Modeling Business Interruption Losses for Insurance Portfolios

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ABSTRACT

After a catastrophe event, the recovery of the community impacted is contingent, in large part, on business interruption (BI). BI potentially represents a major part of the total economic and insured losses. While past studies have focused primarily on the quantification of property damage from natural hazards, this paper presents a methodology to quantify losses from business interruption that are typically covered by insurance policies. This methodology uses the decision tree method in a probabilistic risk analysis framework to estimate downtime of a business after a hurricane event. Thousands of hurricane events are simulated in a catastrophe modeling framework to approximate the probability distribution of downtime. This distribution is then combined with the annual business income information to estimate the distribution of business income losses. Finally, the proposed methodology is illustrated with an application to a hypothetical business.

INTRODUCTION

Economic losses due to natural disasters are increasing in the United States. This increase can be attributed, for the most part, to the increase in population and wealth in the U.S., as well as development along the coast. Since the U.S. has high insurance penetration, insured losses comprise a significant portion of the total economic losses. Although most of the losses are from property damage (i.e., building and contents damage), business interruption losses are a significant portion of total insured losses, as past events show. For example, USD 6 to 9 billion of the USD 25 billion insured commercial losses from Hurricane Katrina have been attributed to business interruption. Therefore, insurance companies need to assess the business interruption risk to manage their exposure from catastrophes. For certain businesses, such as chemical plants and off-shore platforms, business interruption risk can be significantly higher than the risk of damage to property.

Assessing business interruption risk is not only important for insurance companies, it is also essential for individual businesses and communities. Past studies [1] have indicated that BI, not property damage, can be the most important variable in the survival of a business or a community after a catastrophe. At a macro level, business interruption from one business could spread to other businesses, affecting the economic outlook of an entire region. Revenues of government institutions could decrease, such that funds were not available to complete critical projects. This study assesses BI risk from an individual business perspective and from the perspective of an insurance company.

By nature, business interruption losses are harder to measure than losses due to property damage [2]. The lack of BI loss data means that robust benchmarks to evaluate business interruption loss numbers are not available. Other than the modeled loss or expert estimates for business interruption for catastrophes, there is little information on total economic losses from business interruption. Insured loss estimates for business interruption are not available due to the general practice of reporting business interruption losses combined with property losses.
Property Claims Services (PCS), which reports insurance losses for all catastrophes in the United States, abides by this practice. However, business interruption insurance loss data from historical catastrophe events are available to insurance companies. The study in this paper uses the insurance claims data from hurricanes that occurred in 2004 to calibrate and validate the business interruption model described in this paper.

Business interruption losses stem from both direct and indirect causes. Although there are no formal definitions, per se, for either direct or indirect BI losses, BI losses attributable to physical damage are categorized as “direct.” Other causes of loss, including damage at a dependent building, lifeline and utility disruptions, and loss of market share, are termed indirect BI losses. In input-output models used for regional economic impact analysis, some of the losses considered indirect by the insurance industry are defined as direct losses. Insurance policies cannot be used to cover business interruption losses from all causes. For example, business interruption due to interruption at supplier of supplier, or at customer of customer (downside business interruption), are generally not covered in insurance policies. Thus, insurable losses provide a lower threshold to the total economic losses for a region. Actual insured losses will be even less, as not all eligible businesses in a region purchase insurance coverage. Some buy business interruption coverage that is limited. Insurance industry-wide business interruption losses have been historically at low levels due to low take-up rates, high deductibles, and limited BI coverage. Total business interruption losses for the Northridge earthquake and the Kobe earthquake, for example, are estimated to be USD 6 billion and 50 billion, respectively. However, only a small fraction of these losses were insured. The study in this paper focuses on the estimation of business interruption losses for a business or portfolio of businesses—a relatively simple problem compared to estimating regional economic business interruption losses.

