SESM-10-1 Structural Engineering and Structural Mechanics

What We Know about Demand Surge

by

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Demand surge is generally understood to be an economic process in which the cost to repair damage to buildings and other infrastructure in large natural disasters is significantly greater than the cost to repair the same damage in a smaller disaster. It is believed to have occurred in several large natural disasters, resulting in additional repair costs of 20% or more. Thus, it is of particular interest to property insurers and insurance regulators. Despite the importance of the phenomenon, the term "demand surge" has no standard definition, usage, or generally accepted theory that accounts for its occurrence, mechanisms, and quantitative economic effects. "Demand surge" has been used to refer (a) only to the increase of reconstruction materials prices and labor wages, (b) to increased material and labor costs as well as specific, additional losses, for example, attributed to higher contractor overhead and profit margins or decisions by insurers or regulators to expand policy coverage, and (c) to the difference between observed insurance losses and those estimated by commercial catastrophe models. We understand demand surge to be a phenomenon of large-scale natural disasters in which the demand for reconstruction materials, labor, equipment, financing, or some combination of these, exceeds the local supply. Evidence for demand surge comes from as early as fourteenth century England, the 1886 Charleston and 1906 San Francisco Earthquakes, and the present day. It has been reported after earthquakes, hailstorms, cyclones, flooding, and wildfires, in Australia, the United States, the United Kingdom, and continental Europe. By studying the circumstances of natural disasters that did and did not cause demand surge, common explanatory themes emerge from these historical events that allow us to tentatively infer why losses increase in some disasters but not others. The themes are: total amount of repair work; timing of reconstruction; costs of materials, labor, and equipment; contractor overhead and profit; the general economic situation; insurance claims handling; and decisions of an insurance company.

1 Introduction

Demand surge is an important issue for individuals and institutions that sustain losses in natural disasters, particularly for property insurers and governments that finance reconstruction. Estimates of demand surge following large-scale natural disasters have quantified a general increase of costs ranging from 10–40% following Hurricane Katrina (Guy Carpenter, 2005) to 50% after Cyclone Larry (ASIC, 2007, p. 6). For specific materials and labor, news reports have documented price increases of 30% for oriented strand board following Hurricane Katrina (Grogan and Angelo, 2005) to a 2000% increase for securing a tarpaulin to a damaged roof after the 1999 Sydney hailstorm (Sweetman and Morris, 1999). The aggregate of higher repair costs at each damaged property results in a greater loss for an insurer that indemnifies many properties in an affected area. For a single insurer, the additional loss caused by demand surge may mean the difference between survival and ruin. For example, 20th Century Insurance, based in the Los Angeles area, was nearly bankrupted by claims following the 1994 Northridge Earthquake (Stavro, 1998), a disaster that produced a reported 20% demand surge (Kuzak and Larsen, 2005, p. 113).

Primary insurers must anticipate their future losses in order to establish cash reserves, secure reinsurance, and set premiums for their policyholders. Future losses are inherently uncertain. Employing the best available hazard and risk information should reduce this uncertainty and improve the accuracy of predictions. In this context, better knowledge of demand surge can assist insurers in their business decisions. For example, an insurer may anticipate its probable maximum loss as $100 million in a single event in the next year. This estimate may be based on prevailing reconstruction costs and standard claims management practices. However, when this event happens, the insurer must pay $130 million in claims because reconstruction costs increased and the insurer could not efficiently handle the large volume of claims. Because the insurer made reserve and reinsurance decisions based on incorrect assumptions, it must quickly secure an unanticipated $30 million or face bankruptcy. Furthermore, in regulated insurance markets, insurers submit rate filings to government regulators. In an attempt to protect consumers, the regulator may believe that insurers completely control demand surge, and thus insurers cannot charge policyholders for a cost that they can eliminate. A sound knowledge-base for demand surge would establish to what extent demand surge can be controlled by all stakeholders and better inform the business decisions of insurers and reinsurers.

Commercial catastrophe modelers, such as Applied Insurance Research, EQECAT, and Risk Management Solutions, develop models of demand surge. One of us (Porter) created EQECAT's first demand-surge model in the mid-1990s, which is approximately when RMS and AIR first developed theirs. The catastrophe modelers describe their models publicly but withhold details as intellectual property. As a result, there is no independent and public examination of the commercial demand-surge models to establish their validity beyond the veracity of the modeling companies. (The Florida Commission on Hurricane Loss Projection Methodologies does assess commercial catastrophe models to approve their use for rate filings in Florida, but the modelers' methodologies remain confidential (Florida Statute, 2009a, §627.0628(3)(f)).) Because these models are proprietary, there is no synergy of different modelers' insights into demand surge.

Demand surge also bedevils consumers and consumer advocates. Since proprietary models are opaque, skeptical insurance consumers and their advocates have an *ipso facto* license to question the validity of demand surge models.

Consumer advocates have suggested the possibility that additional costs attributed to demand surge are illusory or perhaps can be controlled by the insurer (Ruquet, 2009). An insurance company may counter that, to be economically viable, it must use the best available model to anticipate any demand surge costs and reflect these costs in policy premiums. These extra premiums become a source of serious conflict between insurers and policyholders, as well as consumer advocates.

In this document we develop an understanding of demand surge as a socioeconomic phenomenon associated with large-scale natural disasters. We provide evidence to support an understanding of demand surge as the outpacing of reconstruction materials, labor, equipment, financing, or some combination of these, supplies by their respective demands after a natural disaster. Section 2 demonstrates that there are various definitions and connotations of demand surge, rather than a single, standard definition. Section 3 collects evidence from historical disasters to document how demand for materials, labor, equipment, and financing, in excess of the local supply, apparently led to increased reconstruction costs. Section 4 describes existing models of insured and economic loss after natural disasters, with particular attention to the demand surge component, if it is present. Finally, Section 5 identifies common themes of demand overwhelming supply from historical natural disasters and current models. These themes provide possible explanations for the mechanics of demand surge, and thus they are also hypotheses to be tested in future work.

In the introduction to this paper, we have avoided the term "catastrophe" because several definitions and connotations exist in the natural-disaster literature. The Insurance Services Office's Property Claims Service designates an event to be a catastrophe if the total value of claims reaches a certain threshold, currently twenty-five million USD, and the event affects a significant number of policyholders and insurance companies (Insurance Services Office, 2009). Demand surge is generally understood to be a phenomenon associated with natural disasters that produce large insured loss (that is, roughly in excess of one billion USD) or, more generally, large economic losses. We do not yet limit our understanding of demand surge to the terms of monetary loss, since this quickly becomes a slippery concept: does an estimated insured loss of three billion USD include or exclude demand surge, and how would one know if the estimate included or excluded all demand-surge effects? Setting aside the association of demand surge with insured loss, we choose to speak loosely of "small-scale natural disasters" as those events that do not cause demand surge, as we understand the phenomenon. We use the construction "large-scale natural disasters" to refer to events that induce demand surge, and for lack of a better term, we use "catastrophes" as a shorthand for this construct.

2 Demand surge terminology

This section collects and discusses previous usage of the term "demand surge." As an example, the Actuarial Standards Board defines demand surge as "a sudden and usually temporary increase in the cost of materials, services, and labor due to the increased demand for them following a catastrophe" (Subcommittee on Ratemaking of the Casualty Committee, 2000). The five parts of this definition can be made more explicit: (1) reconstruction materials prices, labor wages, and the costs of reconstruction services in general, increase (2) because of a significant demand for reconstruction activities (3) soon, if not immediately, after (4) a large-scale natural disaster, and (5) these cost increases remain unusually high for a limited period of time before returning to a lower level once supply satisfies demand. Note that, in this definition, demand surge is the increase of costs resulting from increased demand; it is unclear whether demand surge also encompasses the increased demand for materials, labor, and services. In other words, there is no clear distinction between factors underlying the phenomenon and the metric used to measure the phenomenon.

2.1 Demand surge in previous publications

Figure 1 summarizes the literature touching on the definition of demand surge; it presents a collection of quotations that define or otherwise describe the demand surge phenomenon. Sources are ordered chronologically and grouped by industrial sector: commercial catastrophe modelers; mass media and insurance trade publications; insurers, reinsurers, and reinsurance brokers; insurance industry associations; consumer advocates; government bodies and rating agencies; and academics and organizations independent of the insurance industry.

