Analyzing Indirect Economic Impacts of Wildfire Damages on Regional Economy

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Key words: Interregional CGE Model, Disaster, Wildfire Damage, Economic Impact, Tourism

SUMMARY

This paper estimates economic impacts of wildfire damage on regional economies, developing an Integrated Disaster-Economic System of Korea. The system is composed of four modules (Interregional Computable General Equilibrium (ICGE) model for Eastern Mountain Area (EMA) and the rest of Korea, Bayesian wildfire model, transportation demand model, and tourist expenditure model), but in terms of model's hierarchical structure, the ICGE model is a backbone module to be linked with three other ones. The IDES is applied to the simulation of the wildfire in the EMA of Korea, the most frequent occurrences of forest fires. In the simulations, three external shocks are injected into the ICGE model: (1) The wildfire damaged area derived from the Bayesian wildfire model, (2) changes in travel times among cities and counties derived from the transportation demand model, and (3) decreases in visitor's expenditures derived from the tourist expenditure model. The GRP of EMA would decline by 0.249% to 0.548% without the climate change and by 0.511% to 1.232% without the climate change.

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1. BACKGROUND

There are both positive and negative effects of wildfires on regional economies. The positive effects come could be generated through demand side's shocks such as increases in fire suppression spending and post-fire recovery and restoration, rebuilding of damaged areas and construction of temporary housings, and replacement of lost infrastructure facilities, but are expected to be much lower than negative ones (Diaz, 2014). These effects or costs of wildfires range from direct costs of firefighting, loss of regional income from local production, land and property damages, disconnection of infrastructure network and disruption to traffic flows, reduction of tourists visits and increases in public health and safety costs for the emergency services and ecological biodiversity. For example, wildfires in California, 2008 have burned more than 17,582 ha, destroying at least 400 houses and 500 mobile homes. White ash and smoke have spread as far away as 25 miles away from the fires, while they were aggravated by a combination of low humidity, high winds, and high temperatures. This loss is the worst case ever in California, exceeding the loss of 484 residences in the 1961 Bel Air fire. The wildfire is expected to become one of critical disasters against household consumptions, production activities, and logistics in Korea in a sense two thirds of total national lands are covered with mountain and forest areas. Moreover, the fire frequency will further increase due to the climate change as drier conditions leading to increases in the frequency of extreme events and fire activities (Giglio et al., 2012). The economic damages of the disaster can be classified into direct and indirect ones. The former includes physical losses such as business interruption and unemployment, while the latter does the consequence of interactions between transactions across sectors (Cochrane, 2004; Rose, 2004; Ding et al. 2011). However, the indirect damage could not be easily captured due to its innate complexities and uncertainties without a quantitative method to identify economy-wide effects on markets and economic agents' decisions: it implies that the economic values of damages from the disaster have been underestimated because of neglecting the indirect impacts on the economy.

To quantitatively assess indirect economic damages of natural disasters could be a key to develop their resilience investment and recovery plans to reduce risks. It is worthwhile to develop an analytic framework to estimate indirect impacts of the disaster on the economy. The model is expected to provide policy makers with how much financial resource should be allocated in terms of precautionary and rehabilitation activities. The purpose of this paper is to estimate economic impacts of wildfire damage on regional economies, developing an Integrated Disaster-Economic System (IDES). This system is composed of four modules of (1) Interregional Computable General Equilibrium (ICGE) model, (2) Bayesian wildfire model, (3) transportation demand model, and (4) tourist expenditure model. The key module of the IDES is the ICGE model to be developed for two regions, Eastern Mountain Area (EMA) and the rest of Korea (ROK) on the base year of 2013, and to be linked with other three modules. The IDES is applied to the simulation of the wildfire in the mountainous area, the EMA of Korea where large wildfires have frequently occurred similar to California in US, to measure the loss of regional incomes due to the wildfires. The next section is focused on an overview of application tools for analyzing the economic impacts of the disasters on the regions. The section three estimates the economic impacts of the wildfires on regional economies in Korea, developing the IDES with four modules. The final section discusses further research issues with a research summary.

2. LITERATURE REVIEWS

2.1 ECONOMIC IMPACT ANALYSIS OF DISASTERS

Lots of works have been focused on estimation of economic effects of disasters with development of analytical simulation models (Greenberg et al., 2007; Okuyama, 2007; Okuyama and Santos, 2014). The Input-Output (IO) model and the Computable General Equilibrium (CGE) model have been widely used in assessing economic loss of the damages. The IO model is primarily specialized in demand analysis and changes in economic structures from the disaster. Ryu and Cho (2010) estimated the indirect economic damages due to typhoons and heavy rains of Korea, developing 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 the Gross Regional Product (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. Most severely indirectly affected by losses in production are the real estate service sector, transport equipment production, and other business services in Bayern. They proposed to take into account the secondary effects of disaster and supply chain restrictions from other linked sectors in recovery of production possibilities as one of risk management planning.
Another type is an integration of the IO with transportation network and planning 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 the earthquake impact on transportation cost using the IO 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 million ton mile/year and average 10.82 miles. The results provided a basis for 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) estimated the economic impacts of three floods of Rotterdam in Netherlands, using the integrated recursive dynamic multiregional supply-use model with production technologies and constraint on supply of transportation service. Baghersad and Zobel (2015) developed a Linear Programming model based on the IO model to assess the economic consequences of production capacity bottlenecks by disruption of the electricity sector of Singapore. Under 12 different scenarios, the total average inoperability and total inoperability of the entire economy would go down with decreasing initial loss and increasing recovery within the electricity sector, which implied that improving the robustness of the electricity sector could have a stronger impact on the total average inoperability of the economy than decreasing the recovery time.