LITERATURE REVIEW

Past studies [3, 4] have focused on quantifying the property damage from natural catastrophes. There are few studies that focus on the estimation of business interruption losses from natural catastrophes. Studies of business interruption can be broadly grouped into the following four classes: a) supply-chain risk simulation, b) input-output model and its extensions, c) post-event business surveys, and d) insurance studies. Many events have shown the vulnerability of businesses to the disruption of the supply chain network. For example, the Taiwan earthquake in September of 1999 had a disastrous effect on the semiconductor industry. Recently, Hurricane Katrina and Hurricane Rita caused large disruptions in the energy market when they damaged off-shore platforms and petrochemical processing plants in the Gulf of Mexico. The supply chain risk simulation framework models the uncertainty and interdependencies between different businesses in the supply chain network, and can be used to identify and assess the vulnerability of the supply chain and associated businesses [5].

While focus of the supply-chain simulation is to assess the performance of a single business or group of businesses, input-output models have been used to model the impact of different events on the regional economy in terms of output of different industries, regional income, and employment. One scenario the model might address is what would happen if there was a 50% decrease in the demand for new constructions in a region. Traditionally, input-output models have been used to model the demand-side impacts on the regional economy. In natural hazard loss estimation, input-output model studies have been applied to estimate the indirect impact of lifeline failure by earthquake [6]. In a study by Burrus et al. [7] the impact of low-intensity hurricanes on regional economic activity in North Carolina is estimated. Based on the
downtime information for three hurricanes (Bertha, Fran and Bonnie) and on average daily revenues for different industries in North Carolina, this study estimates the direct and indirect regional losses from these hurricanes. Modified versions of these models can be used to model both demand and supply-side impacts on the regional economy. Input-output methodology forms the basis in FEMA (Federal Emergency Management Agency) HAZUS software to model the indirect earthquake losses in the U.S. Recently, computable general equilibrium models (CGE) have been used to estimate indirect losses from utility disruptions caused by earthquakes [8]. This class of models overcomes some limitations of the input-output models, such as the linear relationship and lack of substitution.

The Disaster Research Center in Delaware has performed many systematic studies to obtain data on the short and long-term impact of catastrophes on businesses. Based on these studies, they have identified key factors that influence business disruption and recovery after disasters [9]. Based on the data from the Loma Prieta and Northridge earthquakes, [10] the different factors contributing to downtime are divided into rational and irrational factors. The study indicated that irrational factors can be responsible for significant part of the downtime.

Business interruption studies in the insurance field examine the challenges in estimating business interruption exposure and losses from claims after an event. Using past financial data, a study by Foster and Trout [11] describes different forecasting methods used to project business interruption losses for a business. Other studies [e.g., 12] describe the evolution of business interruption insurance in the industry. The complexity of business interruption coverage and business interruption claims has been regularly discussed in the insurance literature. Studies by insurance industry [13] suggest that there is low awareness of the business interruption coverage and high optimism among business owners for a speedy recovery after business disruption.

Besides other data inputs, both supply-chain simulation and the input-output model approach require the downtime functions for different businesses to estimate the business interruption losses from an event. Business downtime functions relate the hazard intensity or the property damage level (which is a function of hazard intensity) with the business interruption downtime for a type of business. As per authors’ knowledge, other than the downtime functions in FEMA HAZUS software for earthquake hazard, which is based on ATC-13 [14] study, no study attempts to develop downtime functions for different businesses for wind storms. Past studies provide important information on different aspects of business interruption losses, but prior to this study, no work describes the modeling of the insurable losses or downtime for a business or portfolio of business from hurricane hazard.

The goal of this paper is to develop a modeling framework that accounts for building and business characteristics to develop business interruption downtime functions for different types of businesses. The framework should be broad enough to capture the business interruption features and complexity of business interruption insurance policies.

**MODELING BI LOSSES**

**CATASTROPHE MODELING FRAMEWORK**

In catastrophe modeling [15], the first step in modeling business interruption losses is the characterization of the hazard at the locations under consideration (Figure 1). Characterization of the hazard includes simulation of thousands of events (hurricanes) that can occur in the area of interest and the estimation of the hazard footprint for each event. This step occurs in the hazard module of a catastrophe model. Once the hazard is characterized for the locations or areas under
consideration, exposure, which includes building, contents and business income information for different type of properties, need to be characterized.

