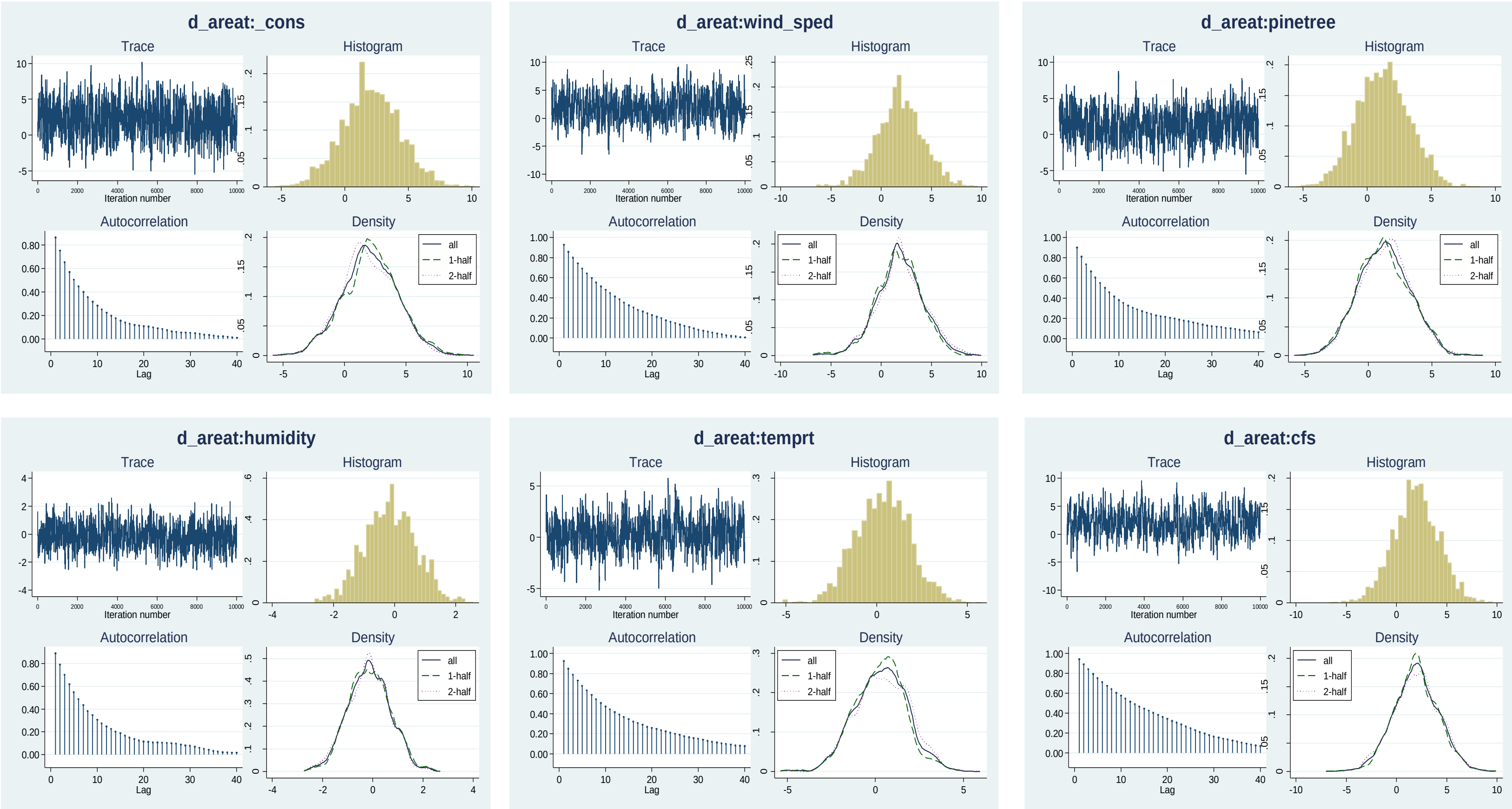

Figure 6. Diagnostics of MCMC Sampling

Basically, it is difficult to predict the damage area of wildfires because there are large standard deviations according to year, season, geographical feature and climate conditions. The range of climatic conditions is derived from upper limit to lower limit of maximum temperature, average wind speed and relative humidity distributions in the Goseong area using the MCMC. The each range assumed the Gumbel distribution of three climatic conditions to predict values of the upper limit. The validity of the wildfire damage area was calculated based on that 27 number of cases were selected and compared to the average damage area 27.82ha per year. When it is considering RCP8.5 scenario for the climate change, average damage area increased by 40.4%, compared to the burnt area under the case of without climate change.

Uncertainty in the climate change is largely divided into three categories: uncertainty due to the general circulation, uncertainty due to the CO2 scenario, and uncertainty due to the natural internal variability of climate (Kim *et al.*, 2014). Climate change can not be fully simulated, and climate prediction models have limitations that are inherently inaccurate (Giorgi and Mearns, 2002; Tebaldi and Knutti, 2007; Tebaldi *et al.*, 2004; Weigel *et al.*, 2008). One damaged area presents that applied number of cases from three different range values of climate conditions at Goseong, which are calculated in the wildfire damage area model in table 16.

Average wildfire damage area is 53.2ha and ranged from 45.8 ha to 65.3ha in the without climate change scenario. The largest damage shows 88.7ha as an upper limit under the case of climate change based on the ranged weather conditions in the table 15. In recent years, rising temperatures due to the climate change have affected to the risk of wildfires from certain times to throughout the year. At the same time, it greatly increased the risk of large wildfires in Gangwon province.