The CGE model has succeeded in transforming a complex and abstract economic structure into a numerical and analytic framework of the supply- and demand-side channels based on microeconomic optimization of economic agents using a variety of assumptions and macroeconomic-closure rules. 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 Gross Domestic Product (GDP) and the energy consumption would fall down in the absence of coastal protection, but certain regions with substantial dike building could increase GRP level in spite of a reduction in the utility level with the coastal protection. Tatano and Tsuchiya (2008) presented a spatial CGE model to estimate the economic losses incurred due to transportation network disruption after the Niigata-Chuetsu earthquake. The simulation showed spillover patterns of economic losses arising from the earthquake with respect to the intra- and interregional trades. This paper discussed counter-measures to reduce negative spillovers to adopt mitigation policies for the reduction of the damage to residential facilities. Rose and Liao (2005) analyzed the economic impact of the disruption of water services in the Portland Metro economy, showing how the indirect economic losses depended on the water shortages, the extent of pre-event mitigation, and post-event inherent and adaptive resilience. While previous studies could integrate economic approaches with estimation of physical damages, more work is required for interactions of economic agents with respect to spatial mobility of factor inputs and commodities using the spatial network. In particular, as discussed in Husby and Koks (2017), the integration of micro-spatial analysis at city level with traditional macro-spatial or aggregated regional models might be suitable for economic analysis of the disasters in the sense that it is essential to understand spatial diffusion patterns of negative effects from the disaster across the spatial units.

Table 1 Impact Analysis of Disasters

Author	Type of Disasters	Model	Impacts / Key Issues
Rose *et al.* (1997)	Earthquake	IO model and Linear programming	Reduction in the GRP by 7%
Cho *et al.* (2001)	Earthquake	IO model	Integration of network model, spatial allocation model and the IO model
Kim *et al.* (2002)	Earthquake	IO model	The IO model combined transportation model
Sohn *et al.* (2003)	Earthquake	IO 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
Bosello *et al.* (2007)	Sea level rise	CGE model	Impacts on the GDP and energy consumptions
Tatano and Tsuchiya (2008)	Earthquake	Spatial CGE model	Direct and indirect spillover effect on regional economies
Ryu and Cho (2010)	Typhoon and heavy Rain	IO model	Reduction in the GDP by 1.18%
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
Husby and Koks (2017)	Disasters	The IO and the CGE model with ABMs	Integration of micro model with the IO and the CGE model

Source: revised from Kim and Kwon (2016)

2.2 ECONOMIC IMPACTS OF WILDFIRES

Cost approach and multivariate analysis have been widely applied to 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$). Kunji et al. (2002) assessed the effect of the wildfire on air quality and health in Indonesia. More than 90% of respondent had respiratory symptoms, and elderly individuals suffered a serious deterioration of overall health. Between September 1997 and November 1997 in Indonesia, there were 527 hazed-related deaths, 0.30 million cases of asthma, 58,095 cases of bronchitis, and 1.45 million cases of acute respiratory infection reported. Sage and Nickerson (2017) estimated the direct impacts of the wildfire damage of Montana in 2017 on the economy with the cost analysis. The entire state lost up to 800,000 visitors due to the summer's fires and smoke in 2016, resulting in a loss of 240.5 million US$ in the visitor spending. Pyke et al. (2016) measured 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 US$ based on the visitor survey. To minimize the economic effects of fire events, they discussed that the tourism planning and stakeholder communication should be key priority.

In terms of multivariate analysis, Rahn (2009) estimated the overall economic impact of wildfires on regional economies in San Diego as 2.45 billion US$ or $6,500 per acre. The total suppression cost was less than 2% of the entire economic impact, which was a relatively negligible cost in contrast to the overall loss. Moseley et al. (2012) analyzed the effects of large fires of California during 2004~2008 on labor markets. Local employment and wages in a county increased during large wildfires; the economic impact of the suppression effort outweighed the economic disruption from large wildfires in the short term. However, in the long term, the large wildfires caused an instability in local labor markets by amplifying seasonal variation in the employment in tourism and natural resource sectors. Kiel and Matheson (2015) revealed that the sale price of housing could decline by 21.9% due to canyon forest fire in Colorado 2010, using the difference-in-difference approach. Kochi et al. (2016) measured economic cost of wildfire smoke exposure in terms of counting medical cost in hospital admissions at the period of 2007 using time-series count model and negative binomial model: the total medical cost was estimated over 3.4 million US$.