In the references quoted, "demand surge" is most commonly understood to have a limited definition across all of our categories of quotation sources. Consider quotes 17, 24, 45, and 53 as examples. Here, "demand surge" refers specifically to temporary increases in materials prices and labor wages following catastrophes. It does not refer to other cost increases, such as higher rates of contractor overhead and profit or waivers of multiple insurance deductibles in clustered events, even if these cost increases can be explained as demand for some product or service overwhelming its supply. Labor costs are the wages paid to workers in the construction industry. However, to be amenable to study, we must still determine precisely which workers, in what location, and over what time period these should be considered, as well as how to characterize this information in a model. Material costs probably refer to the retail

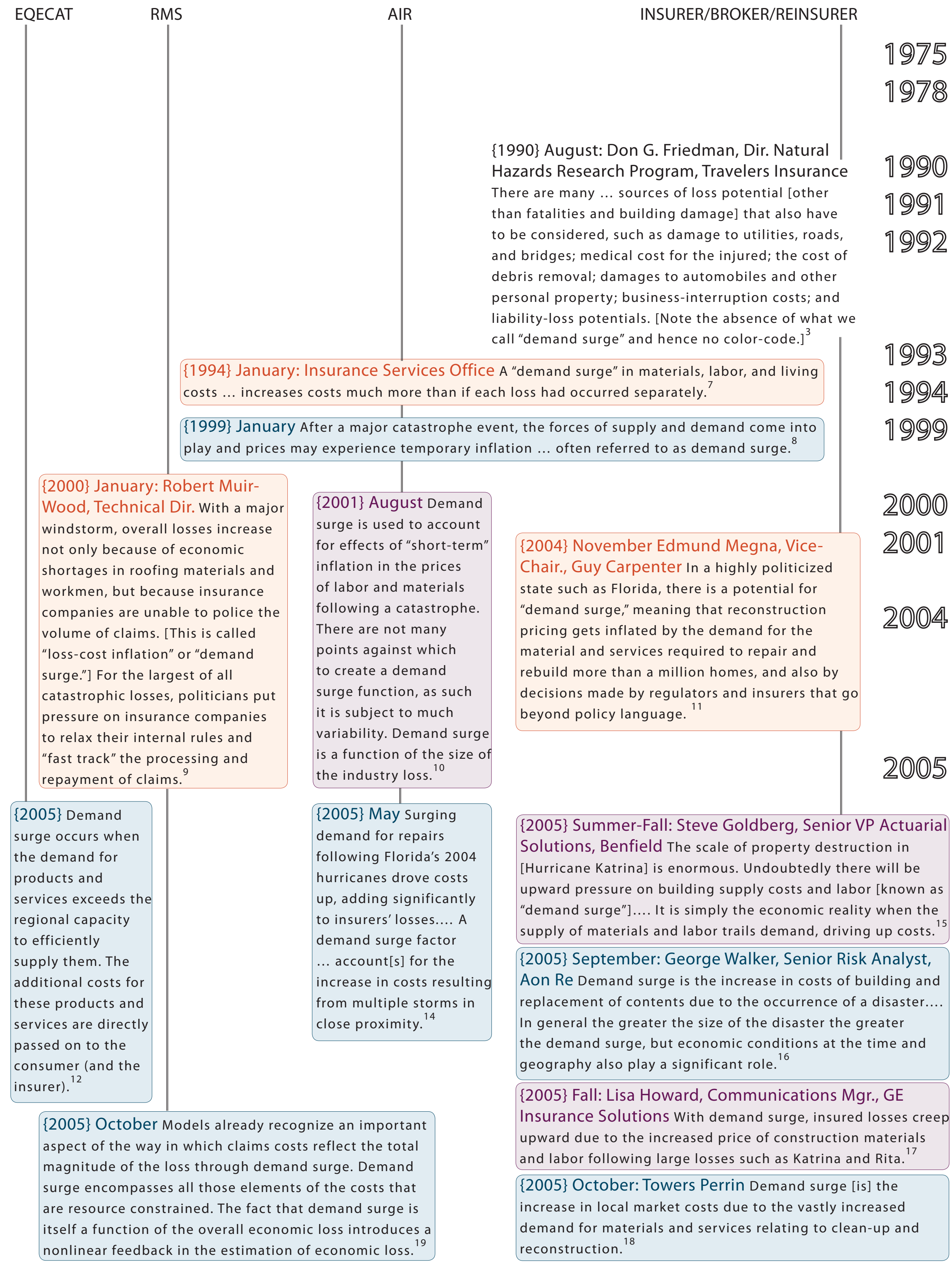

Figure 1: These quotations are definitions of demand surge or examples of how the term has been used. The quotes are color-coded according to four general conceptions of demand surge: (orange) it is the temporary increase in local construction-industry wages, repair-material costs, and other specific costs; (purple) it is only the increase in wages and materials prices in the construction industry; (blue) there is no specific definition, but rather a general description of increased reconstruction costs; and (yellow) demand surge is the discrepancy between actual losses and expected losses.

MEDIA | CONSUMER ADVOCATE | INDUSTRY ASSOC. | GOVT. BODY/RATING AGENCY | ACADEMIC/INS.-INDEPENDENT ORG.

{1975} Rex Patterson, Minister for Northern Australia & Tom Uren, Minister for Urban and Regional Development Because of the substantial demands that the [post-Cyclone Tracy reconstruction] program would imply for scarce resources of labor and materials, it is likely that the relative increase of wages and prices in Darwin would be significantly faster than in the rest of Australia [termed a "relative price effect"].[1]

{1978} J. H. Wiggins Co. [There are] types of losses known to often increase the impact of a hazard many-fold [beyond building damage]: building contents and income losses, transportation effects due to dislocation of suppliers, homelessness and unemployment, as well as costs of applying certain mitigations. [Note the absence of what we call "demand surge."][2]

{1991} September: Neil Doherty, Anne E. Kleffner, & Howard Kunreuther, Wharton School, Univ. of Penn. These [estimated insured losses for a re-occurrence of the 1906 San Francisco Earthquake] include an adjustment for ... the increased cost to repair/replace property during catastrophe conditions.[4]

{1992} December: Peter Kerr, Reporter, New York Times [Allstate and State Farm Insurance Companies] cited the surprisingly slow pace of repair and rebuilding in hard-hit areas of South Florida, the rising costs of construction, and additional damage to dwellings as a result of delays in repairs.... One major factor adding to costs, [Bill Sirloa, spokesman for State Farm] said, is that demand has greatly increased the price of construction products and services in South Florida.[5]

{1993} January: Greg Steinmetz, Staff Writer, Wall Street Journal But more than poor models explain the ever-rising [estimated] losses on the storm [Hurricane Andrew]. Also at work is the inflation sparked by huge demand for material and labor.... "As time goes by, you would think prices would come down," [Mike Kish, claims manager, State Farm] says, "but they haven't."... Helping contain the surge in costs a bit is an influx of contractors.[6]

2000

2001

2004

2005

{2005} Gary Y. K. Chock, Pres., Martin & Chock, Inc. The average extended times [required for substantial completion of repairs and reconstruction following Hurricane Iniki in 1992] are not strongly related to the level of damage; this may be due to the limited resources available to island communities after a major disaster involving a large proportion of the building inventory, i.e., demand surge.[13]

EQECAT | RMS | AIR | INSURER/BROKER/REINSURER

2006

EQECAT

{2006} April: Tom Larsen, Senior VP Product Mgmt. Part of the problem is the need to define what demand surge is. We have always looked at demand surge as the post-catastrophe inflation caused by the excess and frictional costs of bringing in outside labor and paying extra costs for materials. But if you look at how it is being identified, it's as if demand surge is seen as everything the models undershot by.[28]

RMS

{2006} Economic demand surge [is the] increases in the costs of building materials and hourly rates for labor, as demand exceeds supply.[20]

{2006} February: Robert Muir-Wood, Chief Research Officer Demand surge is just one economic component of a whole series of factors that increase losses in the largest catastrophes.[26]

{2006} April: Peter Nakada, Managing Dir. The simple economic model based on supply and demand works up to a point. But if you get a catastrophe big enough, all of a sudden the dynamics of it change. They change because you don't have enough people in the area to fix the houses, and not enough wood and bricks to rebuild. Then you may have to start bringing people in from outside, and if it's big enough you fly people in from outside.[29]

AIR

{2006} May Demand surge accounts for the increase in the costs of repair and reconstruction in the aftermath of a catastrophe.[30]

INSURER/BROKER/REINSURER

{2006} Eberhard Faust & Ernst Rauch, Munich Re After the 2004 hurricanes in Florida, an attempt was made to explain the often underestimated losses by citing such effects as demand surge and major catastrophe surcharges. Following Katrina, many insurers found that the losses they finally had to pay were often far higher than their initial forecast. This was due to the fact that the scale of a major catastrophe is enhanced by the shortage of resources (construction materials and workers needed for reconstruction work) and the limited availability of infrastructure installations.[21]

{2006} Willis Demand surge [is] the increase in building material and labor costs following a catastrophic event.[22]

{2006} Munich Re & American Re The record losses generated by Hurricane Katrina have also shown that there are some aspects which amplify tropical cyclone losses but which are disregarded in current loss models or are not given sufficient weight in the estimate of the overall insured loss.... Some of these aspects are often subsumed under the term "demand surge." The experience gained with Katrina, however, has shown that this is a term that can be used to describe only one partial and limited aspect of the losses resulting from such a major event.[23]

{2006} November: Laurence O'Neill, David Traill, & Andrew Matthews, Insurance Australia Group Post-event demand surge ... results in higher prices for labor and material following an [event].... This factor can have a significant impact on ultimate costs depending on the economic environment, geographic region and the size of the disaster.[33]

{2006} November: Lloyd's There are also secondary "demand surge" effects on eventual insurance claim pay-outs, which must be taken into account. For example, a major hurricane will knock down houses and office buildings, but will also have the secondary effect of boosting the rates charged by plumbers and contractors to repair the damage.[34]

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2006

{2006} Federal Alliance for Safe Homes & The Actuarial Foundation Major catastrophes, such as earthquakes, hurricanes, and wildfires can often create a demand surge for materials and labor, resulting in increased costs to replace damaged property.[24]

{2006} Joseph Kelly & Zanda Lynn, Analysts, Fitch Ratings Demand surge represents construction labor and material price volatility associated with local demand.[25]

{2006} March: Marcellus Andrews, Economist, Insurance Information Institute Insurance dollars will pour into the region [affected by Hurricanes Katrina and Rita], but rebuilding will be limited by material and worker shortages, leading to rising wages and materials prices. This rise in prices due to insurance dollars bumping up against labor and materials shortages is "demand surge."[27]

{2006} June: Chief Risk Officer Forum There is a non-linear size and time dependency for demand surge costs (loss inflation caused by the spiraling demand for construction material and other goods and services).[31]

{2006} November: United Nations Environment Programme Finance Initiative "Demand surge" [is] when recovery costs rocket due to labor and material constraints.[32]