Table 15. Variation Range of Climate Conditions by MCMC at Goseong

Scenario	Range	Max Temp(℃)	Average Wind Speed(m/s)	Relative Humidity(%)
Without Climate Change	Upper limit	40.3	4.4	100.0
	Average	19.0	2.8	64.8
	Lower limit	4.9	1.5	35.0
With Climate Change (RCP8.5)	Upper limit	45.1	16.1	98.1
	Average	25.2	12.8	62.7
	Lower limit	10.4	9.6	37.1

Table 16. The 27 Cases of Wildfire Damaged Area based on Weather Variation by MCMC

(unit: ha)

Scenario / Cases	Without Climate Change			With Climate Change (RCP8.5)		
	Upper limit	Average	Lower limit	Upper limit	Average	Lower limit
1	62.7	57.9	55.3	87.0	82.6	80.0
2	60.9	56.3	53.7	81.7	77.5	74.9
3	59.0	54.7	51.9	76.5	72.4	69.8
4	65.3	60.8	57.8	88.7	84.5	82.0
5	60.9	56.3	53.7	81.7	77.5	74.9
6	61.6	57.6	54.3	78.2	74.3	71.6
7	65.3	60.8	57.8	88.7	84.5	82.0
8	63.4	59.2	56.0	83.5	79.4	76.8
9	63.4	59.2	56.0	83.5	79.4	76.8
10	60.2	56.0	53.9	84.8	80.8	78.6
11	58.4	54.4	52.3	79.5	75.7	73.4
12	56.5	52.8	50.6	74.3	70.6	68.3
13	57.7	53.2	50.8	83.1	78.9	76.4
14	62.8	58.9	57.0	86.5	82.7	80.7
15	59.1	55.7	53.5	76.0	72.6	70.5
16	55.8	51.6	49.2	77.8	73.8	71.3
17	60.9	57.3	55.3	81.3	77.7	75.6
18	59.1	55.7	53.5	76.0	72.6	70.5
19	60.3	57.0	55.3	84.3	81.0	79.2
20	57.7	54.1	51.8	82.6	79.0	77.0
21	55.2	51.3	48.3	80.9	77.1	74.6
22	58.4	55.4	53.9	79.1	75.9	74.1
23	55.9	52.6	50.6	77.4	74.0	72.0
24	53.3	49.7	47.1	75.6	72.0	69.8
25	56.5	53.8	52.3	73.8	70.8	69.0
26	54.0	50.9	49.2	72.1	68.9	66.9
27	51.4	48.1	45.8	70.4	67.0	64.8

The wildfire damage areas are directly linked to the losses of forest products, timber, landscape gardening, and so on. It means that all aspects are completely discontinued to use the forest land area. The amount of land assets per unit area was calculated by applying the forest land area ratio of Gangwon province to the total land assets in the country in table 17.

Table 17. The Land Asset per Forest Areas

	Land Asset (billion US$)	Forest Area (1,000 ha)	Land Asset per ha (1,000 US$)
Korea	5,923.09	6,335	935.04
Gangwon	1,285.31	1,372	937.06

In this dissertation, the losses of land assets are assessed including timber assets in table 18. The loss of land and timber assets caused by the Goseong wildfire damage depends on climate change scenario. It means that the losses of wildfire damages are presented as ranged value with upper limit and lower limit followed by the distribution of each climate source. The losses of land and timber assets consist of sum of the production losses in the forest sectors such as a reduction of capital stock as a factor input.

Table 18. The Loss of Land and Timber Assets by Goseong Wildfire

(unit: 1,000 US$)

	Without Climate Change	With Climate Change (RCP8.5)
Upper limit	122,426.1	166,321.9
Average	102,733.1	142,495.4
Lower limit	85,724.6	121,507.6

3.4. Transportation Demand Model

The transportation demand model generates the shortest travel time (minimum travel distance) between each city and county from a mathematical process of trip generation and distribution, and modal split with assignment. The characteristics of traffic demand have kind of the derived demand, diverse forms, and taking place over space, and have very strong dynamic volatility over time.

The shortest route algorithm in the network assignment results in a set of the shortest travel time (minimum travel distances), travel speeds, and travel demands on the links of the network using the EMME 4 program. Equation 3.28 is explained travel time of passengers from origin to destination considered of traffic volume, node and links.

$$T(OD) = \sum_{k=1}^{n} lt(OD)_k \qquad (l(OD) \in p(OD)) \tag{3.28}$$

T(OD): travel time from origin to destination

lt(OD): travel time of link l(OD)

l(OD): links in p(OD)

p(OD): the shortest line from origin to destination

O, D: origin and destination

n: the number of links in line p

Network consists of nodes, links, and traffic volume of links. The travel time savings are the most important form among road user benefits to be determined with the Volume to Delay Formula (VDF). A node accounts for an intersection, and a link presents a road or rail, which are connecting a node and another node. The node has coordinate values, and the link includes information such as a distance, a difference, a speed, and a capacity of the road section. Forecasting of traffic volume is based on a link allocation model that combines demand with supply and taking its value for each road link. At this time, the concept of a traffic zone called a centroid connector are introduced to connect the O/D and the network. As explained, the traffic demand is analyzed through this series of processes. When traffic fatalities occur due to the occurrence of wildfires, the driver is willing to take appropriate link and node to minimize travel times to maximize the utility level.