Above all, previous works have attempted to measure economic costs of wildfire to focus mainly on forest timber loss, the changes in wildfire suppression budgets and recovery costs. Namely, most papers should have taken into account estimating the secondary or indirect damages to the regional economies, such as the decrease in production activities, the increase in travel times and of tangible and intangible cultural heritage as tourism resources (Marrion, 2016). It would be necessary to measure not only the indirect effects of disasters on the region and its neighboring areas but also negative effects of its subsequent damages including flooding and its smoke on property loss and human health in terms of sectoral linkages. In addition, previous papers on the wildfire have identified the change of forests appearance and the damage on the forest trees and crops. This spatial micro data could have been applied to analyzing the probability of occurrence of wildfires and the spatial diffusion area. Since the damage areas of the wildfires depend on the geographical and environmental factors, the spatial analysis is a key to develop various disaster prevention programs for early-warning system of wildfires and reducing the economic damages.

Table 2 Impact Analysis of Wildfires

Author	Country / Region	Method	Impacts
Mercer *et al.* (2000)	USA / Florida	Spatial and Econometric Analysis	1864 US$ per acre of economic losses
Kunji *et al.* (2002)	Indonesia	Econometric Analysis	Change in mortality
Rahn (2009)	USA / California	Cost Analysis	2.45 billion US$ of costs
Moseley *et al.* (2012)	USA/ California	Econometric Analysis	Increases in local employment and wages
Kiel and Matheson (2015)	USA / Colorado	Econometric Analysis	Decline of housing sale price by 21.9%
Kochi *et al.* (2016)	USA / California	Econometric Analysis	3.4 million US$ of medical costs
Pyke *et al*. (2016)	Australia	Cost Analysis	1.5 million US$ of post-fire flooding costs
Sage and Nickerson (2017)	USA / Montana	Cost Analysis	240.5 million US$ of visitor spending losses

3. ANALYSIS

3.1 MODEL

The Integrated Disaster-Economic System (IDES) is composed of four modules; (1) the ICGE model for economic analysis of macro-regions, (2) the transportation demand model for calibration of travel times, (3) tourist expenditure model for estimating visitors' spending, and (4) the Bayesian wildfire model to estimating the damaged areas. In terms of computational process, the first step is to measure annual wildfire damage size using the disaster model with climate and topographical factors. The next one is to calculate how many the travel time increases and the resulting accessibility decreases in a response to the occurrence of wildfires using the transportation demand model. The third one is to calibrate the reduction of visitor's expenditures using the tourist expenditure model, and the final one is to estimate the negative effect of the wildfire on the regional incomes, injecting (1) the wildfire damaged area of the disaster model and (2) the spatial accessibility level of the transportation demand model into the production function, and (3) the changes in the visitors' expenditures of the tourist expenditure model into the household consumption in the ICGE model.