{2006} December: Susan F. Cogswell, Insurance Commissioner, State of Connecticut Insurance Department "Demand surge" is the cost associated with increased labor, repair and supply needed to rebuild after a severe storm.[35]

EQECAT | RMS | AIR | INSURER/BROKER/REINSURER

2007

{2007} January: Ben Beazley, CEO, Chartwell Independent Insurance Brokers Demand surge is a critical amplification factor resulting from the increased costs for building material and labor following a major catastrophe.[38]

{2007} June Demand surge [is] the increase in costs of materials, services, and labor due to increased demand following a catastrophic event.[39]

{2007} September: Simon How & Ian Hasson, Dirs. Advisory Ins. Claims Serv., PricewaterhouseCoopers Although [many European insurers and, in particular, reinsurers] had made strenuous efforts to quantify and set limits for their exposures through use of the latest modeling techniques, the actual losses [from Hurricanes Katrina, Rita, and Wilma] far exceeded expectations.... Few companies had made adequate provision for the pressure on supply and resulting escalation of expenses arising from a "demand surge" for loss adjusters, emergency repair and rebuilding teams.[41]

2008

{2008} All of the ways in which an insurance payment can increase in the context of a major catastrophe—beyond the loss incurred if a building had been damaged in isolation—are termed loss amplification.[42]

{2008} June: Nationwide Insurance If the damage to the home is as a result of a catastrophe, or at the same time as a catastrophe, demand surge pushes the price higher for labor and materials for all construction.[46]

{2008} September Demand surge … occurs when the demand for products and services to repair damage significantly exceeds the regional supply. Thus, these products and services may have to be brought to the region quickly from distant points, resulting in additional costs for transportation, packaging and manufacture.[48]

{2008} October: Richard Clinton, Pres. By definition, demand surge is the temporary increase in reconstruction and other costs that may occur following catastrophic events.[49]

2009

{2009} May: Paul Anderson & David Chernick, Consulting Actuaries, Milliman When there are a large number of homes that are all in need of repair or rebuilding at the same time, it creates a demand surge, which can drive up the cost of materials and labor. Because demand surge usually only occurs after infrequent catastrophes, it is difficult and uncommon to account for demand surge when estimating the replacement cost.[50]

{2009} July What is Demand Surge? Recent earthquakes and hurricanes have led to observations that construction costs increase in the period immediately after a large catastrophic event. Because this is the time in which insured losses are adjusted, these increased costs have led to larger insured losses than expected and are of potential concern to the insurer.[51]

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2007

{2007} Massachusetts Division of Insurance Particularly because of the differences in the way the modelers define demand surge, the [Massachusetts Property Insurance Underwriting Association] must consider whether the demand surge factor in the model is appropriate for use in Massachusetts.[36]

{2007} January: Australian Securities & Investments Commission Even if a consumer correctly estimates what it would cost to rebuild their home in a one off total loss, it is almost impossible to know what it will cost to rebuild a home that is destroyed in a mass disaster. The surge in building prices that occurs after a mass disaster can be very unpredictable.[37]

{2007} Summer: Coastal Heritage Skyrocketing costs of building materials and labor, especially following big storm seasons in 2004 and 2005, have driven insured losses much higher than modelers had anticipated. Building materials and labor are usually scarce after major hurricanes. Insurers have a name for such scarcity: "demand surge."[40]

2008

{2008} Stephane Hallegatte, Centre Internat'l de Recherche sur l'Enviro. Et le Developpement & Michael Ghil, Ecole Normale Superieure Demand surge [is when] prices in the construction sector increase significantly in response to the large reconstruction demand in a disaster's aftermath.... Demand surge, in particular, is a good measure of the tension in the reconstruction process: when the price gets very high, it means that the construction sector cannot cope with the disaster and that the reconstruction period will be longer than normal, and the production losses larger. Also, it means that affected agents will have to pay more to reconstruct their house or to replace their capital.[43]

{2008} January: J. Robert Hunter, Dir. Of Insurance, Consumer Federation of America Given the surge in demand for home building and repair that occurs in the wake of a hurricane [due to increased demand for materials and labor and due to special repairs to comply with current building codes], and corresponding increases in prices, these changes significantly shift risk and costs to consumers even if the consumers had bought the precise amount of insurance appropriate for their homes absent this sort of demand surge in costs.[44]

{2008} May: National Association of Insurance Commissioners One such problem [complicating claims after a natural catastrophe] is the post event shortage of contractors and building supplies. Following Hurricane Katrina, capacity constraints for labor and materials drove price fluctuations and substantially increased reconstruction costs [also known as demand surge].[45]

{2008} August: Roberto Ceniceros, Reporter, Business Insurance Demand surge refers to price inflation for scarce construction materials, labor and services following a significant disaster. The more widespread the damage, the greater the price for the rebuilding resources.[47]

2009

{2009} July: Reactions Demand surge. The increasing cost of repair work in the wake of a catastrophe because of a shortage in materials and labor. Leads to higher claims.[52]

{2009} August: Insurance Information Institute Demand surge in this context is the increase in the cost of labor and materials as demand rises for building contractors to repair damage after a natural disaster. This pushes up the size of claims.[53]

or wholesale prices charged by the construction industry for the materials required to repair the damage. Again however, the geographic and temporal scope of the products, and which ones (almost to the level of stock-keeping unit (SKU) numbers), must be crisply defined before it is practical to test any hypotheses about their influence on demand surge.[1] Although limiting a demand surge definition to increases in materials prices and labor wages helps to clarify the definition, there is no evidence that these are the only two—or even the most important two—drivers of demand surge. At present, we see no reason to limit the definition to increased materials prices and labor wages when there are other reconstruction resources (such as equipment and financing) that may also be in short supply after catastrophes.

"Demand surge" has also been used to describe the difference between an expected, or modeled, loss and the realized, or actual, loss in a catastrophe. (See quotes 21, 23, 28, and 51.) Using "demand surge" to refer to unexpected losses obscures alternate explanations for the difference between expected and realized losses. Such alternate explanations include modeling error (the inherent discrepancy from the use of a model to estimate loss instead of summing actual losses), input error (the discrepancy between an estimate of hazard, vulnerability, and exposure and a complete description of these model inputs), and error in measuring actual loss (which is commonly extrapolated from losses reported by a subset of insurers). Using demand surge in this way raises the question: if demand surge is all, or part, of the difference between expected and realized loss, can it exist independently of a catastrophe model or a similar method of predicting loss? Is demand surge an observable, model-independent, real-world phenomenon, or is it a product of the conceptualization and quantification of losses from natural disasters?

Most observers' use of "demand surge" is quite general and similar to the definition of the Actuarial Standards Board presented at the beginning of this section. The limited sense of demand surge, as an increase in material and labor costs, is often the first and primary description of increased losses after catastrophes, and additional explanations quickly follow to complete the general definition of demand surge. For example, consider quotes 9, 11, and 44. These quotes offer increasing material and labor costs first to explain larger losses in catastrophes and then provide additional explanations, respectively: insurers are unable to verify a large volume of claims, and they face political pressure to quickly pay claims; the decisions of regulators and insurers expand coverage beyond the stated language of insurance policies; and current building codes require special repairs to maintain compliance. According to this usage, "demand surge" is primarily caused by higher material and labor costs, but there are additional explanations for larger losses in catastrophes. This type of definition begs the question: what is a reasonably complete list of these additional explanations? How does someone determine whether each explanation contributes to demand surge or to a different phenomenon, such as business interruption?

Several general definitions or usages of "demand surge" add "services" to the short list of labor and materials to explain higher costs after catastrophes, but the reference to services is unclear. Querying the Actuarial Standards Board's definition, what post-disaster services should be included or excluded from an analysis of demand surge? As further examples, quotes 18, 31, 39, 47, and 48 also do not specify the types of services to consider. Services might refer to expenditures by insurers to claims adjusting firms, or by insurers to construction contracting firms, or by construction contracting firms to businesses that serve them while they mobilize, market their services, do the repairs, etc. Since insurance claims include additional living expenses and other time-element losses, services in this context could mean virtually any expenditure paid to businesses at any distance from the catastrophe by any insured entity during the life of any time-element claim. The lack of specificity in the definition of services contributing to demand surge indicates that the current understanding of how services affect demand surge is not sufficiently developed.

Considered in isolation from other discussions of demand surge, some explanations are quite vague. Each of the three prominent commercial catastrophe modelers has provided an example: "Demand surge encompasses all those elements of the costs that are resource constrained" (RMS, quote 19); "Demand surge accounts for the increase in the costs of repair and reconstruction in the aftermath of a catastrophe" (AIR, quote 30); and "Construction costs increase in the period immediately after a large catastrophic event ... [leading] to larger insured losses than expected" (EQECAT, quote 51). Hallegatte and Ghil (2008, quote 43) also explained demand surge in very general language: "Demand surge [occurs when] prices in the construction sector increase significantly in response to the large reconstruction demand in a disaster's aftermath." We highlight these specific definitions as examples of how demand surge may be understood in everyday discussions. We use these examples to emphasize the need for a clear, succinct, defensible definition of what demand surge is and is not.

[1] When creating and testing a demand-surge model it would be useful to be very precise, using for example weighted averages of the wages paid and prices charged by businesses with certain industrial classifications. To date none of the available literature seems to propose such precise definitions. For example, a practical definition of "workers in the construction industry" would be employees of any business whose North American Industry Classification System (NAICS) category is in the range of 23300–23599 or 56291. A practical definition of the cost of repair materials might be some weighted average of the prices charged by businesses in NAICS categories 42120–42179, 42295, 44221, 44411–44419, 442291, 442299, and 443111.