In the four−step transport model, the probability of travelers can select a particular mode (K) by the distribution of transporting mode in the logit model (equation 3.29).

$$P(K) = \frac{e^{U_K}}{\sum_i^n e^{U_i}} \tag{3.29}$$

$U_K = utility\ level\ of\ mode\ K$
$U_i = utility\ level\ of\ mode\ i$
$n = number\ of\ mode$

Equation 3.30 is a utility function of transportation zone to zone for selecting transport mode m in the four−step transportation demand (cost) model.

$$U_{ijm} = \alpha_1(Ttime)_{ijm} + \alpha_2(Tcost)_{ijm} + (DUM)_m \tag{3.30}$$

U_{ijm} : $utiltiy\ function\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(Ttime)_{ijm}$: $total\ travel\ time\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(Tcost)_{ijm}$: $total\ travel\ cost\ of\ transport\ mode\ m\ between\ zone\ i\ and\ j$

$(DUM)_m$: $Dummy\ of\ transport\ mode\ m$

Then, transit assignments are utilized the user balance principle from Wardrop (1952), which yields a balance of demand and supply. The travel time of the route used between origin and destination becomes less than or equal to the travel time of the route that is not used. An optimization algorithm of the link impedance (cost) function is used to derive the equilibrium state as shown below equation (3.31).

$$\mathrm{T} = T_0\left[1 + \alpha\left(\frac{V}{C}\right)^{\beta}\right] + distance * weight \tag{3.31}$$

where, T and V is the travel time and flow, respectively on the link, T_0 is the free flow travel time, and C is the practical capacity, α and β are the model parameters, for which the value of α =0.15 minimum and β $= 4.0$ are typically used.

The shortest travel time (minimum travel distance) between each city and county is an input value for the accessibility which is defined as the spatial interaction or development potential contacts with activities (Kim *et al.*, 2004). The accessibility by city and county is derived from discounting the population at all destinations by the shortest travel time (minimum travel distance), while the population is regarded as a proxy variable for the opportunity level at the destination. The functional form is a kind of travel time decay function as a gravity type (Kim *et al,* 2004).

$$ACCPOP_i = \sum_{j=1}^{n} \frac{P_j}{d_{ij}^{\sigma}} \tag{3.32}$$

$ACCPOP_i$: Accessibility index of population of city and county i

p_i: Population size of city and county i

d_{ij}: Travel distance from city and county i to j

i, j: Origin node and destination node

σ : Travel distance parameter

As the result of analysis, the road accessibility on the network is decreased caused by the Goseong wildfire damage which is presented in Table 19. To be specific, road accessibility of Gangwon and ROK has been decreased by 2.36%, 0.12%, by respectively.

Table 19. Changes of Road Accessibility with the Wildfire

	BASE	Wildfire	Difference	% changes
Gangwon	1,459,875	1,425,353	34,522	2.36%
ROK	22,323,766	22,297,492	26,274	0.12%

3.5. Tourism Expenditure Model

In this chapter, the losses of tourist expenditure are estimated due to the increasing transport cost for the trip from the accessibility decrease after suffering the wildfire damage. This accident affects to grow the inefficiency of business, driving restrictions for specific area, canceling a trip, and selecting alternative travel destinations. As far as tourist expenditure is concerned in this chapter, it is necessary to build the regional tourism expenditure model to assess the losses of tourism expenditure of Gangwon province.

The domestic tourism expenditure has been studied as one of tourism demands, which is explained by supply and demand factors using the multivariate regression framework (Song and Li, 2008; Marrou and Paci, 2013). The tourism expenditure model was first developed by Stone (1954) with the assumption of consumer utility maximization under budget constraints. Each commodity group of tourists spending can be calculated as the proportional share of the spending by subtracted from total expenditure (Phlips, 1983). Pyo *et al.* (1991) developed a linear expenditure system to forecast tourism demand in domestic US with independent variables such as income, prices of commodity groups (transportation, lodging, food service, entertainment/recreation, others). This paper suggested income and price elasticities that enable to analyze the effects of income and price changes on tourism quantity demand adopting the data of business receipts related to tourism from 1972 to 1987 issued by the US Travel data Center 1989.

The analysis on regional tourism demand in a domestic territory increased mainly focused on Europe and US. Massidda and Etzo (2012) examined the domestic tourists demand across the Italian regions over the period 2004-2007 within a Generalized Method of Moments panel estimation framework. Regional tourism flows are also positively influenced by characteristics of the destination region like cultural expenditures, attractiveness, transport infrastructure and population density, confirming the crucial role played by the supply side factors. The negative impact of distance (-0.07) is also confirmed, but its magnitude is much smaller than in other studies. Garin-Muñoz (2009) analyzed the inflow of domestic and foreign tourists in a specific region, Galicia, during the period 1999-2006. Considering total nights spent, the estimated elasticities show that both domestic and foreign tourism flows are very sensitive to income in the origin markets and to prices. Deng and Athanasopoulos (2011) proposed a complex analysis of Australian domestic and international tourism flows using a dynamic spatial lag panel model. The model accounted for both temporal and origin-destination spatial dependence. It is also allowed to feature seasonal variation and asymmetry between capital-city and non-capital-city neighbors. Significant evidence of time-spatial correlation was found, along with positive effects of income and of time dummies controlling for two specific events, the Bali bombings and the Sidney Olympic Games. De la Mata and Llano-Verduras (2012) analyzed the domestic flows across the Spanish regions in two distinct years, 2001 and 2007, by using a Bayesian spatial autoregressive model. Although they found evidence of positive spatial autocorrelation, the spatial dependence affected in different ways to the origin and the destination regions. GDP is provided only for the destination regions, while the value added of the hotel industry and the beach length are included as explanatory features only for the origin. The results confirmed the negative influence of geographical distance (elasticity equal to −1.69).