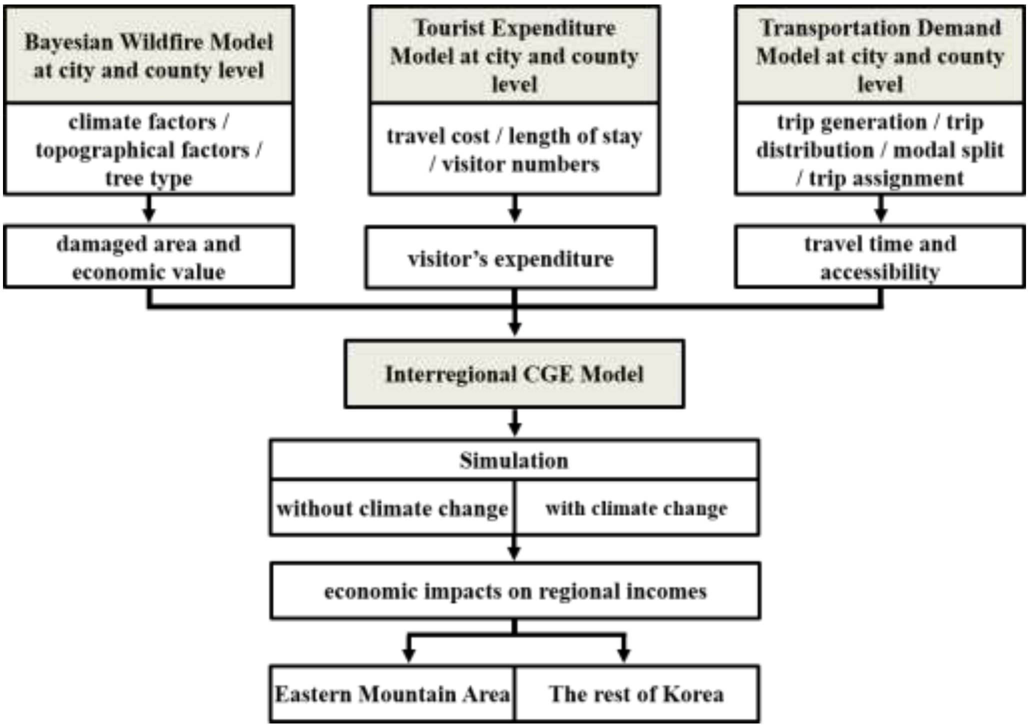

Figure 1 Structure of Integrated Disaster-Economic System

The backbone of the entire system, the IDES is the ICGE model to account for maximization of producer's profit and consumer's utility in the real side economy, following market-clearing prices under equilibrium. There are two macro-regions, Eastern Mountain Area (EMA) and the Rest of Korea (ROK) in Korea, and one representing the rest of the world (ROW) in the model. Production activity is divided into 12 sectors such as four forest sectors (forest products, wood & wood products, pulp & paper products, and processing of timber), five tourism sectors (retail & wholesale, transportation, restaurants & accommodation, cultural services, and sports & entertainment services), primary, manufacturing, and service sector. Each industrial sector is assumed to produce a single commodity, which is disaggregated into an intraregional supply, a regional export, and a foreign export by production destination, while there are three types of commodities such as an intraregional supply (demand), a regional import, and a foreign import in the regional market in terms of the product origin. Each commodity and factor input price is determined through an equilibrium process between supply and demand in each market. The basic structures of the CGE model have been discussed in many textbooks including Shoven and Whalley (1992) and Dixon and Jorgenson (2013), so we do not repeat such details here, but focus on distinguished points from the previous ones.

The production structure model is composed of three-stages. At the top of the structure, the gross output is determined via Leontief production function of value-added and intermediate inputs. The latter is derived from interregional input-output coefficients, whereas the value-added at province level is simply the sum of those of cities and counties. These are specified with spatial econometric Cobb-Douglas production function of labor and capital inputs with the land area variable as a proxy for development potential. The intermediate demands are transformed into demands for domestic products and foreign imports using the Armington approach in the second stage. The total demands for the domestic products are classified into intraregional supplies and regional exports, which are determined by their relative prices and spatial interaction between two regions at the bottom stage. In addition, the profit maximization under the two-level Constant Elasticity of Transformation (CET) function produces an optimal allocation of the gross output via the domestic supplies and the foreign exports. Each regional labor input is assumed to be homogeneous and moves among the regions, while capital stock cannot move from one region to other in the short run. The labor supply relies on the participation rate 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 wage per capita and unemployment rate, as well as the physical distance between the regions.

The total demand consists of intermediate and final demands such as consumption and investment expenditures of private and government sectors. Two tiers of government structure are specified in the model; two macro regional governments and one national government. Government expenditures are composed of the consumption expenditures, subsidies to producers and households, and savings. Revenue sources include taxation of household incomes, value-added, and foreign imports. Aggregate savings are sum of household savings, corporate savings of regional production sectors, 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. In addition, a Social Accounting Matrix (SAM) is calibrated as a benchmark for the development of the Interregional CGE model. The SAM consists of six accounts—factors, households, production activities, government, capital, and the rest of the world—and is treated as an initial equilibrium for the Interregional CGE model. The structure of the ICGE model is shown in Figure 2. 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. It is not easy to assess a validation and prediction performance of the CGE model due to its deterministic foundation: in general the model reliability has been evaluated in terms of measuring the stability of the results over time (De Maio et al., 1999; Kim et al., 2016). In this paper, a sensitivity analysis for various model settings and key parameter values was applied to determine the robustness of the results as discussed in Belgodere and Vellutini (2011) and Kim et al. (2016). The GDP and the GRP of the EMA could be reduced by 0.1–0.3% and 0.2–0.5%, respectively, if the elasticities of substitution and transformation for the Armington and CET functions increased by 10%: it means that the model is comparatively reliable for counterfactual analysis.