2.2 Alternate terminology for "demand surge"

In addition to the definitions and usages of "demand surge," there are other terms that refer to the same phenomenon or similar ideas. Three groups (Munich Re and American Re, Risk Management Solutions, and Risk Frontiers) have separately offered additional terminology to identify and explain the increased losses after catastrophes. These terminologies and the accompanying explanations help to define the idea of demand surge, but none provides a precise definition of this phenomenon.

Munich Re Group and American Re (2006) categorized sources of insured loss as: physical loss drivers; non-physical loss drivers; and insurance-specific loss drivers. Physical losses are repair costs from damage sustained in a disaster. Non-physical losses are increased repair costs explained by the disruption of the local economy, for example, from outages of public utilities or transportation systems or shortages of labor and materials. Insurance-specific losses result from: handling a large volume of claims; the inability to distinguish the cause of damage (for example, earthquake versus fire or wind-driven versus rising water); business interruption coverage; or the extension of insurance coverage for losses not covered in the policy.

Risk Management Solutions proposed the term "loss amplification" to describe the increase of loss following catastrophes that is not adequately modeled by assuming independent losses at exposed properties (Grossi and Muir-Wood, 2006). In other words, because there is a large volume of repairs in a region, the loss at each property is greater than if fewer properties had been damaged. Grossi and Muir-Wood (2006, p. 2) identified four issues that contribute to loss amplification: economic demand surge ("increases in the costs of building materials and hourly rates for labor, as demand exceeds supply"); repair delay inflation ("increases in the amount of damage or costs of interrupted business associated with delays in making the repairs"); claims inflation ("increases in the size of claims as the ability of insurance adjusters to inspect properties is impeded due to the number of claims"); and coverage expansion ("the degree to which the terms of the original insurance contract becomes expanded to cover additional sources of loss or higher limits").

Risk Frontiers, formerly the Natural Hazards Research Centre, is based at Macquarie University and studies topics of interest to the insurance industry. In Risk Frontier's quarterly newsletter, McAneney (2007) used the term "post-event claims inflation" to refer to the increase of payments for insurance claims after major disasters. Here, "demand surge" referred specifically to the outpacing of supply by the demand for goods and services, resulting in higher prices. McAneney (2007) listed other factors that contribute to post-event claims inflation: "the magnitude of the event and the average loss ratio, remoteness of location, fraud on the part of builders and policy owners, contemporaneous strength of the construction industry, cost to bring badly-damaged non-code buildings up to code in Cyclone-impacted areas and the response of the government."

The questions raised in Section 2.1 could equally well apply to the alternate terminologies described here. What specific repair costs are of interest, and is the total cost or a weighted average of per-unit costs of interest? What is the basis for any increased loss: the loss assuming pre-disaster costs or the loss if the same damage had occurred in a small-scale disaster? How can we separate demand surge losses from losses caused by other phenomena, given these definitions? To begin to address these questions, we look first to the historical record. As we will show, the experiences of past disasters, both large- and small-scale, form the foundation for all conceptualizations and explanations of demand surge.

3 Historical evidence for demand surge

Past natural disasters, both large- and small-scale, provide evidence for demand surge. The experiences of historical events suggest that catastrophes change the equilibrium of demand and supply of materials, labor, equipment, financing, or some combination of the four. The concept of demand surge was born from these past experiences; it was not a theoretical expectation, subsequently verified by observation or experimentation. This section brings together observations from the aftermaths of historical natural disasters that illustrate why reconstruction costs did or did not increase because of issues of supply and demand. Most of this evidence is anecdotal, and at the time, it was not reported in connection with problems of supply and demand.

We begin this section with natural disasters that have sufficient documentation on issues of demand and supply of materials, labor, equipment, and financing. We continue with events that have been claimed to cause demand surge, but we have not documented this causal claim. We finish the section with two events not known to have produced demand surge. Although we endeavored to accumulate descriptions of demand surge in past natural disasters, this collection is not exhaustive.

3.1 Great Storm of 1703

An extra-tropical cyclone devastated Southern and Central England on 26–27 November 1703. In his introduction to Daniel Defoe's collected accounts of the Great Storm, Hamblyn (2005, p. x) outlined the meteorology and destruction of the cyclone. The storm originated in the North Atlantic and struck Wales and Central England with estimated surface winds of 150 knots (280 kilometers per hour; Wheeler (2003) citing Lamb (1991)), before continuing over Scandinavia and the Baltic Sea. The storm's damage footprint was 300 miles wide. It caused an estimated 8,000 deaths on land and at sea. There was extensive and severe damage to buildings, especially in London and Bristol, and, in forests along its path, the cyclone felled millions of trees.

Defoe (1704, pp. 26–36) described three weeks of unusual winds punctuated by two terrible nights. There were two weeks of high winds before the storm intensified in the afternoon of Wednesday 24 November, accompanied by squalls of rain and terrible gusts of wind. The extreme winds continued through the following day. On Friday evening, Defoe saw the mercury in his barometer at its lowest level ever; the mercury was so low that he "suppose[d] the Tube had been handled and disturb'd by the Children." The storm raged Friday night and the early morning of Saturday, with residents fully expecting their houses to be blown down between 1 a.m. and 2 a.m. The strongest winds of the event blew between 5 a.m. and 6:30 a.m. and abated by 8 a.m. After a quick, extreme bout of rain and thunder Saturday afternoon, the winds diminished but were still unusually strong. The storm ended with a fury on the evening of Tuesday 1 December[2] that would have been historic had the storm four nights prior not been so cataclysmic. Defoe summarized the event as "one continued Storm from *Wednesday* Noon to *Wednesday* Noon."

In 1704, Defoe published his and others' accounts of the storm and its aftermath. He reported that "the Streets [of London] lay so covered with Tiles and Slates, from the Tops of the Houses, especially in the Out-parts, that the Quantity is incredible: and the Houses were so universally stript, that all the Tiles in Fifty Miles round would be able to repair but a small Part of it" (Defoe, 1704, p. 57). Although the storm was not as severe on subsequent days and nights, the winds caused additional damage: "Several People who had repair'd their Houses, had them untiled again [on the fifth night after the most severe winds]" (Defoe, 1704, p. 35).

In the immediate aftermath of the storm, prices of materials and labor wage rates rose significantly. Defoe (1704, p. 57) reported that the price of plain tiles rose from 21 shillings per thousand to 6 pounds[3], a 470% increase. The price of pantiles (commonly used as a roofing tile) rose from 50 shillings per thousand to 10 pounds, a 300% increase. Defoe states that the wage rate of bricklayers rose to 5 shillings per day, but he does not report the pre-storm rate.

Following the immediate rise of prices and wages, they fell. Defoe stated that the fall in the price of roofing tiles was not explained by the meeting of demand with adequate supplies. Rather, property owners and tenants could not pay the heightened costs. The roofs of some properties went un-repaired, and the occupants were exposed to the elements that winter. The roofs of other properties were repaired temporarily with wood planks ("deal boards") until enough tiles could be manufactured during the tile-making season. At the writing of his account, however, Defoe was skeptical that a sufficient number of tiles would be manufactured: "But 'tis not an irrational Suggestion, that all the Tiles which shall be made this whole Summer, will not repair the Damage in the covering of Houses within the Circumference of the City, and Ten Miles round" (Defoe, 1704, pp. 57–58).

Defoe also noted that any rainfall in the weeks after the storm passed would have certainly caused additional damage to building contents:

> It pleased God so to direct things, that there fell no Rain in any considerable Quantity, except what fell the same Night or the ensuing Day, for near Three Weeks after the Storm, though it was a Time of the Year that is generally dripping. Had a wet Rainy Season followed the Storm, the Damage which would have been suffered in and about this City [of London] to Household Goods, Furniture and Merchandise, would have been incredible, and might have equall'd all the rest of the Calamity: but the Weather prov'd fair and temperate for near a Month after the Storm, which gave People a great deal of Leisure in providing themselves Shelter, and fortifying their Houses against the Accidents of Weather by Deal Boards, old Tiles, Pieces of Sail-Cloth, Tarpaulin, and the like. (Defoe, 1704, p. 63)

This passage also indicates that property owners were substituting any appropriate and available materials to temporarily, if not permanently, repair their buildings.

Defoe's personal observations are limited to the city of London, but he collected and published accounts from most regions affected by the storm. Reports from outside London indicated that the rural population was likewise coping with shortages of roofing materials. From Ilminster, Somerset, in southwest England, an unnamed source reported a 150–200% increase in the price of reed thatching, which was the standard roofing material locally (Defoe, 1704, p. 80). The same source also noted the local population substituted "Bean, Helm and Furse" as thatching materials, even though these raw materials had never been known to be used as thatching before. In Kingston, a mile from Illminster, buildings that had been tiled were re-roofed with reed thatch "not in Compliance with the Mode, but the Necessity of the Times" (Defoe, 1704, p. 80). Henry Stanton, in Fareham, Hampshire (on the southern coast) also reported that wood planks ("Slit Deals") were used in place of "Slats and Tyles until Summer come to make some. And so much Thatching wanting, that it cannot be all repaired till after another Harvest" (Defoe, 1704, p. 89). Although these are the only two explicit references to materials shortages in the English countryside in Defoe's compilation, there must have been similar shortages and substitutions throughout the affected areas.

[2]Under the Julian calendar, November had twenty-nine days. The Calendar (New Style) Act of 1750 passed by the English Parliament mandated the switch from the Julian to the Gregorian calendar.

[3]There are twenty shillings to one pound.