Marrocu and Paci (2013) examined domestic tourism flows for the Italian provinces by applying origin-destination spatial interaction models and simultaneously accounting for both demand and supply side factors. Tourism is highly differentiated product and diversified destination places to meet the needs of increasingly varied mixes of tourists. The determinants considered include a set of both pull and push location characteristics, namely income, density, accessibility, a set of cultural, natural and recreational endowments and geographical distance. Yang *et al.* (2014) investigated the domestic tourism demand of urban and rural residents in China based on the data from the National Household Tourism Survey. Chinese domestic tourism demand is explained as a function of absolute income, relative income, domestic tourism price, and substitute price in this study. As a major contribution of this study, relative income was measured using the distance between individual income and average income over a city/province. This paper highlighted the effect of relative income on domestic tourism demand in some sub-regions of China by applying the multilevel model. More specially, regional differences between residents in different sub-regions and different patterns of determinants between urban and rural residents were identified and discussed.

Through the literature articles, spatial movements of domestic tourists need to be considered the regional characteristics of the origin-destinations and including the transportation and information service. Therefore, this dissertation is adopted independent variables: road accessibility, destination potential sources, tourist convenient facilities and attractions to estimate each influence on regional travel expenditure following the previous literature. Unfortunately, the regional tourism demand research for domestic Korea is insufficient because of a limit to the data based on origin–destination format. In this dissertation, we overcame the limitations of the data and created road accessibility variables by integrating the Korea Tourism Travel Surveys and the traffic network data 2015 from the Korea Transport Institute.

We defined the tourism industry five sectors based on the classification of Tourism Satellite Account in this dissertation. The tourism consumption expenditure in Gangwon destination accounted for 9.8% and 99.2% of the household consumption expenditure of Gangwon and the ROK, by respectively in the table 21. In the case of the ROK, Tourism expenditure in the ROK as a destination occupy 16.9% and 13.7% of total household spending for Gangwon and the ROK, respectively.

Table 20. Tourism Consumption Expenditure in Regional Tourism Industry

(unit: billion US$)

Region	Sector	Gangwon		ROK	
		Tourism	Others	Tourism	Others
Gangwon	S5	0.032364	0.297208	0.871476	0.007391
	S6	0.034618	0.317909	0.056327	0.000478
	S7	0.036751	0.337497	1.103291	0.009357
	S8	0.004618	0.042412	0.023616	0.000200
	S9	0.033707	0.309547	0.512098	0.004343
ROK	S5	0.285407	1.406987	8.726751	55.172043
	S6	0.026044	0.128393	2.557525	16.169115
	S7	0.167915	0.827781	6.167090	38.989418
	S8	0.004387	0.021628	0.344515	2.178085
	S9	0.032778	0.161585	2.213038	13.991210

Note: S5. Retail and wholesale services, S6. Transportation service, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services

The tourism expenditure function was developed with data of Korea Domestic Tourist Survey, regional statistics, and origin–destination information. The reduction of tourism expenditure in Gangwon is estimated shocks by changing the road accessibility from rising transportation cost. To be specific, the analytic database are derived from Korea Domestic Tourist Survey 2013 in Korea Culture and Tourism Institute (KCTI, http://www.tour.go.kr/) and the regional basis aggregated data from the regional statistics in the Korea Statistics, respectively. It is able to combine with these two data to design the Origin/Destination (OD) framework, and then develop the travel time distance through the spatial tool in ArcGIS software. The accessibility index is a weighted average of population of the node and link impedance (travel distance) between origin and destination generated from a gravity−type estimator as a proxy for transportation services in the tourism expenditure model(Kim *et al.*, 2004, 2017). The descriptive statistics of 18 destinations in Gangwon province and the 236 origin places in ROK are shown in Table 22.

Table 21. Descriptive Statistics of Variables in Tourism Demand Model for Gangwon

Variable (unit)	Obs	Mean	Std. Dev.	Min	Max
Tourism expenditure (million KRW)	653	852.00	3,040.00	−	72,200.00
Person inome(million KRW)	653	48.76	25.96	0.30	200.00
Age (year)	653	46.32	17.81	15.00	97.00
Travel frequency	653	2.02	2.33	1.00	11.00
Daily travel cost in previous year(KRW)	653	158,036.00	178,932.10	−	2,340,000.00
Employee numbers in Tourism sector (person)	653	1,208.73	1,050.20	213.00	4,030.00
Number of hotel room	653	551.16	429.38	−	1,172.00
Number of total firms	653	9,386.85	6,794.93	1,849.00	27,338.00
Number of culture legacy	653	45.76	36.49	7.00	124.00
Population of origin place	653	391,739.40	250,781.70	10,153.00	660,302.00
Index of road accessibility(Index)	653	2,782,076.00	1,723,990.00	1,139,715.00	7,311,430.00

The dependent variable of tourism expenditure model, tourism expenditure, was calculated as the product of tourist numbers, travel cost, and length of stay. Independent variables are included personal income, previous year's daily travel costs, number of establishments in a destination, population of origin places, number of culture legacy, and road accessibility, which have positive signs on tourism expenditure as shown in table 22. To be specific, tourism expenditures in Gangwon will be increased by 0.222%, 1.392%, 0.316%, and 0.030%, by respectively, when personal income, daily travel cost for previous year, number of firms in a destination, and road accessibility increase by 1% each.

On the other hand, the number of travel companies in the destination has mainly played a role of transmitting tourists to the outside of the region, thus showing a negative sign in the tourism expenditure model. The variable of travel frequency for the destination was consistent with previous research that repeated visitors tend to reduce their travel expenditures.