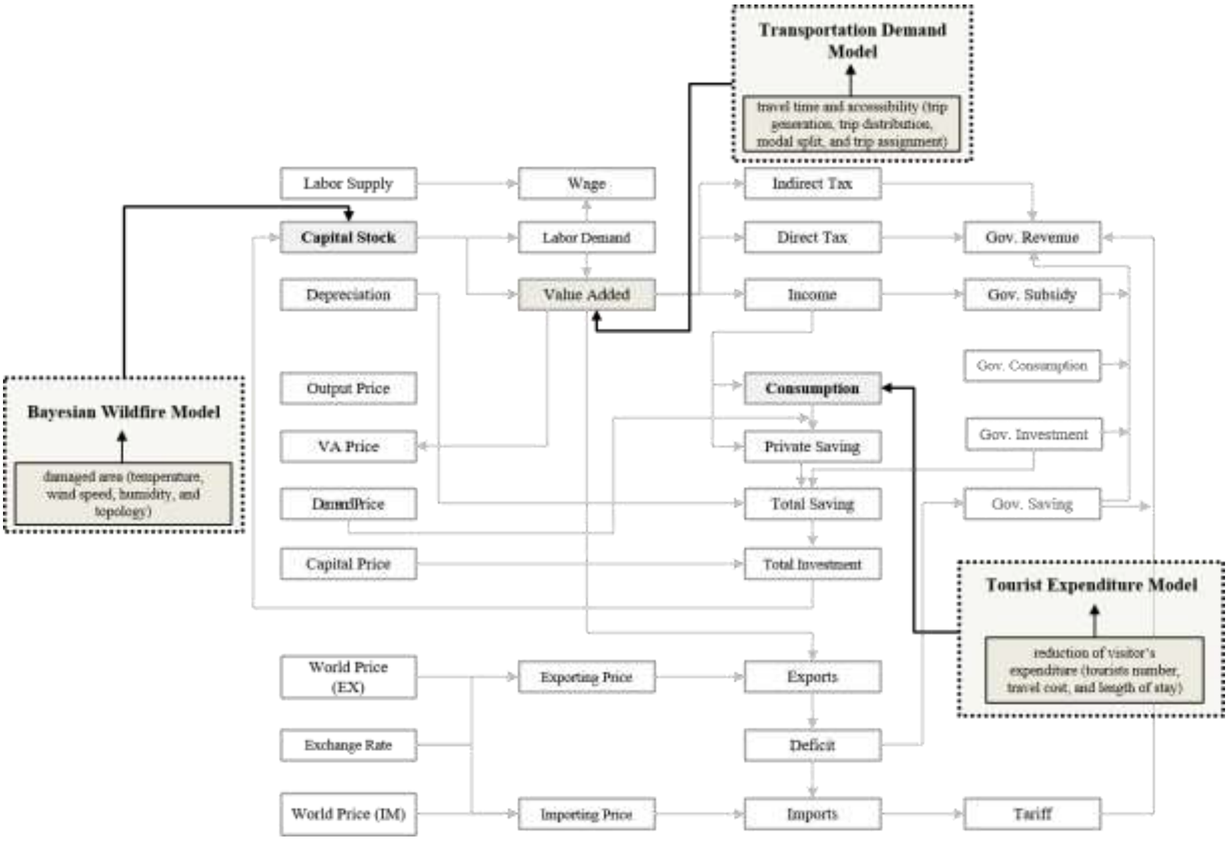

Figure 2 Structure of Interregional Computable General Equilibrium Model

Table 3 Major Equations of Interregional CGE Model

Output	Output = Leontief (Value added, Intermediate demand)
Value added	Value added = Total Factor Productivity*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)
Total Factor Productivity	Total Factor Productivity = TFP (Accessibility, Population)
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

Source: revised from Kim and Kwon (2016)

The second module of the IDES is the wildfire model to calibrate the wildfire damage area with climate and topographical factors. The model in this paper is estimated with the Bayesian estimation method: it has been recently utilized for the fire research area together with most popular logistic regression model, maximum entropy model, and the random forest model (Mori and Johnson, 2013; Jaafari et al., 2017). Mori and Johnson (2013) argued suitability of Bayesian model for simulation of the risk of wildfires, especially in small areas. The Bayesian approach estimates a posterior probability for the extent of wildfire damage with assuming prior probability, and as a robust method, infers 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 independent variables of the disaster model are maximum temperature, humidity, wind speed, slope of topography, and pine tree ratios as independent variables whereas the human factors cannot be included in the model due to the limitation of data (Woo, 2015). Meteorological observations (maximum temperature, relative humidity, and average wind speed) and topographic features (slope and pine tree ratio) are provided by the Korea Meteorological Administration and the Korea Forest Service, respectively. The daily weather conditions of Eastern Mountain Area are monitored by multiple disaster monitoring stations, and the slope and pine tree ratio by grid zone are analyzed by the spatial analysis tool of ArcGIS. 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 for the slope is the average maximum technique which combines the neighborhood algorithm with the maximum downhill Slope algorithm provided by ArcGIS10.1. The model is estimated as following equation.

$$DA_i = 2.060 + 0.332\,HT_i + 1.888\,WS_i - 0.147\,HU_i + 1.250\,PT_i + 1.938\,CFS_i \quad (1)$$

$$(22.637^{***})\ (4.049^{***})\quad (16.561^{***})\quad (-4.083^{***})\quad (11.905^{***})\quad (15.260^{***})$$

$R^2 = 0.710$

(* $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$.)

DA_i: Wildfire damaged area (ha)

HT_i: Highest temperature (℃)

WS_i: Average wind speed (m/s)

HU_i: Relative humidity (%)

PT_i: Ratio of pine tree in the area (%)

CFS_i: Cos converted facing slope (degree)

The next module is the transportation demand model to generate the shortest travel time (minimum travel distance) between each city and county through a mathematical process of trip generation and distribution, and modal split with assignment. The shortest route algorithm in the network assignment results in a set of the shortest travel time, travel speeds, and travel demands on the links of the network using the EMME 4 program. The user balance principle of Wardrop (1952) to yield a balance of demand and supply is applied to the transit assignment, while an optimization algorithm of the link impedance (cost) function is used to derive the equilibrium state. The shortest travel time from the Transportation Demand Model can be an input value for the accessibility which is defined as the spatial interaction or development potential contacts with activities as a gravity type (Kim et al., 2004). This accessibility level is injected into the production function in the ICGE model.
The last module in the IDES is the tourist expenditure model to estimate the spending using the multivariate regression framework in terms of supply and demand factors (Song and Li, 2008). Major independent variables of the tourist expenditures in EMA are visitor's personal income, daily travel cost for previous year, the number of firms in a destination, and the road accessibility. The equation is estimated with Korea Domestic Tourist Survey and transportation demand information in 2013. Korea Domestic Tourist Survey 2013 (n=653 for EMA) is derived from Culture and Tourism Institute (KCTI, http://www.tour.go.kr/) and the regional statistics. The road accessibility is a weighted average of population of the node and link impedance (travel time distance) between 236 origin and 18 destination regions in EMA generated from a gravity-type estimator as a proxy for transportation services in the tourist expenditure model (Kim et al., 2004, 2017). The occurrence of the wildfire could decrease the road accessibility to trip for EMA, which help reduce total tourist expenditure of the destinations in EMA. For instance, if the accessibility increases by 1%, the expenditure would decrease by 0.030%, as shown in the following equation.