3.2 1886 Charleston, South Carolina Earthquake

The earthquake that occurred north of Charleston, South Carolina, at 9:51 p.m. local time on 31 August 1886 was the largest earthquake to affect the eastern United States since permanent European settlement in the Seventeenth Century. The moment magnitude has been estimated at 7.0, with a maximum Modified Mercalli Intensity of X (Stover and Coffman, 1993). Ninety-two people were killed (Cochran, 1886). Almost every building in the city of Charleston was damaged, and many buildings sustained damage so severe that they were later demolished. The loss from property damage was estimated at US$5-6 million in 1886 value; several fires ignited following the earthquake, and the estimated property loss from the earthquake and fire damage was $8 million (Pinckney, 1906). Ground motions were felt in the cities of Boston, Milwaukee, and Chicago, and also on the islands of Cuba and Bermuda.

The extent of destruction in Charleston created a demand for labor that far exceeded the local supply. Wage rates for skilled and unskilled labor increased dramatically above the pre-earthquake levels. On Labor Day, seven days after the earthquake, the Knights of Labor union authorized a modest, fifty-cent-per-day increase in union wages (News and Courier, 1886b). However, skilled and unskilled laborers were actually commanding wage rates more than double the pre-earthquake rates. Union bricklayers would work for no less than US$5 per day, a 67% increase above the pre-earthquake rate, and the union president stated that "the bricklayers were entirely satisfied with ... $5 a day" (News and Courier, 1886a). There were rumors, however, that bricklayers received $6 or $8 per day, a 100-170% increase (News and Courier, 1886c). In one instance, plasterers were hired to repair The Citadel at $4.50 per day, but they asked for a raise upon hearing that plasterers elsewhere in the city were making double this; their request was rejected, the workers were fired, and replacements were found (Williams and Hoffius, 2009). In response to these hikes in wage rates, some homeowners chose to wait to re-plaster their houses until the rates returned to pre-earthquake levels, and the city shut down its relief efforts to pressure laborers to reduce their wage rates (Stephen Hoffius, personal communication, January 2009).

Skilled and unskilled labor considered traveling to Charleston, lured by the heightened wages. Laborers from the surrounding countryside found employment in Charleston (News and Courier, 1886e), and "hundreds of applications from mechanics, from every part of the country, who want to find employment in Charleston, are being received by the committee on relief" (News and Courier, 1886d). Although the applications for employment indicate that distant labor was willing to travel, we have not found evidence that they followed through and arrived in Charleston. Presumably, in 1886 travel would have been much more expensive and uncertain than today, both in terms of money and time. It would have been risky for a laborer living in a distant city to travel to Charleston without a guarantee of plentiful work at a sufficient wage rate.

In addition to heightened wage rates, the labor shortage also created a waiting list for repairs in the city. One observer noted that a delay in repairs, while certainly causing a hardship on the owners, may also increase the loss at the property (News and Courier, 1886d). The observer made this reference to increased loss in passing while calling for labor to quickly respond to the reconstruction demand without "selfish consideration." The source did not elaborate on how delayed repairs might increase property loss.

There were also reports of shoddy, or otherwise inadequate, repair work. The Relief Committee (a group of Charleston residents formed to organize relief and reconstruction efforts) required people receiving donated money to indicate their satisfaction with the work performed. Many property owners noted unsatisfactory work (Butler, 2007). Robert S. Schuyler, an architect visiting the city to observe the damage, noted rebuilding consistent with the pre-earthquake construction quality (Schuyler, 1886). Schuyler pointed out that this poor existing construction may have contributed to the devastation, and had the construction been of higher quality, the damage may have been less severe. There were no building codes in 1886 and thus no strong mechanism for the city to control construction quality.

3.3 1906 San Francisco Earthquake and Fire

At 5:12 a.m. local time on 18 April 1906, an earthquake struck the San Francisco Bay area. The epicenter was due west of the city of San Francisco, and the fault ruptured bilaterally, north and south, over a total length of 430 km on the northern San Andreas fault (Ellsworth, 1990). Strong shaking lasted for 45–60 seconds, with minor shaking felt in Los Angeles, central Nevada, and southern Oregon. The peak Modified Mercalli Intensity was IX near the fault, and the moment magnitude was later inferred to be 7.7–7.9. Reports often cite 700 deaths caused by the earthquake and resulting fire, but the true figure may have been closer to 2,000 (Ellsworth, 1990).

The 1906 disaster is a classic example of a fire-following earthquake. Urban conflagrations were a hazard of the time, with recent, major fires in 1871 Chicago and 1904 Baltimore. Most residents believed that a large fire was inevitable: "'One day San Francisco will be destroyed by fire' had so often been said that at last no one believed it" (Marks, nd, p. 2). In 1905, the National Board of Fire Underwriters noted that San Francisco had "defied all actuarial standards by not burning up" (quoted in Fradkin (2005, p. 237)). The fire following the 1906 Earthquake burned for three days. In the aftermath, some San Franciscans wanted to define the destruction as fire-induced:

generally speaking, urban fires could be mitigated and controlled, whereas major earthquakes were unpredictable and uncontrollable. Also, standard insurance policies excluded earthquake, but covered fire, damage.

Reid (1908) summarized the reconstruction of San Francisco this way:

> Immense numbers of the people had to leave at once for lack of shelter and food,–at first for lack even of water. Then came weary months of waiting to realize on securities, to collect insurance, negotiate loans, and persuade the outside world that the spot was not doomed, that San Francisco was not to be henceforth as dead as Nineveh and Tyre. After that came scarcity of building material, scarcity of labor, impossible prices, questions of public health, and all the other disadvantages you can readily imagine.

Note the implied timeline of recovery: the shortages of materials and labor became significant only after residents and business owners could secure adequate reconstruction capital.

The expectations of labor unions and bankers soon after the catastrophe underestimated the extent of damage and loss. One week after the earthquake and fire, the officers of the local plumbers' union believed that "they will have plenty of plumbers to meet all demands, not only on emergency work, but when normal conditions are re-established" (State and Local Building Trades Councils of California, 1906). The minutes of the Painters' Union, Local 19, noted on 29 April 1906 that "San Francisco has a future, and the painters who remain will reap a harvest, as work will be plentiful in a very short time" (Wilson, 1906). The painters' union suspended overtime pay and asked its membership to work only eight hours per day to give those unemployed the opportunity to work. These requests presume a limited demand for painters, at least in the first weeks following the disaster. The Executive Committee to the San Francisco Clearinghouse, a cooperative agreement among the major private banks, expected to finance the reconstruction of San Francisco wholly with local capital. They reasoned "that with [US]$150,000,000 from the insurance companies, the banks in a strong solvent position, a bountiful harvest promised in the state, and the general underlying soundness of business, help from outside would not be essential" (quoted in Phillips (2003)). In fact, insurance companies would eventually pay $220-250 million in 1906 value to claimants. Although boldly stated in the immediate aftermath of the disaster, expectations of the reconstruction were not always realized.

Between 300 and 400 insurance claims adjusters, both local and from across the United States, handled the large volume of claims on insurance policies. G. H. Marks of the London Assurance Corporation described the task of adjusting insurance claims after the earthquake and fire:

> How were we to check the claims? All usual means were absent. Under ordinary circumstances we have some data to go upon—the ruins contain many evidences, but here the ruin was so complete, and everything that was consumable had so entirely vanished, that little or nothing could be learnt by a visit to the scene of the fire. In ordinary circumstances there are next door neighbours and friends that can readily confirm the Assured's statements, but here all neighbours had gone—no one knew where, some, thousands of miles away, others scattered through many a refugee camp, and almost as difficult to find as the proverbial needle in a hay-stack—nor could confirmation be obtained by reference to the retail or wholesale firm from whom the articles were purchased—they had been burnt out too.
>
> Every Insurance Company's Office had been destroyed by the fire, and some had lost all or a great portion of the records of their business and could only find out very laboriously, and then not with absolute certainty, what properties they covered....
>
> Immediately after the disaster, temporary offices were established by the different companies for dealing with the claims—a few in San Francisco but mostly in Oakland, four miles across the Bay. For the first few weeks nothing could be done but receive in an unending stream, the "notices of loss" required by the conditions of the policies.
>
> To handle such a number of claims required careful and thorough organisation, and that at a time when everything was in confusion. As soon as it could be arranged, each of the companies gathered together a staff of loss adjusters from all over the country.
>
> Crowds of anxious men and women besieged the offices of the companies every day—often remaining for hours day after day until their claims could be dealt with....
>
> We had a unique opportunity of studying character as day by day we watched the never ceasing queue of loss claimants patiently waiting to interview the Adjusters, and upon the whole the impression was favourable. They were of course "out to get their Insurance money," as the slang expression so tersely put it, but there is nothing wrong in getting what you are entitled to, and under similar circumstances each of us would probably be equally keen.
>
> The nervous strain of day after day meeting a constant stream of claimants, and the incessant call for good temper, courtesy, and tact, soon told upon all who were actively engaged in this business. Few of the adjusters could stand more than three months of it, and all were much relieved when, about six months after the conflagration, we could leave the few remaining cases to be dealt with by the permanent staff in the ordinary way. (Marks, nd, pp. 6, 8)

Some properties were indemnified by several companies. In the months following the earthquake and fire, insurance companies tried to develop a common approach to adjusting and settling these claims. On 21 April 1906, representatives of all insurance companies with joint interests in damaged properties met in Oakland, California, across the Bay from San Francisco. This meeting established a General Adjusting Board, charged with adjusting losses that involved more than five companies. Modeled after the response to the 1904 Baltimore fire, the General Adjusting Board oversaw subcommittees that did the work of adjusting each claim and submitting the findings to the respective insurance companies. The companies settled each claim, using the recommendation of the subcommittee.