![Figure 1: Schematic of Windstorm Loss Model](image)

After the exposure and hazard intensity is estimated for a location, the next step is to characterize the vulnerability of the properties affected by an event. This part is captured in the damage module of the catastrophe modeling framework. This module includes separate vulnerability functions for building, contents, and the business income for a property affected by the event. Information provided by the model user (e.g., insurance company) about property replacement values, annual business income information, and limits and deductibles on insurance losses is combined with the vulnerability relationships to get the insured losses for building, contents, and business interruption losses. This paper focuses on modeling the business interruption component of the total losses, which is discussed in detail in the next section. The vulnerability relationships in the damage module of the windstorm loss model for business interruption relate the business interruption downtime with the building damage level (which is itself a function of hazard intensity) for a type of business.

**DEFINITION OF BUSINESS INTERRUPTION DOWNTIME**

Downtime, which may have different meanings for different fields, is observed to be the most disputed item in business income claims settlement [16]. Downtime could be the time it takes a business to repair or replace the property, so as to be in 100% operational. It could be the time until a business regains the profit level it had before the disaster struck or the regional economy returns to level it would have been without the disaster. Downtime may include delays to meet building code requirements for repair of the damage property. In this paper, downtime is equal to the time that is typically defined in insurance policies. Business interruption downtime in the ISO (Insurance Service Organization) policy form, termed period of restoration, starts 72 hours after the physical damage to the property and ends earlier than the date the property should be repaired, rebuilt, or replaced with reasonable speed and similar quality; or the date when operations have resumed at a new permanent location. The downtime can be extended for a limited period to regain the market share by purchase of separate endorsement. In the insurance policy, the insured are expected to apply all due diligence to reduce business interruption losses. As those with insurance have financial resources from insurance, downtime could be very different for insured and uninsured businesses. It is in the interest of both the insurance company and the insured to settle insurance claims quickly in order to reduce business interruption losses. Thus downtime estimates based on data from uninsured businesses could be biased to the high end for insurance applications.
**DECISION ANALYSIS OF A BUSINESS OWNER**

In addition to property characteristics such as size and complexity, business interruption downtime depends on the decisions of a business owner, which will be influenced by the business characteristics. A decision tree allows for the systematic formulation of the business owner’s decision in situations of uncertainty. Figure 2 shows a decision tree for a business owner (for a business with no dependent businesses) in the event of a hurricane. Downtime associated with each path in the decision tree and the likelihood of the paths can be estimated to compute the mean and probability distribution of the downtime. For a given path, total business interruption downtime is a function of the time associated with different sub-events as shown in Figure 3.

**Figure 2: Decision Tree for a Business Owner after a Hurricane Event**

For example, a business owner may choose to wait until repairs are done to begin operations again. In this case total business interruption downtime will include pre-repair time, repair time, and the post-repair time (*i.e.*, time to regain market share after the business is in full operation). Different time components may not simply be added together, as illustrated in the figure below. Figure 3 shows that the time required for different activities associated with a decision may be concurrent. For example, if there is civil authority (*i.e.*, curfew) after a catastrophe event that restricts the access of customers to the business for a period of time as well as physical damage to the business, civil authority time cannot be simply added to the building repair time to estimate the total downtime.

**Figure 3: Components of Business Interruption Downtime**

Since the occurrence of an event, the hazard footprint of the event, and the damage given the hazard at a location are random, the event tree needs to be evaluated a number of times in order to get the probability distribution of downtime for a business.
KEY FACTORS AFFECTING BI LOSSES

Building Characteristics

Downtime associated with different time components (e.g., repair time) depends upon the level of property damage, building characteristics, and business characteristics. Intuitively, the level of building damage should be a significant predictor of business interruption loss. For the same damage ratio (defined as the ratio of repair cost to total replacement value of the building), large buildings take more time to repair than smaller buildings. Further, some buildings and contents for a business are simpler in design than others and thus easier to replace. For example, architectural features of a church building may take longer to restore to pre-disaster conditions than a Wal-Mart building. Contents in a manufacturing facility, such as an auto assembly plant, are more difficult to replace than the typical contents of an office buildings.

