Revealing building vulnerability to windstorms through an insurance claim payout prediction model: a case study in South Korea

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\textbf{ABSTRACT}

The aim of this study is to develop regional vulnerability functions of buildings to estimate the loss from windstorms. Windstorms trigger critical financial damage to assets around the world. Insurance companies assess the financial risk of their exposures by employing windstorm risk assessment models. The vulnerability function in the risk assessment model is generally based on the analysis of actual damage records from insurance companies. However, the absence of detailed loss data is an obstacle to developing vulnerability functions. To fill this gap, this study provides a methodology to develop a function using an insurance company’s loss data associated with windstorms. Vulnerability functions are generated based on the wind speed, line of business, and value of the property. The findings and methodology of this study offer a practical way of reflecting the real economic losses and regional vulnerability of buildings and help to develop vulnerability functions for insurance companies and emergency planners.

\textbf{1. Introduction}

The frequency of severe windstorms has been rapidly augmented, and the amount of losses caused by windstorms has increased as well. Hurricane Katrina in 2005 caused about 108 billion USD of total financial damages, and the hurricane was recorded as the costliest natural catastrophe in the United States. The states located on the United States Gulf Coast were paralyzed by the direct and indirect damage from the hurricane. Hurricane Sandy and Hurricane Ike have been labelled the second and third most costly hurricanes. Hurricane Sandy in 2012 caused 71.4 billion USD in damages, and Hurricane Ike in 2008 caused 29.5 billion USD in damages (Blake et al. 2007). Furthermore, the series of three severe European windstorms in December 1999, Anatol, Lothar, and Martin, swept western and central European countries with record-breaking wind and storm surges. The total economic losses were about 13 billion Euros (Ulbrich et al. 2001). Typhoon Haiyan, also known as Super Typhoon Yolanda, struck in 2013 and has been dubbed the most extreme tropical cyclone ever documented at landfall. Southern Asian countries were devastated and had extensive damages caused by the typhoon’s severe wind and storm surges. The total damages were about 2.86 billion USD.
Governments, emergency planners, and the insurance industry adopt risk assessment models and loss records to manage risk at the regional or country level. Industrialized countries exploit insurance as a key method to transfer the financial risk causing windstorms. Therefore, it is critical for the insurance industry to assess the risk precisely. Insurance companies utilize the windstorm risk assessment model to estimate the potential economic loss they are exposed to. The risk assessment model is a combination of four elementary modules: hazard, exposure, damage, and vulnerability. The hazard module describes the event physically and defines the intensity of the windstorms, including the central pressure, rainfall, and wind speed. The exposure module represents a detailed building inventory and geographic information of the buildings. The damage module calculates the financial loss with the particular coverage of the policy, such as the deductible and limit of liability. The vulnerability module reflects the correlation with damage and hazard, and quantifies the amount of damage using vulnerability functions (Khanduri & Morrow 2003). Vulnerability functions are generated based on the results of analysing the losses associated with the windstorms. Hence, the accuracy of the vulnerability function is highly associated with the quality of the data.

Analysing the losses resulting from windstorms is vital in the insurance industry. Primary and reinsurance companies have to arrange for unexpected damages from extreme natural disasters like Hurricane Katrina in 2005, the Northridge earthquake in 1994, and the Thailand flood in 2011. The companies set catastrophe zones and allocate a budget for each zone to distribute the risk and avoid troubles from extreme disasters. Moreover, the essential values in the insurance industry, such as the probable maximum loss, excess of loss reinsurance, and limit of liability, are created on the basis of analysing loss experiences. The values apply to reasonably sharing and allocating the risks (Cummins et al. 1999; Kim et al. 2016). Consequently, developing advanced vulnerability functions is the best way to assess the exact financial risk from windstorms.

However, in reality, developing vulnerability functions is challenging due to the lack of detailed loss records. The most specific and precise loss data are the claim payouts of insurance companies, which can be used to examine the vulnerability of individual buildings using the characteristics of the building inventory. The claim payouts are decided based on the examination results of the engineers and adjusters. Nevertheless, insurance companies are not able to so much as document the loss as aggregated or filed without detailed property information, such as the construction type, building height, building materials, and building age. For developing and emerging countries with poor insurance penetration, it is especially difficult to get specific loss records to develop vulnerability functions. The insufficiency and inconsistency of information makes it difficult to explain the relationship between damage and hazards in developing countries. Even if some building vulnerability is not easily or directly quantifiable, more work on identification and development with proxy measurements of risk is necessary to decrease the uncertainty of the assessment model.