In the weeks following this meeting, differences arose among insurance companies over the guidelines for handling the claims. At a general meeting of the insurers on 12 June in Oakland, the attendees voted on a set of principles for adjusting claims. Essentially, the resolution stated that the insurance companies would apply a 25% reduction to the ground-up loss[4] when the cause of damage—either earthquake or fire—was unclear. Sixty-one companies approved this resolution, thirty-two disapproved, nine were absent, and eighteen were excused from voting (Hosford *et al.*, 1906). Although otherwise supporting the work of the General Adjusting Board, thirty-five companies decided not to reduce payments to their policyholders. On 21 June, the (aptly named) Thirty-Five Companies adopted guidelines stating that claims on their policies should be settled on a case-by-case basis according to the actual policy terms. The Thirty-Five Companies appointed a Committee of Five to review claims on their policies when the methods of adjusting were unclear or there was not sufficient representation of the Companies on the adjusting subcommittee (Hosford *et al.*, 1906).

As part of its work, the Committee of Five investigated why there were so few adjustments completed at the time of its formation in late June, more than two months after the disaster. The Committee "found that certain companies were interested in so many of the losses assigned to their adjusters by the General Adjusting Bureau that it was impossible to handle the losses more expeditiously, especially so in many cases where the office records of the insurance companies were either destroyed or were in vaults which could not be reached until many weeks after the disaster; while in other cases there was an evident disposition on the part of some insurance companies to delay and unduly protract adjustments" (Hosford *et al.*, 1906, p. 17).

Also in its concluding report of 31 December 1906, the Committee of Five made recommendations to the Thirty-Five Companies on how to handle claims better after future disasters. (We summarize their recommendations here and provide the full text in Appendix A.) The Committee of Five began by recognizing how much effort had to be expended to achieve agreement on methods for settling claims with several interested insurers among the more than 100 insurance companies. They also acknowledged that many insurance companies understandably did not want to set guidelines before collecting the relevant facts and records. Nonetheless, the Committee suggested that insurance companies would have realized better and less expensive results, in addition to "creating a better feeling amongst policyholders," if the companies had agreed to a common approach much sooner (Hosford *et al.*, 1906, p. 24). The Committee reported that uncertainty among policyholders made its work more difficult and resulted in higher costs to the insurers.

In general, the Committee found claimants to be "fair, patient, and honest." However, the Committee acknowledged that, in their haste to submit claims, policyholders often "innocently exaggerated their statements," since the prevailing conditions made an accurate claim "almost impossible." The Committee noted two cases in which "expert accountants" identified intentional fraud and reduced the total insurance payment by US$100,000, demonstrating the value of the accountants' work. If more widely employed, the Committee wondered, how many additional fraudulent claims would have been identified?

As evidenced by the many months of resolving claims, the Committee of Five acknowledged that the number of claims "overwhelmed" the insurance companies. It raised the question, however, whether an insurance company had the right to discount a payment when the claimant sought immediate resolution. After all, the insurance companies allowed a "lapse of so great a time in the taking up of the adjustments." The Committee noted that some claimants accepted without question the discount, likely in order to avoid further examination of the claim by the insurance company.

Tallying the insurance effort, the Committee of Five estimated that there were nearly 100,000 claims on insurance policies, resulting in a gross insured loss of US$200 million in 1906 value (Hosford *et al.*, 1906). The Committee counted 233 companies that sustained losses in the San Francisco Earthquake and Fire, including over 100 insurance companies and a "large number of native and foreign surplus-writing companies" (p. 26).

At the time, the insurance industry recognized the general confusion surrounding the settlement of claims. Domestic fire insurance companies, meeting in New York on 31 May 1906, agreed that "the problems arising in connection with the settlement of [the fire following earthquake] losses are complex and intricate to an extent never before equaled in the history of underwriting by reason of the following and other factors, namely: (a) the difficulty of clearly segregating losses for which companies are liable from those from which they are exempt; (b) the existence of many varying forms of policy contracts; (c) the loss of essential records both by insurance companies and by the

[4]The ground-up loss is the value of damage at a property before applying insurance deductibles, co-pays, or limits in order to calculate the insured loss.

assured" (Hosford *et al.*, 1906, p. 13). The General Manager of Munich Re concluded that the insurance industry must agree on a common, "concise earthquake clause." "In San Francisco we have experienced that companies which had stipulated in their policies the exclusion of all direct and indirect earthquake losses were, due to competition with other companies, obliged to pay their losses in order not to lose their business for all future" (quoted in Hoffman (1928)). He believed that all direct and indirect earthquake losses should be explicitly excluded because "no premium suffices to cover such an undefinable risk." This issue of payment by an insurer for excluded loss may be an indirect result of the overwhelming demand for reconstruction financing via insurance. If the scale of the 1906 disaster had been smaller, the insurance companies might not have faced pressure from their policyholders or their competition to satisfy their clients beyond the terms of their policies.

G. H. Marks, the representative of the London Assurance Corporation, documented the effect on insurance premiums for the companies that paid their claims in full versus those that did not:

> At the end of six months from the date of the disaster the newspapers classified the companies according to the way they had met their claims. There were five classes, the first of which was known as Class A, or "Roll of Honor," and consisted of 39 companies....
>
> Their names have been spread broadcast over the States not only through the Press, but through the report of a special committee of the Chamber of Commerce of San Francisco, ably drawn up by Professor Whitney, the report made at the instigation of the National Association of Credit Men, and the exhaustive report issued by the Alfred M. Best Company, of New York City.
>
> The natural result has been that on the Pacific Coast these 39 companies have had all the business offered to them that they could carry, and have been able to make most valuable connections. The results are shown very forcibly in the following figures giving the premiums received by such companies, before and after the conflagration:

	1905	*1907*
Premiums received on Pacific Coast		
by the 39 Class A Companies	$10,075,627	$18,717,690
By all other Companies	10,490,013	10,029,678
	$20,565,640	$28,747,368

> The Class A Companies increased their business between 1905 and 1907 85.7%. The other companies show a decrease of 4.4%. (Marks, nd, p. 7)

The judiciary also played a role in the reconstruction of San Francisco. United States courts ultimately ruled on disputes over the wording of fire following earthquake exclusions in typical insurance policies. On 5 October 1908, the Ninth Circuit Court of Appeals upheld the finding of a lower court that insurance companies were liable for losses caused by fires indirectly ignited by the earthquake (Williamsburgh City Fire Ins. Co. v. Willard, 1908). The appeals court found:

> Applying the maxim that in construing the terms of an insurance policy, if there be any ambiguity, it must be construed most strongly against the insurers, since the language of the policy is their own, effect to that intention can only be given in the present case by holding that the second exemption [for loss caused by volcanic eruption, earthquake, etc.] exempts only from liability for loss by fire which is caused directly by volcano, earthquake, etc., and that a loss indirectly caused by the progress of fire from a distance, although originally started by an earthquake, is not within the exemption.

A decision of the Second Circuit Court of Appeals on 13 November 1911 confirmed payment to the insured in Norwich Union Fire Ins. Soc'y v. Stanton (1911), using the same argument given in Williamsburgh City Fire Ins. Co. v. Willard (1908).

Returning to 1906 and the physical reconstruction of the city, construction materials were in great demand following the catastrophe, and their supplies were uncertain. The Journal of Progress (1907) quoted A. P. Gianninni, a bank vice-president:

> We must guard against a shortage of material. Every effort must be made, and that early, to provide against any such contingency. We have been a little hampered in our building for the want of rock, but we have put into service a number of scows to haul rock from California City [near present-day Paradise Cay on the San Francisco Bay, just north of San Francisco] and have thus been enabled to keep on working.... To give you some idea of the extent of building operations you cannot buy old brick now. All have been contracted for.

It seems very likely that accompanying the materials shortage were higher materials prices and the necessity to substitute available materials for those unavailable.

On the first anniversary of the 1906 San Francisco Earthquake and Fire, a former mayor, James D. Phelan, described the current strife between local banks and labor representatives (quoted in Evening Post (1907, p. 1)):

Nature of the Loss	*Percent Insured*
Business Premises	60
Business Contents and Stock	40
Dwellings	70
Dwelling Contents	20
Motor Vehicles	45
Health	60

Table 1: Underinsurance by type of loss in Cyclone Tracy, 1974. Reproduced from Haas *et al.* (1976).

> During the year since the fire the work of reconstruction has been very extensive and rapid, so much so that it has really given rise to the labor troubles which beset us to-day. You will recall that San Francisco invited mechanics of all kinds to come to the State and help to rebuild. The insurance companies paid $180,000,000 in losses, and money was abundant among the people and in the banks....
>
> The large army of laborers that came to San Francisco from the interior of the State and outside the State and the abundance of work for them created an artificial condition, and wages and materials advanced. Now that the emergency period is past, an economic readjustment is going on, which has caused the recent friction. The labor leaders in San Francisco, when money became scarce last month, by reason of the extraordinary demand for rebuilding, asked whether the banks had not conspired with a view to lowering wages and reducing prices. That is always a natural suspicion on the part of laboring men, but I have abundant evidence that the scarcity was due to legitimate causes. As in the case of Baltimore and Chicago, it became plain that Eastern capital would have to be enlisted in the work of reconstruction, and in order to interest Eastern capital normal conditions as to wages and material should be restored as speedily as possible. If there is no money, there is no work, and labor will be the first to suffer, because people temporarily housed are not obliged to build, and they will only build permanently when prices are favorable.

Whether or not the local bankers actively conspired to withhold financing in order to deflate materials prices and labor wage rates, reconstruction financing was a primary concern one year after the catastrophe.

As part of a case study of the local economy following the 1906 disaster, Douty (1977) analyzed constraints on reconstruction. He found that initially the repair of urban transportation systems limited the repair and rebuilding of private properties. Both skilled and unskilled labor could remove debris and perform road repairs equally well. Once the transportation system could function minimally, demand increased for skilled construction labor, drawing them away from unskilled work, thus reducing the supply of labor for unskilled tasks. The constraint on the rate of reconstruction for a "substantial period after the 1906 disaster" was the supply of skilled labor.