$$
\begin{aligned}
lnTE_i^t = &-1.159 + 0.222\, lnINC_i^t + 0.055\, AGE_i^t - 0.001(AGE_i^t)^2 + 1.392 lnTC_i^{t-1} - 0.203 lnEMP_D^t \\
&\quad (-0.670^{*})\ \ (3.450^{***})\ \ (5.110^{**})\quad (-5.980^{***})\quad (28.720^{***})\quad (-2.570^{***}) \\
&+0.111\, lnHTL + 0.316\, lnFIRM_D^t + 0.170\, lnCULT_D^t + 0.078\, lnPOP_O^t + 0.030\, lnACC_{OD}^t + \epsilon_i \qquad (2) \\
&\quad (2.450^{**})\quad (2.970^{***})\quad (1.990^{**})\quad (2.200^{**})\quad (1.820^{*})
\end{aligned}
$$

$R^2 = 0.645$
(* P < 0.10. ** P < 0.05. *** P < 0.01.)

TE_i^t: Tourist's expenditure

INC_i^t: Tourist's personal income

AGE_i^t: Tourist's age

TC_i^{t-1}: Tourist's daily travel cost at previous year

EMP_D^t : Number of employees in travel firms in destination region (D)

HTL_D(t): Number of hotel room in destination region (D)

$FIRM_D^t$: Number of firms in destination region (D)

$CULT_D^t$: Number of culture legacy in destination region (D)

POP_O^t: Population size of origin region (O)

ACC_{OD}^t: Road accessibility between origin region (O) and destination region (D)

3.2 SIMULATION

The IDES is applied to estimate economic effects of the wildfire on regional incomes. As a case, we assume that the wildfire takes place in Goseong County in Eastern Mountain Area, where more than half of the large wildfires occur in Korea. This area is well known for tourist attraction and is covered with mountain area as much as 80% in the total area, holding for the 2018 Pyeong Chang Winter Olympics. However, the EMA has geographical disadvantages of heavy forest fuel accumulation and relatively low accessibility due to high-sloped mountains above 1,000m, which it is difficult to put out wildfires. In addition, in a sense that the wild fire's occurrence tends to be very sensitive to weather conditions such as the wind speed and the humidity level, the model is used to measure how the climate change affects economic losses of the wild fires as a counterfactual analysis. There are various alternatives of RCPs for the wildfire damage simulation, and the RCP8.5 is selected to capture economic impact of wildfires in the EMA as a proxy of high emission scenario of GHG. Two experiments for this application is as followings.

Baseline: No wildfires in the Eastern Mountain Area (EMA)
Experiment 1: Wildfires in the EMA without the climate change
Experiment 2: Wildfires in the EMA with the climate change under the high GHG emission (RCP8.5)

The economic effect of each experiment is compared with the base case, and all exogenous variables of each case have the same values as in the base case. In the simulations, three external shocks are injected into the IDES: (1) The wildfire damaged area in Goseong derived from the Bayesian wildfire model, (2) changes in travel times among cities and counties due to the wildfire from the transportation demand model, and (3) decreases in visitor's expenditures derived from the tourist expenditure model. That is, in the event of wildfire disaster, the shock to the regional economy in terms of supply side is reduction in the production potential by labor and capital shortages and malfunction of production systems such as disruption of production machinery. This damage to the transportation network increases transportation costs or distorts the commodity flows, and has spillover effects on neighboring regions through production chains and decreases the regional attractions to change consumer patterns.

These shocks by the wildfires are expected to result in (1) increases in the damaged areas, (2) reductions in wood inputs and land stock in the production process of forest and tourism industries, and (3) increases in travel time (distances) by temporary disruption of road network. In the occurrence of the wild fires, all roads within a radius of 5km from the damaged area are assumed to be closed: any mobility of vehicle and population including economic activities is not allowed in the simulation. The baseline accounts for what would happen without any significant change, and the differences in the damaged area, the accessibility and the tourist expenditure between the baseline and the scenario are considered a 'shock' to the model. The shock is injected into the ICGEP model, after which a new set of equilibrium values can be generated subject to the price normalization rule and the exogenous consumer price inflation rate. Each baseline and counterfactual simulation produces a sequential path of economic behavior following an internal consistency under its own population scenario. In this paper, the damage impacts are measured as a short-term flow such as changes in the value-added and the production of goods and services, and the results from the counterfactual experiment are compared with those from the baseline case.