The goal of this study is to develop regional vulnerability functions of buildings to estimate the loss from windstorms. This study provides a methodology to develop functions for countries with inadequate building inventory information. Herein, an insurance company’s loss data in South Korea associated with windstorms is adopted. Vulnerability functions are generated based on the wind speed, line of business, and value of the property. The generated vulnerability functions are validated with actual loss data of major typhoons using each year’s actual exposure.

2. Importance of in-house models

Numerous international organizations, initiatives, and private interests have made substantial efforts to develop risk assessment tools to better estimate and react to or mitigate the risk from natural hazards. In the public domain, Central America Probabilistic Risk Assessment for South America, Risk-Scape for New Zealand, New Multi-Hazard and Multi-Risk Assessment Method (MATRIX) for Europe, and HAZUS Multi-Hazard for the United States are well-known multi natural hazard assessment models. The models evaluate the physical, direct financial damages, and indirect damages at the country or community level from tropical cyclones, earthquakes, floods, and storm
surges. Nonetheless, the models are not designed to cover the insurance industry. In the insurance industry sector, there are many natural hazard model vendors such as risk quantification and engineering (RQE), Applied Insurance Research, and Risk Management Solutions. The primary and reinsurance companies exploit the companies’ models to assess the risk of exposure to natural hazards and reinsurance outward and inward (Sanders et al. 2002). The hazard model companies solely depend on their hazard models. They recommend setting up an in-house natural hazard model to self-estimate a company’s own risk based on its capital, business preference, and portfolios. In addition, they propose their own viewpoint on risk judgments, saying that the results of vendors’ models are either conservative or progressive.

3. Vulnerability function

The evaluation of building vulnerability to windstorms is a critical part of the windstorm risk assessment model. The vulnerability of buildings is reflected by a vulnerability function, also known as a damage curve or vulnerability curve. The vulnerability function to windstorms describes the connection between damage (mean damage ratio) and hazard intensity (wind speed), and determines the amount of damage. The mean damage ratio is given as a percentage of the damage and represents the windstorm vulnerability of the building. The ratio is identified as follows: the total cost of the damage or repairs caused by a windstorm is divided by the total cost of the building at the experienced wind speed of the building. A low ratio represents lower vulnerability and robustness in the face of windstorms.

Therefore, the financial damage record is required to develop the vulnerability function. Although the damage record is accessible to the insurance company, the problem is the resolution of the loss data, such as building age, building materials, construction type, and building height. If an insurer has one regular type of building in a specific region, such as low rise apartments, resorts, or malls, the insurer is able to build a vulnerability function with slight trouble owing to the stereotype of the building stock and only small differences in geospatial features.

In reality, however, insurers cover more than just one local level, and the types of buildings covered are diverse as well. The loss data also may not be available at a higher resolution, particularly in developing countries. Therefore, the question remains of how to generate a function representing the extensive diversity of buildings in an insurance company’s portfolio. This study develops a vulnerability function based on elementary variables, e.g. a line of business such as residential, commercial, and industrial; and the value of the property, considering both the accessibility and vulnerability of buildings in the region.

4. Loss experiences

4.1. Typhoons and damage

This study employs windstorm damage data from a primary insurance company in South Korea from the year 2003 to 2013 at an individual property level. Owing to the data resource, the scope of the study is limited to South Korea and the aim of the study is to develop a regional vulnerability function that is able to reveal the regional characteristics of geographic and building vulnerability using existing evidence.

The amount of payout associated with windstorms is a ground-up loss, which is the original loss or the whole loss to the company. The losses do not take the deductible or reinsurance and retention into account.