Tourist expenditure (TE) model

$$lnTE_i = \beta_0 + \beta_1 lnINC_i + \beta_2 AGE_i + \beta_3 AGE_i^2 + \beta_4 COUNT_i + \beta_5 lnTCOST_i^{t-1} + \beta_6 lnEMPLEI + \beta_7 lnHTLCP + \beta_8 lnNFIRM + \beta_9 lnCULTLG + \beta_{10} lnPOPi + \beta_{11} lnACC + \epsilon_i \quad (3.33)$$

Table 22. Estimates of Tourism Expenditure Model for Gangwon

Variable		Estimate	S.E
Intercept		−1.159*	1.729
Personal income (KRW)	lnINC	0.222***	0.064
Age(year)	AGE	0.055***	0.011
Age* Age	AGE^2	−0.001***	0.000
Travel frequency for the destination	COUNT	−0.012*	0.017
Daily travel cost for previous year	lnTCOST	1.392***	0.048
Number of employee in travel firms in destinations	lnEMPLEI	−0.203**	0.079
Number of hotel room in a destination	lnHTLCP	0.111**	0.045
Number of firms in a destination	lnNFIRM	0.316***	0.106
Number of culture legacy	lnCULTLG	0.170**	0.085
Population of origin places	lnPOPi	0.078**	0.035
Index of accessibility	lnACC	0.030*	0.095
Adjusted R−square		0.645	

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level, value in parentheses indicates standard error of the coefficient.

According to the 2013 Korea Domestic Tourism Survey, tourism spending accounts for 24.96% of total household spending, with a monetary value of 153.61 billion US $. Tourism expenditure amounted to 23.23 billion US$ for wholesale, transportation, lodging, food, culture, sports, entertainment service, and 11.67% of which is spent 2.71 billion US$ in Gangwon province.

It is assumed that any production and transportation activities are not allowed within a radius of 20 km of the wildfire damaged area for seven days. The damaged area can be calculated from the wildfire damage area model, which affect to the travel time distance on the national road network in the transport demand model. In the tourism expenditure model, the reduction of road accessibility by 2.42% in Gangwon affected to be decreased 5.78% in total tourism consumption expenditure in Gangwon, as its monetary currency value is 164.02 million US$.

Chapter 4. Simulation

4.1. Overview of Simulation

The study area is located in Gangwon province, where more than half of the large wildfires occur in Korea and the road traffic rate in Gangwon is relatively lower than other regions. In addition, Gangwon is well known tourist destination, especially for domestic tourist. Gangwon has high risk of wildfires because more than 80% in the total area is covered with mountain area in Gangwon. In other words, the Gangwon was appropriated as the study area on analyzing economic impact on the tourism and forest industry in particular. To be specific, the 2000 Goseong wildfire burned 23,794 ha, the largest wildfire in Korea since 2000, and can be strongly dependent on the topography including temperature, humidity and wind speed.

This chapter presented the process of experimental simulation through the IRCGE framework for estimating the economic effect of the wildfire damage in Korea. The calibrated IRCGE model is executed in comparative static simulations in the short run. Based on the wildfire damages on economic impacts of the regional or industrial aspect, it can be applied to policy instruments of the allocation of government budget, subsidy or grant organization, and tax reduction to minimize the wildfire damage. In this dissertation, the indirect impact is evaluated in terms of gross domestic production (GDP), gross regional production (GRP), and such macro-economic indicators.

The simulations are estimated regional economic effect of wildfire damages, which are divided into scenario 1(without climate change) and scenario 2 (with climate changes following the RCP8.5) based on the weather forecasting report from Korea Meteorological Administration 2012. This report argued that the climate change of Korean Peninsula is ongoing and it predicts the trend of global warming until the year of 2100. The high greenhouse gas emission scenario (RCP 8.5) is considered into changing values in the upper or lower limit of climate variables as the scenario of the climate change in Gangwon. Specifically, it is predicted a temperature rise of 0.62 degrees per 10 years according to the climate change scenario RCP8.5.

Baseline: No wildfires in Gangwon
Scenario 1 : Wildfires in Goseong county of Gangwon province without climate change
Scenario 2 : Wildfires in Goseong county of Gangwon province with the climate change of the high greenhouse gas emission (RCP8.5)

The damaged area of wildfires with no climate change in Gangwon is 65.3ha as the upper limit and it affects to decrease value added in forest sectors caused by decreasing capital stock in the forest products production model and forest manufacturing model. With considering the climate change, the wildfire damaged area ranged from 60.9ha to 88.7ha in RCP8.5 after applied positive or negative (±) standard deviation of each climate data. In addition, its average loss of land and timber asset in Gangwon is 937,000 US$ per ha and the final demand reduction of wildfires in forest industry amounted from 66.91ha to 70.84 million US$ in scenario 1 and from 62.69 to 83.12 million US$ in scenario 2 by increasing burnt area with the case of climate change. The climate change scenarios are predicted for the case with the climate change is higher than the case of without the climate change due to rising temperature and wind speed based on a forecasting of 2030 of the Korea National Weather Service.

Overall forest assets in Gangwon on the year of 2013 are 1,285.31 billion US$, accounting for 21.7% of the nation's total, including land and timber assets. It is included the residential and commercial building land, the attached land, the agricultural land, the forest land, the cultural entertainment land, and other land equivalent to the land assets in net capital stock of the Balance Sheet of the

Bank of Korea. The total amount of timber assets is distributed according to the ratio of the land assets to the total amount of land from the National Statistical Office. The classified timber assets are distributed according to the forest area by provinces.

4.2. Result of Impact Analysis by Wildfires

The wildfire experiment in this dissertation, it is supposed that the wildfire occurred in Gangwon province, which is located in the eastern area of the country. The location represent 21.6% of total forest area in Korea. Additionally, one of large wildfires has been damaged 23,448ha in Gangwon province for 2000 year. In the dissertation, the indirect impacts are measured in terms of gross domestic product (GDP) and gross regional product (GRP) under interindustrial mobility of labor and capital factors across regions. It is assumed that any production and transportation activities are not allowed within a 20 km radius of the damaged area.