Business Characteristics

All businesses are not equal. Two businesses of the same size and complexity having suffered the same level of property damage can respond differently to business interruption. Businesses generally do not wait for conditions to improve before they resume business. Every business has a certain level of resiliency to business disruption. Resiliency can be related to the inherent nature of the business as well as to the external sources. Businesses such as office buildings, which can be easily relocated, have inherent resiliency to mitigate the business disruption. In contrast, a hotel cannot relocate. Business characteristics, such as dependence on local versus regional resources, dependence on lifelines and other factors such as multi-location versus single location businesses, and the importance of the business to society, can impact the response of a business. Besides inherent factors, external efforts by a business, such as contracts with other suppliers, can affect how a business will respond to an event. Generally large and complex businesses perform business-impact analysis and have continuity plans in place to mitigate the impact of disasters.

Other Factors

Insurance company losses are also dependent upon policy features in the company’s portfolio of businesses. Business interruption downtime and losses can significantly increase if the policy has coverages for contingent business interruption (business interruption due to damage of dependent businesses), utility damage, and civil authority (i.e., business interruption due to restricted access to a business as a result of curfew), extra expenses, and extended time period.

At a macro level, a catastrophe could modify the overall economic outlook of a region, which might affect the expenditure habits of local households. This in turn can affect the business interruption losses of individual businesses. Regional post-event mitigation actions by government agencies could also affect the business interruption losses of individual businesses.

MODEL FORMULATION

BI for a Business with No Dependent Businesses

No business is totally independent of other businesses. For this study, an independent business is defined as a business which can have business interruption either due to physical damage to its own property or lifeline disruption (i.e., civil authority and utility disruption). Such a business is
not significantly dependent upon other businesses for production and sales. Examples of this business are businesses involved in retail sales and personal and repair services.

Let $T_s$ be the business interruption downtime without considering civil authority, utility disruption, and loss of market share. Then,

$$T_s = t_p + t_r \quad \text{with probability} = 1 - p_o \cdot p_t,$$

$$= t_l \quad \text{with probability} \quad p_t,$$

$$= t_o \quad \text{with probability} \quad p_o,$$

(1)

where $t_p$, $t_r$, $t_l$, $t_o$ are the pre-repair time, repair time, relocation time, and continued operation time (in equivalent full day of business interruption) before business is in full operation, respectively for a type of business at a property damage level. $p_t$ and $p_o$ are the likelihood of relocation and continued operation for a type of business at a property damage level. Assuming that business cannot run unless the lifelines are restored, the downtime after considering civil authority and utility disruption will be

$$T_{cu} = \max(T_s, t_c, t_o),$$

(2)

where $t_c$, $t_o$ are times of restoration of access to the property and utilities, respectively. Even after the business is back in full operation, it takes some time before it regains its previous pre-event market share. This time component ($t_m$) can be added to obtain the total business interruption downtime, which is given by

$$T = T_{cu} + t_m$$

(3)

The estimation of the model parameters is discussed in the section titled “Estimation of Model Parameters and Insurance Policy Assumptions”.