Douty (1977) also considered whether the availability of capital constrained reconstruction. Consistent with the statements of James D. Phelan, Douty reported that San Francisco builders found financing difficult to secure in the summer of 1907. "It appears that the only serious financial problems in the post-disaster period grew out of the 1907 recession and were largely unrelated to the San Francisco catastrophe" (p. 307). Douty argues, though, that savings could be a constraining factor in other reconstructions if financial and insurance markets are not well developed or if government aid is not forthcoming.

3.4 1974 Cyclone Tracy

On 24–25 December 1974, Cyclone Tracy destroyed the remote town of Darwin, Australia. At landfall the storm was a Category 4 in the Australian tropical cyclone category system (Category 3 on the Saffir-Simpson Hurricane Scale). Haas *et al.* (1976) described the evolution of the storm and the consequent damage. Winds in Darwin began to increase between 10 p.m. and 11 p.m. There was no electrical power in most areas by 1 a.m., and the storm had removed most roofs by 2:30 a.m. The winds did not subside until 6 a.m. The storm completely destroyed 8,000 houses and severely damaged another 4,000 in a city with a population of 47,000. The Australian Department of Repatriation and Compensation soon found significant underinsurance of property in Darwin (Table 1; reported by Haas *et al.* (1976)). The Insurance Council of Australia (2009) estimated an insured loss of A$200 million in 1974 value.

The Australian Commonwealth government directed much of the reconstruction of Darwin, including debris removal and rebuilding. Papers collected in the National Archive of Australia document the information available to the Department of the Prime Minister and Cabinet, as well as its decisions on rebuilding. In January 1975, Rex Patterson, the Minister for the Northern Territory, asked the Cabinet to level the wage rate for all workers: "Volunteer casual labour for [clean-up, sanitation and health, and restoration of power and water] has been paid at the rate of sixteen dollars per half day. This has caused some resentment amongst more permanent labour on award wages employed by both private industry and Government Departments who normally receive less than this and feel they are less well off. There has been a considerable transfer of this labour force to the more well paid areas. I propose therefore that the minimum rate of pay for all workers engaged in essential tasks in Darwin should be one hundred and sixty-four dollars per week [A$16.40 per half day, assuming a five-day work week]" (Patterson, 1975a). The Cabinet, however, did not agree with Dr. Patterson and affirmed the *status quo* (Australian Cabinet, 1975).

On 28 February 1975, the Commonwealth government established the Darwin Reconstruction Commission and tasked it with overseeing the city's rebuilding. Borrowing cost estimates from the Commission's anticipated report on the reconstruction program, Rex Patterson and Tom Uren, Minister for Urban and Regional Development, commented on the feasibility of the Commission's proposed, five-year plan for A$770 million in "capital works:"

> Because of the substantial demands that the program would imply for scarce resources of labour and materials, it is likely that the *relative* increase of wages and prices in Darwin would be significantly faster than in the rest of Australia.
>
> Taking this "relative price" effect into account (together with [the assumption of present day prices and the exclusion of expenditure of some statutory bodies]), it seems likely that the figure of [A]$770 million is likely to be substantially less than the final cost of reconstruction....
>
> Building and construction costs in Darwin are already higher than the Australian average and could well become significantly higher if the Commission's indicative program were to be adopted. The first contracts let for cyclone resistant houses are for an average cost of [A]$42,500 per unit: with the operation of "rise and fall provisions," the actual average cost is more likely to be in the vicinity of $50,000 per unit [a roughly 20% increase]....
>
> Darwin reconstruction will make heavy demands on resources of building and construction workers and materials. Below a population level of approximately 40,000 persons at 1980, assuming a fairly even rate of building and construction activity through the period 1975-80, it would be possible to achieve reconstruction by using a construction workforce at about the pre-cyclone level. However, above this population level the manpower demands would rise so that, to reconstruct for 56,000 persons by 1980, the building and construction workforce would have to almost double, to between 5,000 to 6,000 workers as a [*incomplete word*] in 1978.
>
> The implication of such an increase would be that workers would have to be attracted from other parts of Australia. In the short term this is feasible, given present rates of unemployment in the building industry, but it would seem to us to necessitate the payment of substantially higher wages. (Patterson and Uren, 1975)

The Commonwealth government recognized that public service employment drove the population and economy of Darwin. Thus, the government could realistically influence the population—and consequently the demand for housing—by adjusting the number of government jobs. A target population level was part of their deliberations.

In its 5 June report, the Darwin Reconstruction Commission (1975) confirmed the situation anticipated by Patterson and Uren (1975) and described likely consequences of the proposed rebuilding plan. The Commission noted: "It can be argued that there are cost penalties associated with the rapid rate of reconstruction proposed. This is primarily because of the need to shift substantial quantities of labour, materials and equipment to Darwin and the associated establishment costs. Existing transport facilities are likely to be over-strained and expenditure to improve them may be required. On the other hand, these factors can be offset in part by expected economies of scale—evidence of this has already been displayed in the housing tenders received. Moreover, the social costs of delaying the provision of permanent housing for the 30,000 existing inhabitants cannot be ignored." The Committee acknowledged an obligation to provide permanent housing in Darwin as soon as possible. However, immediate and rapid reconstruction efforts would come with inherent costs. The Commonwealth government could offset some of these costs through its centralized reconstruction effort, which, presumably, could not have been realized if numerous, independent private companies effected the reconstruction.

The evolving situation in Darwin also influenced the Commonwealth government's ongoing deliberations. In response to a letter from the Prime Minister on 7 July 1975, Rex Patterson suggested that new information might reduce reconstruction cost estimates:

> Since [the Commission report of 5 June] the building code has been modified and it is estimated that this will result in savings of approximately [A]$2,500 for timber framed houses and $800 for houses constructed of concrete. The Commission is also investigating alternative methods of construction which, it is hoped, will result in lower costs for the future. It is also arranging for various contractors to establish proto-type houses which will still meet the building code but result in lower costs. It is expected that with more experience in the application of the code and as contractors are surer as to their cost structure, the future contract prices will be less than $40,000. It is obvious that some of the original tenders had of necessity included establishment costs which should not be repeated in later contracts. On the other hand, all

> contracts will include rise and fall provisions and price rises in material costs at the source of supply could of course affect the situation. (Patterson, 1975b)

Dr. Patterson continued:

> It is true that there were early forecasts that there would be wage demands out of keeping with the rest of Australia when the project got under way. These forecasts were based on events which have occurred in other major projects in isolated areas, particularly those associated with mining ventures. In view of the recent events on the industrial front and the fact that the Government does not necessarily have the same financial/profit commitment of a commercial organisation, the unions' bargaining strength will not be as strong. In Darwin itself the failure of the unions to win the recent claims for the Government to meet air fares and other costs has weakened the position of the union officials who took the attitude that they could force the Government to meet the claims. The present industrial situation is very quiet and there is no reason to believe that in the immediate future unions will prejudice their own livelihoods by creating a situation which would slow down or bring to a halt the reconstruction of Darwin. In short it would seem that wage rates and other costs will not rise more rapidly than in other parts of Australia.

According to recent estimates, building costs in Darwin after Cyclone Tracy approximately doubled compared to the pre-event costs (Walker, 2005; O'Neill *et al.*, 2006). Walker (2005) explained that costs of both labor and materials contributed to the near doubling of construction costs. Construction contractors made bids of approximately A$700 per square meter, but the final costs were closer to $1400 per square meter (Dennis O'Brien, personal communication, October 2008). Some of these increases may be attributed to the higher building standards adopted in response to the damage caused by Cyclone Tracy.

3.5 1992 Hurricane Andrew

In the early morning of 24 August 1992, Hurricane Andrew made landfall south of Miami, Florida. At the time, Hurricane Andrew was classified as a Category 4 storm (Saffir-Simpson Hurricane Scale) at landfall, but ten years later, the National Hurricane Center upgraded it to a Category 5 storm (Landsea *et al.*, 2004). Rappaport (1993) reported counts of the casualties and damage caused by the hurricane. The storm directly caused twenty-six deaths and indirectly an additional thirty-nine fatalities. Andrew destroyed 25,524 houses and damaged 101,241 more. Mobile homes were particularly vulnerable: ninety percent of all mobile homes in southern Dade county were destroyed. The Insurance Information Institute (2009) estimated the insured loss at US$15.5 billion in 1992 value, or $23.8 billion in 2008 value.

Much of the loss in South Florida was covered by insurance. Hurricane Andrew generated over 725,000 insurance claims (Rappaport, 1993). In order to handle such a large volume of claims, an estimated 24% of United States claims adjusters were in the field (Johnson, 2005). The Wall Street Journal reported that one claims manager in Florida estimated a one-third increase of residential rebuilding costs as a result of increased prices for materials and labor (Steinmetz, 1993). The same article described a dispute between State Farm and a homeowner. The homeowner's contractor quoted US$18,000 to replace the roof, but State Farm told the homeowner that the replacement should cost 70% of that figure. Presumably, this was not an isolated dispute between an insurer and policyholder, but rather, it seems likely to us that there were many similar disagreements throughout South Florida in the months following Hurricane Andrew.