For the analysis, 16 provinces are classified into two regions; one damaged Gangwon province and the rest of Korea (hereafter ROK). The industrial sectors are integrated into Forest sector, Tourism sector, Primary, Manufacturing, and Service sectors. When the wildfire happen at Goseong county in Gangwon province, there would be a sharp downturn in the national and regional economies similar to the expectation. The indirect impact on regional economies is the reduction of GRP, value added, Consumer Price Index (CPI), and so on. This analysis focused on indirect economic impact on regional changes of value-added caused by the wildfire. The economic impacts presented its loss value and the growth rate in the form of a range when it is considering the uncertainty of the climate condition. It means that the sign of positive or negative can be inconsistent and appeared together depending on the ranged value of the indirect economic effect.

The GDP could decreased from −0.039 to −0.087 billion US$ without the climate change case and from −0.051 to −0.535 billion US$ under the climate change. The Consumer Price Index (CPI) decreased from 0.01 to 0.030%p under the case of without climate change and by −0.11~0.11%p in the case of climate change, which is affected by the losses of the forest and tourism composite goods due to the wildfire. This would decline ranged from −0.069 to −0.153 billion US$ of GRP for Gangwon but increase from −0.027 to −0.065 billion US$ for ROK under the case of without the climate change. The climate change could lead to magnify the economic loss from −0.143 to −0.344 billion US$ for Gangwon and from −0.191 to 0.182 billion US$ under the climate change. In addition, the wildfire has a negative effect on the value−added in forest sector and tourism sector for Gangwon: the forest sector in the Gangwon by −12.10%~−17.43% and by −0.71~−0.85% in tourism sector under the case of without climate change. The negative effects on the GRP tend to become more severe in Gangwon than the ROK: the growth rate is 0.23~0.55%, which is much lower than that of the ROK by 0.01~−0.01%. The influence of the climate change for Gangwon are 1.5 to 2.2 times larger than value−added losses of the scenario under the without climate change.

However, somewhat interesting outcome is that the GRP of ROK could improve from 0.027 to 0.065 billion US$ without the climate change case and from −0.191 to 0.182 billion US$ under the climate change. That is, ROK is able to enjoy significant “reflexive benefits” by increasing the share in the domestic market for some time while Gangwon are experiencing value−added loss from the disaster. This should be noted that the economic benefits on the region should not be regarded as a positive effect of the wildfire in a sense that the increase in the GRP is generated through the sacrifice of the damaged region. It implies that it is necessary to establish regional coordination among local governments in order to obtain effective rehabilitation schemes to share the costs and benefits from the accidents. Taking into account inter−industry linkage structure embedded in the economic system, it would be worthwhile to implement sector−specific recovery activity plan to have the regional economic resilience to bounce back.

Table 23. Changes in GDP and GRP

1) Change in GDP, Value added, CPI, and Output (unit: billion US$, %)

	Without Climate Change		With Climate Change	
	Lower limit	Upper limit	Lower limit	Upper limit
Total GDP	−0.087	−0.039	−0.535	−0.051
VA of Gangwon	−0.153	−0.069	−0.344	−0.143
VA of ROK	0.027	0.065	−0.191	0.182
CPI	0.000	0.000	−0.001	0.001
Output of Gangwon	−0.225	−0.088	−0.580	−0.212
Output of ROK	−0.053	0.263	−3.591	1.500

2) Growth rate (baseline=100)

	Without Climate Change		With Climate Change	
	Lower limit	Upper limit	Lower limit	Upper limit
Total GDP	99.99	100.00	99.96	100.00
VA of Gangwon	99.45	99.75	98.77	99.49
VA of ROK	100.00	100.00	99.99	100.01
CPI	100.01	100.03	99.89	100.11
Output of Gangwon	99.59	99.84	98.93	99.61
Output of ROK	100.00	100.01	99.88	100.05

*Gangwon: Gangwon Province; ROK: The Rest of Korea
*The forest sector include S1. Forest Products, S2. Wood and wood products, S3. Pulp and paper products, S4. Other manufacturing products and processing of timber. The tourism sector consist of S5. Retail and wholesale services, S6. Transportation services, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services. Other sectors take in S10. Primary Industry, S11. Manufacturing Industry, and S12. Service Industry.

Table 24. Changes in Value-Added

1) Chang in Value-Added (unit: billion US$)

		Gangwon		ROK		Total	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Without Climate Change	Forest Sector	-0.087	-0.061	-0.010	0.002	-0.098	-0.058
	Tourism Sector	-0.045	-0.037	-0.017	0.004	-0.061	-0.034
	Primary Sector	-0.003	0.000	-0.002	0.000	-0.005	-0.001
	Manufacturing Sector	-0.003	0.002	-0.048	0.093	-0.051	0.095
	Service Sector	-0.015	0.032	-0.018	0.095	-0.033	0.126
	Total	-0.153	-0.064	-0.095	0.194	-0.248	0.129
With Climate Change	Forest Sector	-0.116	-0.087	-0.104	0.021	-0.220	-0.066
	Tourism Sector	-0.073	-0.045	-0.101	0.040	-0.174	-0.005
	Primary Sector	-0.003	-0.003	-0.039	0.010	-0.042	0.007
	Manufacturing Sector	-0.015	-0.005	-1.788	0.674	-1.802	0.669
	Service Sector	-0.022	-0.002	-0.530	1.809	-0.551	1.807
	Total	-0.228	-0.143	-2.562	2.554	-2.789	2.411

2) Growth Rate (baseline=100)