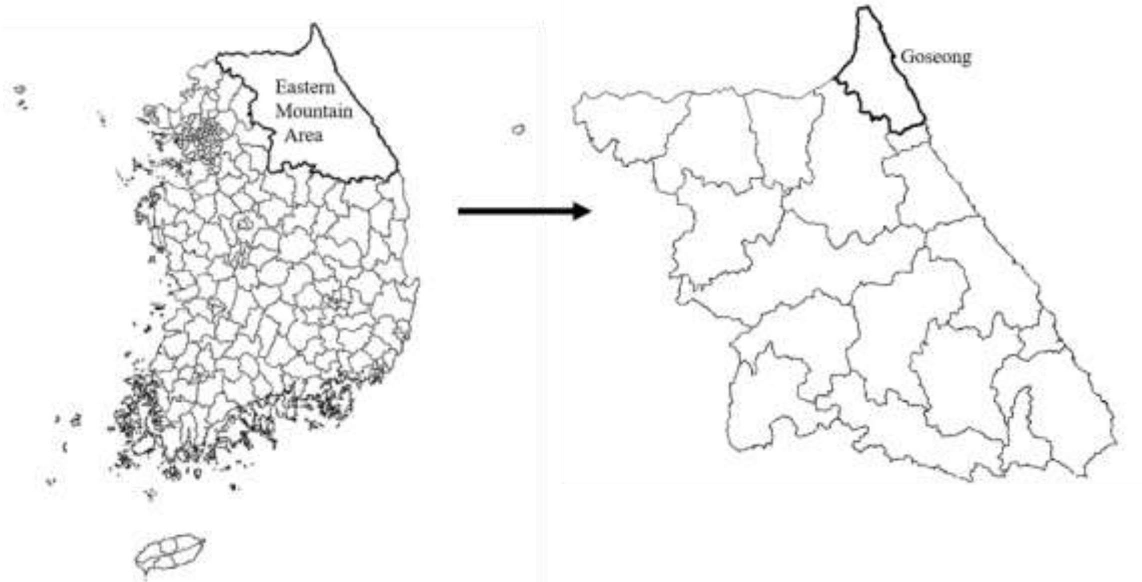

Figure 3 Damaged Areas of Wildfires

If the wildfire takes place in Goseong, the first step is to measure the damaged areas using the disaster model. The annual or monthly values of three independent weather-relevant variables such as the humidity, the wind speed and the temperature have been widely volatile, so each variable is assumed to follow the Gumbel probability distribution based on extreme value theory rather than normal distribution (Lee et al., 2006; de Zea Bermudez et al., 2009). The Markov Chain Monte Carlo (MCMC) simulations are applied to find the lower and the upper levels of input values of three key variables using mean and standard deviation of each variable. The Monte Carlo model as a stochastic simulation model can carry out a stochastic simulation by reproducing a virtual situation (Binder and Heermann 2010). As a result, the sizes of damaged areas depend on three combinations of independent variables: each variable has lower and upper limits, so there are eight sets of value choices of three variables as shown in the following Table 4. It shows ranges of the wildfire damaged areas for two case (with and without climate change) from the results of Monte Carlo simulations of a combination of lower and upper levels of three stochastic variables (temperature, average wind speed and relative humidity distributions) in the Goseong area. The average damage area under the climate change of RCP8.5[1] scenario could increase by 40.4%, compared to the scenario of without climate change.

Table 4 Wildfire Damaged Area by Weather Condition under

Scenario / Cases	Without Climate Change		With Climate Change (RCP8.5)		Weather Condition		
	Lower limit	Upper limit	Lower limit	Upper limit	Temperature	Wind Speed	Relative Humidity
1	55.3	62.7	80.0	87.0	Lower	Upper	Lower
2	53.7	60.9	74.9	81.7	Lower	Lower	Lower
3	51.9	59.0	69.8	76.5	Lower	Upper	Upper
4	57.8	65.3	82.0	88.7	Lower	Lower	Upper
5	53.7	60.9	74.9	81.7	Upper	Upper	Lower
6	52.3	56.5	69.0	73.8	Upper	Lower	Lower
7	49.2	54.0	66.9	72.1	Upper	Upper	Upper
8	45.8	51.4	64.8	70.4	Upper	Lower	Upper

The next one is to quantify effects of the wildfire on the travel times using the transportation demand model. The approach finds that the wildfire could increase an average travel time of the EMA by 2.42% because of imposing a "no passing" zone on the area within a radius of 5km from Goseong. The third stage is to estimate changes in consumption expenditures of visitors on Goseong using tourist expenditure model: the expenditures are determined by multiplying the number of tourists, travel costs, and length of stay. The consumption amounts of the EMA and the ROK residents on Goseong would decrease by 5.78% and by 6.07% respectively. When the wildfire occurs at Goseong County, there would be a sharp downturn in the Gross Regional Product (GRP) as expected. The GRP of EMA would decline by 0.249% to 0.548% without the climate change and by 0.511% to 1.232% without the climate change. It implies that the climate change could lead to magnify the economic loss from 0.263% point to 0.684 % point for EMA, depending on the weather conditions. In addition, the wildfire would have a negative effect on value-added in forest sector and tourism sector for EMA: the value added of the forest and the tourism sectors could decrease by 12.116% to

[1] Representative concentration pathways (RCPs), RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). The scenario of comparatively high greenhouse gas emissions (RCP8.5) assumes high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions in absence of climate change policies (Riahi et al., 2011).