**BI for a Business that is Dependent on Other Businesses**

An example of a business that is dependent on other businesses is a manufacturing business. The business under consideration is the principal business and businesses on which the principal business is dependent are the dependent businesses. Let’s assume that $M$ is the principal business that manufactures a product $C$. For this product, $M$ needs two key inputs, $A$ and $B$, which are provided by supplier $S^A_1$ and $S^A_2$ for input $A$ and by suppliers $S^B_1$ and $S^B_2$ for input $B$, respectively. The product $C$ is supplied to distributors $D_1$ and $D_2$ who distribute the product to retail stores $R_1$ and $R_2$. Figure 4 shows the supply chain network for the business $M$. Each of the businesses in the supply chain are also dependent on the lifelines for the operation (not shown in Figure 4). Let $\alpha_A, \alpha_A' = 1 - \alpha_A, \alpha_B, \alpha_B' = 1 - \alpha_B$ be the respective percentage inputs from $S^A_1, S^A_2, S^B_1,$ and $S^B_2$ to $M$ and $\alpha_M, \alpha_M' = 1 - \alpha_M, \alpha_{D1}, \alpha_{D1}' = 1 - \alpha_{D1}, \alpha_{D2}, \alpha_{D2}' = 1 - \alpha_{D2}$ be the percentage outputs from $M, D_1,$ and $D_2,$ respectively. Let $T_{S1}, T_{S2}, T_{S3}, T_M, T_{D1}, T_{D2}, T_{R1},$ and $T_{R2}$ be the downtimes to each of the businesses as if they are independent of other businesses in the supply chain. It is assumed that businesses in the entities are not dependent upon businesses other than those in the supply chain.
The total business interruption downtime for principal business $M$ can be calculated by the following expression

$$a'_M$$

In the above equation, $I$ is an indicator function equal to zero for a time interval if there is no downtime for the business during that time interval, otherwise it is equal to 1. The above equation integrates the business interruption for business $M$ at a time interval (e.g., a day) over the maximum downtime of any business in the network. The equivalent downtime can be multiplied by the business income per unit time to get the total business interruption losses. If the business income is variable over time, then business interruption at a time interval can be multiplied by the business income for that time interval to get business interruption losses for that time interval, and then these losses can be integrated over the maximum downtime of any business in the network.

The Equation 4 assumes that the supply chain system has no resiliency, i.e., no inventory build up or export is possible in case of reduction in demand and no alternate supplier is there to meet the input demand for $M$ in case of a reduction in supply. This implies that $x\%$ (say 30\%) daily reduction in demand of $D_1$ leads to a $30\%$ reduction for $M$. Assuming business income is constant over time, $30\%$ reduction can be expressed equivalently in downtime of 0.3 days in the above equation. Similarly on the supply side, a $30\%$ loss of daily input of $A$ leads to a $30\%$ reduction in output of $M$ in a fully constrained supply chain system, which is expressed in terms of 0.3 day in the above equation. An input-output model framework for this supply chain could also be used to estimate the business income loss for $M$. The results using input-output model should be the same if the input-output model is applied dynamically over the maximum downtime of any business in the network.

**ESTIMATION OF MODEL PARAMETERS AND INSURANCE POLICY ASSUMPTIONS**

Model parameters are estimated based on the available data. Like many complex risk analysis problems, estimation of many model parameters is challenging and requires subjective assessment.
Building and Business Characteristics Parameters

Building characteristics parameters include building size, building and contents complexity, and prerepair and repair times. The Department of Energy [17] provides the size distribution for different type of businesses. For example, on average, hotels and hospitals are larger in size than retail stores. For a given building damage level, pre-repair and repair times depend on the property size and its complexity. Standard construction methods for estimation of repair time and the tables on time of completion of construction projects from the U.S. census [18] are used to estimate repair times for different type of businesses. Business characteristics parameters include relocation time, time in partial operation (in equivalent days of no operation) before the business is in full operation, and likelihoods of relocation and being in operation. Damage surveys done by the authors for specific storms (e.g., Hurricanes Charley (2004) and Wilma (2005)) are used to quantify some of these parameters for which no empirical data is available.

Other Parameters and Insurance Assumptions

Other model parameters include restoration time for lifelines, market recovery time, and take-up rates for different optional insurance coverages in business interruption policies. For the hurricane hazard, the distribution network of the electrical power system is most vulnerable to hurricane winds. Explicit modeling of the power distribution network is complex and computationally intensive. Based on the restoration times from past hurricanes, the damage to lifelines can be correlated to the hazard intensity at the locations under consideration.