		Gangwon		ROK		Total	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Without Climate Change	Forest Sector	82.57	87.90	99.97	100.01	99.72	99.83
	Tourism Sector	99.15	99.29	99.99	100.00	99.97	99.98
	Primary Sector	99.88	99.98	99.99	100.00	99.98	100.00
	Manufacturing Sector	99.89	100.08	99.99	100.03	99.99	100.03
	Service Sector	99.91	100.19	100.00	100.01	100.00	100.02
	Total	99.45	99.77	99.99	100.01	99.98	100.01
With Climate Change	Forest Sector	76.89	82.61	99.69	100.06	99.36	99.81
	Tourism Sector	98.61	99.15	99.95	100.02	99.92	100.00
	Primary Sector	99.89	99.85	99.86	100.04	99.87	100.02
	Manufacturing Sector	99.49	99.83	99.51	100.18	99.51	100.18
	Service Sector	99.87	99.99	99.92	100.26	99.92	100.26
	Total	99.18	99.49	99.81	100.19	99.79	100.18

*Gangwon: Gangwon Province; ROK: The Rest of Korea

*The forest sector include S1. Forest Products, S2. Wood and wood products, S3. Pulp and paper products, S4. Other manufacturing products and processing of timber. The tourism sector consist of S5. Retail and wholesale services, S6. Transportation services, S7. Restaurants and accommodation services, S8. Cultural Services, S9. Sports and entertainment services. Other sectors take in S10. Primary Industry, S11. Manufacturing Industry, and S12. Service Industry.

Chapter 5. Conclusions

5.1. Summary

The purpose of this dissertation is to develop an analytical framework for estimating regional indirect impacts of wildfire damage on forest and tourism industry. The methodology was composed of Inter Regional Computable General Equilibrium (IRCGE) model, wildfire damage model, transportation demand model, and tourism expenditure model. The IRCGE model is described two macro regions under the neoclassical economic theory, which established with social accounting matrix in 2013 base year. The wildfire damage area model estimated burnt areas considering high uncertainty based on data of temperature, wind speed, humidity from the Ministration of Korea Meteorology and wildfire statistics, forest type, slope features by spatial unit from Korea Forest Service. The transportation demand model considered the efficiency of road accessibility between zones of the road network of Korea. Lastly, tourism expenditure model is estimated by reduction of tourism spending as increasing transportation cost caused by the wildfire. The estimated burnt area in the wildfire damage area model affected to the production loss, decline in final demand of forest products, increase of transportation expenses, and the decrease of tourism expenditure in the destination.

In order to examine the validity of the developed IRCGE, a simulation on the Goseong wildfire was conducted for Gangwon province considering Intergovernmental Panel on Climate Change (IPCC)' s prospects for climate changes, the emission scenario of the Representative Concentration Pathways(RCP8.5). There is a suitable place to analyze the indirect impact on forest and tourism industry because it is a typical tourist destination and mountains covered more than 80% of the total area of the province. Markov Chain Monte Carlo method was adopted to estimate ranged burnt areas considering the high uncertainty of climate and topography due to the nature of wildfire, the change of transportation accessibility, and the loss of tourism expenditure.

The economic effects of Goseong wildfire were analyzed by using the experiment of the wildfires damage under the cases of without or with climate change. Gross Domestic Product (GDP) in Korea due to the wildfire damage decreased by −0.01% under the without climate change, −0.04% when considering climate change. The Gross Regional Product (GRP) of the Gangwon Province decreased from −0.25% to −0.55% (−0.069 ~ −0.153 billion US$) due to Goseong wildfire under the no climate change and from −0.51%

to −1.33% (−0.143~−0.344 billion US$) under the climate change (RCP 8.5). The value added of industrial changes in Gangwon province decreased from −12.10% to −17.43% in forest sector and from −0.71 to 0.85% in tourism sector due to the fire damage. The value added losses of the industry under the climate change will be about 1.5 to 2.2 times larger than the scenario without climate change. On the other hand, GRP in the rest of Korea (ROK) enjoyed reflex benefits from 0.027~0.06 billion US$ due to the wildfire damage in Gangwon Province, and value added changed within the range of −0.191 ~ 0.182 billion US$ in ROK under the climate change scenario.

This dissertation developed a framework for estimating economic effects with considering the climate change applicable to other natural or manmade disasters. The developed framework was applied to wildfire damage and confirmed its usefulness. The results of the analysis can be used as a basis for establishing the government budget for disaster prevention and magnitude of the subsidy considering prioritized monetary losses by each industry. In addition, it can be used to calculate the insurance premium for damage compensation.

5.2. Further Research

In terms of methodology, it is necessary to develop a quarterly model that is not an annual model in this study in order to improve the accuracy of the economic effect estimates, which enables to reflect seasonal variations in climate, production capacity and short-term disasters. For the quarterly IRCGE model, the coefficient of technology should be decomposed based on the initial data such as the input calculation table and the social accounting matrix. Also, it is necessary to introduce a dynamic model to analyze the economic effects of disasters considering the time required for long-term recovery depending on the damage level of the disaster. The dynamic model can overcome the disadvantages of the static model by applying the technology coefficient matrix to consider changes in production technology.

With regard to the policy, first, it is necessary to supplement the strategy of wildfire suppression to minimize the wildfire losses, to increase the scale of the disaster prevention budget, and to quickly prevent the spread of large wildfire. For example, the Ministry of Security and Emergency Management, which has improved the dualized wildfire evacuation structures, has established the first wild fire fighting action team, and regularized the wildfire monitoring workforce and raised the wage level. Second, it can be necessary to provide detour roads to improve transportation accessibility to wildfire damaged regions and also to increase business efficiency in wildfire areas and around regions. Most industries including manufacturing suffered from the increase of travel distance and then it can lead to a decline in value added and a negative impact on productivity. Third, in response to the decrease in tourism spending caused by the wildfire damage, local governments should minimize the damage through active tourism marketing policy to promote tourist visits and provide alternative transportation vehicles. Losses resulting from temporary closed parks and entertainment resources need to be presented compensation policies to support subsidies from the government.