17.425% and by 0.767% to 0.846% respectively. Meanwhile, the economic damages at the national level could not be as substantial as possible because the factor inputs and regional trades would continue to move across the sectors and regions to keep stability of economic conditions.

Table 5 Impacts of Wildfire on Value-Added and GRP of EMA (unit: %)

	Without Climate Change			With Climate Change (RCP8.5)		
	Lower	Mean	Upper	Lower	Mean	Upper
Four Forest Sectors*	-12.116	-14.750	-17.425	-17.425	-20.020	-23.114
Five Tourism Sectors**	-0.767	-0.740	-0.846	-0.854	-0.990	-1.386
Primary Sector	-0.017	-0.047	-0.119	-0.148	-0.178	-0.623
Manufacturing Sector	0.017	0.077	-0.112	-0.174	-0.206	-0.753
Service Sector	0.187	0.048	-0.088	-0.012	-0.419	-0.702
GRP of EMA	-0.249	-0.371	-0.548	-0.511	-0.836	-1.232
GRP of ROK	0.002	0.002	0.005	0.000	0.014	-0.014
GDP (Total GRP)	-0.003	-0.006	-0.006	-0.010	-0.004	-0.040

* Four forest sectors: forest products, wood & wood products, pulp & paper products, and processing of timber
** Five tourism sectors: retail & wholesale, transportation, restaurants & accommodation, cultural services, and sports & entertainment services

However, somewhat interesting outcome is that the GRP of ROK could increase by 0.002% to 0.005% for the case of without climate change, while the GDP could decrease slightly by 0.003% to 0.005% without the climate change and by 0.010% to 0.040% without the climate change. That is, the ROK is able to enjoy unexpected benefits by increasing the share in the domestic market for some time while EMA are experiencing value-added loss from the disaster. That is, 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 in the short term. It shows that it would be worthwhile not only to implement regional coordination and rehabilitation programs among local governments to share the costs and benefits from the accidents but also to have the regional economic resilience to bounce back. For instance, it is possible to develop dark tourism products for the damaged areas by wildfires as a source of compensating for reduced tourism incomes and to use them as a means of promoting wildfire prevention policies. As the drone has been utilized in forestry research and practices due to its flexible, low-cost, and high-resolution according to Tang and Shao (2015), the investment of fixed-wing drones and video control equipment could improve Korean wildfire management system in a series of process of the early detection of wildfires, rapid suppression and even the recovery step.

Since tourism industry is more vulnerable to the climate change, it is necessary to develop adaptation strategies to climate change and mitigation efforts to extreme catastrophes in tourism industry in order to maintain regional economic viability. Additionally, policy alternatives can be implemented for how climate-dependent tourism destinations to cope with increasing weather variability. One of mitigation strategies of an unexpected wildfire can be the intra-industrial diversification to reduce vulnerability of local consumer-oriented industries to external tourism demand shock. It increases the initial recovery rate after the disaster with climate change while growing industrial diversification and specific spending mix of tourism destination in terms of economic resilience management.

4. CONCLUSION AND RESEARCH AGENDA

This paper develops an Integrated Disaster-Economic System of Korea to estimate economic impacts of wildfire damage on regional economies. The system is composed of four modules (ICGE model for Eastern Mountain Area and ROK at province level, and the Bayesian wildfire model, the transportation demand model, and the tourist expenditure model at city and county level), but in terms of model's hierarchical structure, the ICGE model is linked with three other modules. The IDES is applied to the simulation of the wildfire in Goseong County in the EMA of Korea. In the simulations, three external shocks are injected into the ICGE model: (1) The wildfire damaged area in Goseong derived from the Bayesian wildfire model, (2) changes in travel times among cities and counties due to the wildfire from the transportation demand model, and (3) decreases in visitor’s expenditures derived from the tourist expenditure model. The GRP of EMA would decline by 0.249% to 0.548% without the climate change and by 0.511% to 1.232% without the climate change. One of major contributions in this paper is to integrate regional economic model with the place-based disaster model and the demands of tourism and transportation (trip) and to build up quantitative linkages between macro and micro spatial models in a bottom-up system for the impact analysis of disasters. This approach could be applied to economic issues of integrated pest management for agricultural products and disaster planning for the commodity flows, too.

As further research issues, the spatial diffusion pattern of wildfires should be examined at city and county level since the weather conditions usually depend on not only natural resources but also built-environment and structures. More efforts need to be focused on the dynamic analysis for interactions and spillover effects among environment and economic agents. It is necessary to improve fire occurrence probability model with spatial covariates and autocorrelation using spatial point processing method on the basis of fire occurrence data. On the policy side, the development of dark tourism products can be used as a means of promoting wildfire prevention policies, thereby minimizing the amount of tourism spending reduction and utilizing it as a new regional financial revenue source. Finally, it would be possible to develop an allocation method of government budgets on the forest preservation if we take into account economic values of forest assets or damage to the natural resources with estimation of costs of suppression and recovery investments as well as the direct and indirect economic effects derived from this paper.

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