Insurance companies may not have information about many of the data inputs that go into the model. For example, details of the supply chain network for a specific portfolio of businesses may not be available. Reasonable assumptions can be made about the supply-chain network to estimate supply-chain effect on business interruption downtime. For example, based on the nature of a business, it can be classified as local, regional, national, or international. Local, regional, national, and international dependence can be defined based on the distance from the principal business (i.e., business under consideration). The thresholds for inter-business distances for local, regional, national, international can be assumed to be 100, 500, 5000, and >5000 miles, respectively. In a practical world, each business is dependent on a mixture of local, regional, national, and international businesses. The rank correlation for wind speeds between two locations at different sentences based on the 10,000 years simulation of hurricanes can be estimated to approximate the dependence between the damage of two businesses. Assuming damage is fully correlated with hazard intensity, a business, which is dependent on other businesses at a distance of 1, 5, 10, 25, and 50 miles is estimated to have a dependence of 0.98, 0.95, 0.85, 0.70, and 0.40 respectively. Based on the simulated wind footprints of numerous hurricanes, the distribution of dependent building damage level (e.g., none damage, minor damage, etc.) is conditional on the principal building damage for different distances, which can be empirically derived for local and regional businesses (Table 1a, 1b). In the absence of detailed information about the supply-chain network, the distance-dependence relationships with information on degree of dependence between principal business and other businesses and the number of dependent buildings can be used to approximately simulate the supply-chain effect on business interruption.
Table 1a: Dependent Building Damage Level Distribution (in columns) Conditional on the Principal Building Damage for a Local Business (based on average distance of 10 miles).

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Minor</th>
<th>Moderate</th>
<th>Severe</th>
<th>Destruction</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Minor</td>
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<td>10%</td>
<td>13%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Moderate</td>
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<td>89%</td>
<td>1%</td>
<td>79%</td>
<td>0%</td>
</tr>
<tr>
<td>Severe</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>Destruction</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Table 1b: Dependent Building Damage Level Distribution Conditional on the Principal Building Damage for a Regional Business (based on average distance of 100 miles).

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Minor</th>
<th>Moderate</th>
<th>Severe</th>
<th>Destruction</th>
</tr>
</thead>
<tbody>
<tr>
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<td>53%</td>
<td>80%</td>
<td>65%</td>
<td>76%</td>
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<tr>
<td>Minor</td>
<td>24%</td>
<td>33%</td>
<td>18%</td>
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<td>20%</td>
</tr>
<tr>
<td>Moderate</td>
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<td>15%</td>
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<td>5%</td>
</tr>
<tr>
<td>Severe</td>
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<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Destruction</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Similarly, for actual business interruption loss data, which is used for the calibration and validation of the business interruption model, there generally is not information on the cause of interruption or detailed insurance policy attributes. Based on the insurance industry-wide information, assumptions are made about the take-up rate for different optional business interruption coverages. For example, insurance industry-wide take-up rates for contingent business interruption coverage (i.e., coverage for business interruption due to business interruption at a dependent business) are estimated to be small.

**CALIBRATION AND VALIDATION OF BI DOWNTIME FUNCTIONS**

Historical loss data generally does not provide a breakdown of losses by property and business interruption. A few studies, though, do provide expert estimates for business interruption losses for major catastrophes. Recent hurricanes have provided a large set of loss data for the evaluation and improvement of catastrophe models. Although there is no public information on losses for business interruption, claims data from many insurance companies provide separate losses for business interruption that allows for calibrating and validating the business interruption downtime functions. Although data quality and resolution has improved since Hurricane Andrew, loss details, such as the exact cause of business interruption, are generally not available.