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국문초록

Regional Indirect Impacts of Wildfire Damages on Outputs of Forest and Tourism Sectors

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본 연구의 목적은 예측이 어려운 재난의 경제적 효과 추정에 적용 가능한 미시-거시 연결된 분석틀인 지역간연산가능일반균형모형(Inter Regional Computable General Equilibrium Model: IRCGE)을 개발하는 것이다. 개발된 IRCGE모형은 우리나라 산림지역의 대표적 재난인 산불피해에 적용하여 그 유용성과 추정치의 타당성을 검토하였다. 분석대상지역은 국내 가장 큰 산불이 발생하였던 강원도 고성지역으로 산림이 80% 이상을 차지하고, 대표적인 관광목적지이므로 산림 및 관광산업의 경제적 간접효과를 동시에 분석 가능한 적지로 판단하였다. IRCGE모형은 일반 CGE모형에 기후변화 및 공간 특성을 고려한 산불피해면적모형, 산불진화로 인한 교통비용을 반영한 교통수요모형, 산불로 인한 관광수요 감소를 적용한 관광지출모형 등의 3개 미시모형을 연결한 분석틀이다. 먼저, 산불피해면적모형은 산림청의 산불통계와 기상청의 방재기상자료를 포함한 지형, 임상 등의 공간자료를 토대로 구축되었다. 교통수요모형은 국가교통네트워크자료를 토대로 통행발생, 통행분포, 수단선택, 통행배정의 4단계에 따라 산불지역 도로통제로 인한 254개 시군구별 도로접근성 변화를 분석하였다. 관광지출모형은 2013년 국민여행실태조사를 토대로 산불피해로 인한 강원도 관광지출액의 변화를 추정하였다.

IRCGE모형을 이용한 고성산불피해의 경제적 효과 시뮬레이션은 기후변화 이전과 이후의 2가지 시나리오로 구분하여 산불피해면적 범위자료를 토대로 분석하였다. 먼저, 산불피해로 인한 우리나라 국가총생산(GDP)은 -0.01%에서 기후변화 고려 시 -0.04%까지 감소하였다. 고

성산불로 인하여 강원의 지역총생산(GRP)는 −0.25~−0.55%에 해당하는 690억원~1530억원이 감소하였고, 기후변화(RCP8.5)를 고려하면 −0.51~−1.33%인 1430억원~3440억원으로 피해수준이 크게 증가하였다. 산불피해로 인한 소비자물가지수(CPI)는 −0.01%p~−0.030%p가 감소하였고, 기후변화 시나리오에서는 −0.11%p~0.11%p의 변화를 보였다. 강원도 산림업과 관광업의 부가가치는 산불피해로 인하여 −12.10%~−17.43%와 −0.71~0.85%가 각각 감소하였다. 기후변화를 고려한 해당 산업의 부가가치 감소는 기후변화없는 시나리오의 약 1.5~2.2배 증가하였다. 한편, 기타지역의 GRP는 강원의 산불피해로 인한 270억원~600억원의 반사이익을 누렸고, 기타지역 기후변화 시나리오에서 부(−)의 1,910억원에서 정(+)의 1,820억원의 범위에서 부가가치 변화가 나타났다.

본 연구의 기여는 다양한 재난에 적용가능한 경제적 효과추정 분석틀을 개발한 것이다. 개발한 분석틀은 산불피해에 적용하여 그 유용성을 확인하였다. 개발된 미시−거시 연결모형에 다양한 재난을 분석한 미시모형을 추가하는 방식으로 이용할 수 있다. 기존 연구는 재난의 직접효과 추정에 집중되어 지역 및 산업간 간접효과 연구가 미흡한 상황이었다. 본 연구는 재난의 간접효과를 분석하여 연관산업의 부가가치 손실과 다른 지역의 간접 피해를 확인할 수 있었다. 분석결과는 산업별 재정지출의 우선순위 결정에 활용할 수 있다. 추가적으로 이는 산불방재예산, 보조금 규모 수립에 근거자료로 활용이 가능하며, 피해보상을 위한 보험금 산정에 이용할 수 있다.

향후 연구과제는 방법론과 정책적 측면으로 구분하여 살펴보았다. 먼저, 방법론적 측면에서 기후의 계절성, 생산능력의 변동 및 단기 재난을 반영하여 경제적 효과 추정치의 정확성을 제고하기 위한 분기모형을 개발할 필요가 있다. 분기 IRCGE모형을 위하여 투입산출표와 사회계정행렬 등의 초기자료를 시간을 기준으로 기술계수를 분해할 수 있다. 또한, 재난의 피해수준에 따라 복구에 필요한 기간을 고려한 재난의 경제적 효과를 분석하기 위하여 동태모형을 도입할 필요가 있다. 동태모형은 생산기술의 변화를 고려하기 위하여 기술계수행렬을 적용하여 정태모형의 단점을 극복할 수 있다. 정책적 측면은, 산불피해최소화를 위한 산불진화 및 방재 예산편성, 산불발생지역의 사업 효율성을 제고하기 위한 교통접근성 보완, 관광지출액 감소에 대응한 지방정부의 관광마케팅정책 추진과 대체 운송수단의 활용방안 등을 연구할 필요가 있다.

주요어: 지역경제효과, 재난, 산불, 관광지출, 지역간연산가능일반균형모형
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