The major eight typhoons struck the Korean peninsula and caused significant financial losses. The typhoons are Typhoon Maemi in 2003, Typhoon Nari in 2007, Typhoon Kompas in 2010, Typhoon Muifa in 2011, Typhoon Tembin in 2012, Typhoon Bolaven in 2012, and Typhoon Sanba in 2012, as shown in Figure 1. The typhoons were straightly swept or extremely impacted the Korean
peninsula and caused vital losses as seen in Figure 2. Typhoon Maemi in 2003 was the most costly and critical typhoon on record with regard to the total amount of losses (85.7% of the total amount of losses) and the number of losses (66% of the total number of losses). Typhoon Kompas and Typhoon Bolaven were the next most costly and significant typhoons. Their losses occurred throughout the nation. Specifically, the provinces located in the southern part of the Korean peninsula, Gyongsangnam-do and Busan, were disastrously damaged by the typhoons. Gyongsangnam-do was devastated by these typhoons in regards to the dollar amount of damages (41%) and the number of losses (25%). Busan was also critically destroyed by the typhoons with respect to the dollar amount of damages (35%) and the number of losses (29%).

The claims consist of the information such as amount of loss, accident date, detail of accident, address, total value of property, and policy conditions. However, the detailed building inventory information is not included in the claim records.

Table 1 numerically describes the descriptive statistics for the losses and data. The total number of losses is 1736. The central tendencies of each category are represented by the amount of average and median. The amounts of standard deviation test the scope of categories. The amounts of maximum and minimum signify the distribution of categories. The kurtosis and skewness define the form of distribution. For instance, the kurtosis of loss denotes that the peak of distribution is tall and pointed, since the amount of 155.0 is greater than 3. The skewness of loss indicates that the distribution is noticeably skewed to the right, since the value of 11.6 is greater than 0.

Each wind speed is gathered from the maximum wind speed (10 min. sustained) record of Korea Meteorological Administration bearing in mind both the accident date and location of individual property level claim record.

Figure 1. Tracks of major typhoons (years 2003–2012).
4.2. Line of business (LOB) and TSI

The loss data are from the numerous insurance policies in South Korea with limited specific building inventory information. Vulnerability functions for individual building classification are necessary to demonstrate a specific analysis of a building. In the absence of building stock information, the elementary variables of claim payout are identified as key values to generate vulnerability curves considering availability and dominantly representing the vulnerability of buildings in the region:

(1) Line of business: industrial, residential, and commercial
(2) Total value of the property

Two variables are commonly applied as risk indicators in risk management and risk assessment models. The line of business is universal terminology in the insurance industry and stands for the

| Table 1. Descriptive statistics. | Value of property (Mil. KRW) | Loss (Mil. KRW) | Ratio (%) | Wind speed (m/s) |
|---------------------------------|-----------------------------|----------------|-----------|-----------------|
| N                               | 1936                        | 1936           | 1936      | 1936            |
| Average                         | 78,944                      | 121            | 1.4%      | 21.4            |
| Median                          | 12,424                      | 14             | 0.1%      | 26              |
| Std. Deviation                  | 330,917                     | 721            | 5.6%      | 7.7             |
| Maximum                         | 4,513,228                   | 11,634         | 83.1%     | 39.5            |
| Minimum                         | 25                          | 0.1            | 0.0%      | 3               |
| Kurtosis                        | 107.2                       | 155.0          | 91.2%     | 0.0             |
| Skewness                        | 9.5                         | 11.6           | 8.4%      | −0.6            |
closely connected services or products that are business necessities. In insurance, the term also refers to similar policies in accountancy, and provisions such as property and casualty policies can be categorized into industrial, residential, and commercial. Therefore, the category of the LOB can cluster the buildings into those with similar physical and financial features.

The total value of the property refers to the full amount of the insured’s property. The dollar value is one of the key factors used to determine the insurance rate. The total value of the property is also statistically significant with windstorm damages. Kim et al. (2016) denoted that the total value of the property has a negative relationship with the windstorm damage, as the total value of the property increases as the windstorm damages decreases. He also found that the value is not only a critical indicator, but also has the most dominant impact on the damage among the significant variables (Kim et al. 2016).

In the nature of relative building vulnerability, in addition, the extensively used loss indicators for public and private windstorm models such as construction types (e.g. wood, masonry, reinforced concrete, and steel), building height, and building age can be elucidated by the total value of the property. Wood, masonry, steel, and reinforced concrete are the primary construction types. In general, depending on the construction type, the property value and vulnerability of the building have an inverse relationship. The value is gradually increased in the order of wood, masonry, steel, and reinforced concrete. However, the opposite order is adopted for vulnerability. For instance, a wooden building is more vulnerable to windstorms than a masonry building with a lower appraised value (Khanduri & Morrow 2003; D’Ayala et al. 2006). The building height can be categorized as low-rise, mid-rise, and high-rise. The property values and vulnerability in the category of building height have a confident negative relationship. The value is steadily augmented in the order of low-rise, mid-rise, and high-rise. Conversely, the opposite order is accepted for vulnerability. For instance, a smaller building is more susceptible to windstorms than a taller building with a lower property value (De Silva et al. 2008). For building age, the property value and vulnerability of the building have a negative relationship. The value regularly decreases as the building’s age increases. On the other hand, the reverse relationship is established for vulnerability. For instance, an old building is more prone to windstorms than a new building with a lower building value (Highfield et al. 2010; Kim et al. 2016).