As discussed in the previous section, many of the details about business interruption policy, such as the location and degree of dependence, may not be available to an insurance company to input into a catastrophe model to assess the business interruption losses on its portfolio of businesses. The appropriate assumptions as discussed in the previous section are made to estimate the modeled downtime. The observed downtime for a business is estimated based on average daily business income and business interruption loss in the insurance loss and policy information. The model parameters are fine-tuned within the range of reasonability to obtain the overall good match with the actual observations. Figure 6 shows the scatter plot between business interruption days and the building damage ratio.
It is clear from Figure 6 that there is significant business interruption at relatively low level of building damage. At low level of building damage ratio, business interruption cannot be very well explained based on the building damage only and may be attributable to utility disruption, business interruption at dependent businesses, and to policy features such as extra expense. Details in the claims data do not provide information to identify the exact cause of high business interruption downtime days at a zero building damage ratio, as indicated in the Figure 6.

Different parts of the business interruption downtime functions (Figure 7) are influenced by different model parameters. The impact of business interruption due to dependent businesses and other factors such as extra expense is particularly important at low levels of damage. At moderate levels of building damage, the likelihood of continued operation while repairs are underway determines the shape of the BI curve. As building damage increases and continued operation becomes less likely, the likelihood of relocation increases. Thus the ability to relocate determines the shape of the curve at higher building damage levels.
**BI Losses**

After the business interruption downtime functions are defined for a business, they can be combined with the business income information to estimate the business income losses. Business income per the ISO business interruption policy form is defined as sum of: a) the net income (net profit or loss before income taxes) that would have been earned or incurred if no physical loss or damage had occurred and b) the continuing normal operating expenses, including payroll. It is important to note that business income loss is not just loss of profit, but also includes the continuing operating expenses which could be a significant part of total business income loss for a business. Insurance guidelines recommend the use of business interruption worksheets to determine the business income exposure for each covered location in the event of a disaster.

**Model Application to a Business**

**Business Description**

In this section, the model is illustrated using a hypothetical business. In this instance, a business (e.g., orange juice packaging plant) is mainly dependent on local businesses for production and sales and is located in zip code 33605 in Hillsborough County in Florida. The business has two suppliers, one for raw orange juice and one for packaging material, which are both located in nearby zip codes. For simplicity, it is assumed that the supply-chain system has a single distributor and a single retail store. Business is thus dependent on four other businesses. 10,000 years of hurricanes are simulated to record annual maximum wind speed at each of the business location in the supply chain. Wind speed is used to compute property damage which is then used to compute distribution of business interruption days for each business in the network. The equation in Section “BI for a Business that is Dependent on Other Businesses” is then used to compute the annual maximum downtime for each year.

**Risk Profile Curve for BI Downtime**

Figure 8 shows the risk profile curves for BI downtime days for the business M as a business that is dependent on other businesses and as an independent business. The BI for M without considering the supply-chain impact is significantly less than the BI for M as part of supply-chain system. Figure 8 indicates that there is a 1% chance that BI downtime will exceed 10 days annually as an independent business and 23 days as a business with dependent businesses. If the daily business income exposure is USD 100,000, there is 1% chance that business interruption losses will exceed USD 1 million and USD 2.3 million for the business as an independent business and as a business with dependent businesses, respectively.

![Figure 8: Risk profile for business M as a principal and independent business.](image-url)
ACKNOWLEDGEMENT
We would like to thank insurance companies who provided the claims data for the study.

CONCLUSIONS AND FUTURE WORK
This study describes a modeling framework that can be used to estimate business interruption losses that are typically covered by insurance policies. The model accounts for both the building and business characteristics when estimating business interruption downtime. The modeling framework allows for the development of downtime functions for different type of businesses. With this framework, it has become possible to capture the business interruption downtime pattern over a full spectrum of property damage as observed in actual data. The model application to a business has indicated that business interruption risk can be significantly higher for a business that is dependent on other businesses than for a business with no dependent business. Nevertheless, the model described in this paper has certain limitations. Due to lack of data, many parameters require subjective judgments in the estimation of parameters. In the future, business interruption surveys for hurricanes can be performed to reduce the uncertainty in the estimation of some of the model parameters. A detailed case study that illustrates the application of the model to an insurance portfolio can be done to understand the different aspects of the model.

REFERENCES