Moreover, an unknown variable in the input data for running windstorm risk models would bring about an increase in the uncertainty of the results and prediction errors in a situation with a lack of specific building information. The reason is that the unknown variable should be assumed to be a default variable in the model. This assumption may lead to a distortion in actualities. Therefore, in the case of non-existing detailed building information, using a model that consists of the minimized variable would decrease the uncertainty of the results and prediction errors.

4.3. Quantification of vulnerability

The insurance losses are divided based on the line of business, e.g. industrial, commercial, and residential buildings. The divided loss is analysed to develop vulnerability functions for the portfolios of the occupancies in South Korea.

This study adopts the non-linear regression analysis method. The losses are transformed by natural log before the analysis owing to the lognormal distribution of the losses. Second-order (quadratic) polynomial models generate based on the two parameters, i.e. wind speed and total value of property.

Figure 3 shows the vulnerability curves for South Korea in each line of business, e.g. commercial building, industrial building, and residential building. The functions are a combination of two variables, wind speed and the total value of the property. The value of the property reflects the vulnerability of the building as well as the building inventory of each line of business in South Korea. The wind speed represents the severity of windstorms. The growth of the value of the property leads to a decrease in the damage ratio at the same wind speed.
Figure 3. Vulnerability functions: (a) commercial, (b) industrial, and (c) residential.
To validate the functions, this study estimates the prediction errors of the vulnerability functions compared to the actual losses and predicted losses from the historical events. The study selects three major typhoons, Typhoon Rusa in 2002, Typhoon Maemi in 2003, and Typhoon Bolaven in 2012, as they are three of the most critical typhoons in South Korean history. The typhoons directly and indirectly affected South Korea, with unprecedented wind speeds and precipitation. They triggered a number of casualties, property damage, and insured losses. The prediction errors are estimated by the following equation:

\[
\text{Prediction Error (\%)} = \frac{(\text{Predicted Loss} - \text{Actual Loss})}{\text{Actual Loss}} \times 100
\]

This study adopts the exposures of an insurance company in 2002, 2003, and 2012 to achieve realistic calculations. Each typhoon loss is predicted using the vulnerability functions and exposure in that year. As seen in Table 2, the prediction errors are −0.7% to +12.7%, which means that the function is able to estimate the typhoon’s loss within the range of −0.7% to +12.7%. Consequently, even though the results do not represent all scenarios, this result supports the idea that functions are reliable in practical matters, and the property values reflect the building vulnerability as an indicator.

| Typhoon (year) | Prediction error (%) |
|---------------|----------------------|
| Rusa (2002)   | −0.7%                |
| Maemi (2003)  | +12.7%               |
| Bolaven (2012)| 2.8%                 |

6. Conclusion

Windstorms cause serious financial losses to property all around the world. Insurance companies estimate the financial risk of their exposures utilizing windstorm risk assessment models. The function in the assessment model is mostly generated based on the analysis of actual losses from insurance companies. However, the lack of detailed loss data is one of the biggest problems in the development of vulnerability functions. Therefore, this study suggests a method to develop the functions using an insurance company’s loss records in South Korea. The method is able to afford a simple way of assessing the building vulnerability and representing the relative vulnerability in a region with the least accessible data.

Hence, the findings and results of the research could offer a critical guideline for governments, emergency planners, and insurance companies to predict losses from windstorms. This study could be useful for analysing economic losses in order to lessen such losses. For example, reinsurers and insurance companies could recreate an in-house model with the methodology for a chosen area to assess the potential risk. They could easily assess the risk and make a judgment, and they could also use the base rate of the insurance policy as an experiencing rate for estimated losses. Furthermore, they would be able to exploit the function as a dual model to validate the results from vendor models. They could compare the results and make a judgment following their risk appetite, business preference, and portfolio.

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