The large extent of damage also overwhelmed the local supply of reconstruction materials. Before Hurricane Andrew made landfall, timber product prices in South Florida were unusually high because of reduced logging[5] and a late start to the summer construction season (Grogan and Setzer, 1992; Setzer, 1992). Nationally, the price of 5/8-inch plywood increased 15.9% in the month following Hurricane Andrew (Grogan and Setzer, 1992). In Central Florida, material pricing was volatile: 5/8-inch plywood was quoted variously at US$14.45, $17.95, and $22.69 per sheet (Grogan and Setzer, 1992). Setzer (1992) quoted an observer of timber-product prices who noted that the post-Andrew demand in South Florida was "pretty small" in comparison with demand nationally. Nonetheless, the hurricane caused an "emotional response typical after a disaster." It would be interesting to document the fraction of U. S. construction materials absorbed by hurricane repairs to verify that local price increases were explained by emotional–and not supply–considerations.

The prices of concrete block, drywall, and roofing materials were also reported to increase (Grogan and Setzer, 1992). Specifically, "a 200-square-foot roll of roofing felt priced at [US]$8 before the hurricane now sells for $12 [a 50% increase]. Drywall is being rationed, and 4-by-8-foot plywood sheets that used to cost $10.50 now cost up to $15 [a 43% increase], the [Builders Association of South Florida] said" (United Press International, 1992). In response to

[5] Some readers may remember the multi-year debate between environmentalists and the logging industry over old-growth forests in the U. S. Pacific Northwest. Environmentalists sought to preserve the habitats of endangered species (primarily the northern spotted owl). By the autumn of 1992, timber harvests had been significantly reduced to comply with judicial injunctions (Grogan, 1992b).

price increases such as these, some materials suppliers fixed prices at the pre-event level, donated large quantities, or sold at cost and limited the quantity per customer (Setzer, 1992).

Heavy equipment was in demand for debris removal, according to a news item in Engineering News-Record (Grogan and Setzer, 1992). When the United States Army Corps of Engineers solicited bids for debris removal immediately after Andrew, the Corps rejected one-third of the bids as too high and awarded contracts bid at approximately US$25 per cubic yard. One month later, the awarded contracts had been bid at $7. One contractor charged with debris removal received offers of heavy equipment that were equally divided between "outrageous" and "acceptable."

Engineering News-Record reported that contractors nationally had been hit hard by a slump in construction demand and, in Florida, a wet summer preceded Hurricane Andrew (Grogan, 1992a; Korman *et al.*, 1992). The construction slump forced contractors to reduce their profit margins to win jobs. The soggy summer caused some contractors with work to write off the costs of delays and of rain damage to buildings under construction, further lowering their overhead and profit margins. With an abundance of hurricane repair work, some contractors reportedly saw the opportunity to recuperate some of their losses or foregone profits from the previous summer. Furthermore, out-of-state contractors came to Florida to work on the repairs: "After the storm, an army of pickup trucks with Alabama and Georgia license plates descended on South Florida as fast as the television crews. Complete with workers and lumber, the newly arrived builders are scouring battered neighborhoods and advertising their services with cardboard signs tacked on telephone poles" (Steinmetz, 1993). Local and out of state contractors alike saw business opportunities in the overwhelming demand for reconstruction following Hurricane Andrew.

Labor wages were also reported to increase dramatically. "Laborers getting [US]$10 an hour two months ago are now making $18 an hour [an 80% increase]" (United Press International, 1992).

3.6 1992 Hurricane Iniki

Hurricane Iniki made landfall on the Hawaiian island of Kaua'i around 3:30 p.m. local time on 11 September 1992. The NOAA Disaster Survey Team (1993) described the meteorological conditions of the hurricane, as well as its extent of destruction. Over the island, the maximum sustained winds were between 130 and 160 miles per hour, which is equivalent to a weak Category 4 storm on the Saffir-Simpson Hurricane Scale. Seven people were killed, and approximately 100 were injured. The total damage was estimated at US$1.8 billion in 1992 value. The same report quoted counts of damage from the American Red Cross: 14,350 residences were affected by the hurricane, with 1,421 destroyed and 5,152 sustaining major damage. The damage to structures was primarily due to wind, but some structures along the coast were damaged by a combination of waves and storm surge. The island of Kaua'i lost electrical power and telephone service, and fifty percent of utility lines and poles were destroyed. Four weeks after the storm, only twenty percent of the electrical power supply was restored.

Observers noted several factors that affected the reconstruction of properties on Kaua'i. At some locations, construction costs were double the pre-Iniki costs, which may have been exacerbated by the four- to six-week wait for materials from the mainland United States at the time (Diane Inouye and Mike Nonaka, personal communication, January 2009). State Farm, a large U. S. insurance company, sent an additional seventy insurance adjusters to Kaua'i (Beller and Dykewicz, 1992). In addition, the County of Kaua'i Building Department allowed the rebuilding of damaged properties to their pre-Iniki condition: for example, single-wall construction could be rebuilt with single-wall construction and corrugated metal roofing could be replaced without a wood sheathing underlayment (Chock, 2005).[6] Had the building department required reconstruction to the standards of new construction (specifically, the 1991 Uniform Building Code Appendix Section 2518, adopted by Kaua'i County on 7 December 1992 (Federal Insurance Administration, 1993)), the demand for reconstruction materials would have been greater. In this scenario, there would have been a higher demand for 2-by-4-inch studs, wall and roof sheathing, and uplift tie straps.

3.7 1994 Northridge Earthquake

A moment magnitude 6.7 earthquake struck the San Fernando Valley in Los Angeles at 4:30 a.m. local time, causing widespread damage. The most notable structural failures were collapses of freeway overpasses, collapses of wood-frame buildings with soft stories, failure of pre-cast tilt-up concrete walls, and fractures of brittle welds that connect beams to columns in steel moment-resisting frames. The Insurance Information Institute (2009) estimated the insured loss to be US$12.5 billion in 1994 value, equivalent to $18.16 billion in 2008 value. Insurers later informed the California Earthquake Authority that they saw a 20% increase of loss because of demand surge (Kuzak and Larsen, 2005, p. 113).

In personal communication, John Osteraas, a structural engineer, described his observations of claims adjusters and construction contractors after the Northridge Earthquake. There was an insufficient number of claims adjusters

[6] In his discussion of post-Iniki reconstruction, Chock (2005, p. 611) also mentioned the reconstruction effort after the 1982 Hurricane Iwa. "The normal permitting process was totally waived for post-Hurricane Iwa reconstruction, and so repairs did not significantly improve the pre-Iwa building stock. By accounts of structural engineers, the predominant reconstruction practice after Hurricane Iwa was to replace 'in-kind' without conformance to code standards." Although building standards may be higher when a building is damaged than when it was built, the building may not always be required to be rebuilt to the current standards.

in the local area, and insurance companies brought in adjusters from other parts of the United States. Adjusters from seismically inactive areas may not have had proper training or any experience with seismic damage, and thus they may not have been able to adjust claims properly for this type of damage. Also, the demand for contractors to repair damage exceeded the supply, resulting in a less-competitive environment. Construction contractors would raise significantly their bids on reconstruction projects, maybe as much as twice what they would have bid in a competitive environment. If the bid was accepted, the contractor could sub-contract the work and keep some of the profit, but if the bid was not accepted, there was plenty of other work available (John Osteraas, personal communication, September/October 2008).

Seismic Safety, a seismic retrofit company in the Los Angeles area, hired additional workers to keep pace with the demand for its services after the Northridge Earthquake (Seismic Safety, personal communication, March 2009). The company could not find new workers at the pre-earthquake wage rate, and so the owner raised the wage rates for both new and existing labor. To finish a job quickly, they would add a fourth or fifth worker to the job. Adding the fourth worker decreased the overall efficiency of the crew, but the job was completed faster. Adding a fifth worker further speeded completion of the job but required the additional expense of sending a second truck to the job site.

Although there was heightened demand for reconstruction materials after the Northridge Earthquake, construction material prices in the Los Angeles area did not increase. Materials suppliers could not increase prices, even if they had wanted to do so, because of competition from other suppliers (Setzer, 1994). Thus, even though insurers told the California Earthquake Authority of 20% increased loss because of demand surge, our evidence suggests that the supply constraint was on the number of available construction workers and construction contracting firms, rather than on materials prices.

John Wiggins, a natural hazards consultant in the Los Angeles area, published his impressions of insurance payments for Northridge claims:

> The insurance companies in California after the Northridge earthquake overpaid by as much as a factor of two, according to my calculations. Some of the reasons for overpayment were: fear of the insurance commissioner; fear of the California courts (bad faith); improperly written and monitored policies; paying non-earthquake policies; improperly trained adjustors who pay too much; paying high bids (see first and second reasons); inspection engineers worrying more about their errors and omissions liability than about valuing claims; escalation of costs under catastrophic conditions; and Department of Building Safety changes in repair requirements. I have firsthand knowledge of every one of the factors mentioned above that caused escalation in insured payments. (Wiggins, 1996)

3.8 2005 Hurricane Katrina

Hurricane Katrina made landfall in Louisiana at 6:10 a.m. local time on 29 August 2005 as a Category 3 storm (Saffir-Simpson Hurricane Scale). The hurricane primarily damaged properties in Louisiana, Mississippi, and Alabama. In the aftermath of the storm, parts of the extensive levee system in New Orleans were overtopped or suffered geotechnical failure, flooding large sections of the city. The Insurance Information Institute (2009) estimated the insured loss at US$41.1 billion in 2005 value, or $45.3 billion in 2008 value.

The pre-Katrina construction economy and experiences with previous disasters affected expectations of construction cost increases. Before Katrina made landfall, there was an existing high demand for construction materials and equipment (Hampton, 2005). The additional demand for reconstruction materials and the practice of just-in-time supply led to expectations of price volatility and shortages after Katrina (Nicholson, 2006). Within one month of the storm, a construction-cost consultant expected 10–15% higher construction costs in the affected area, and one construction management firm increased estimates of material prices for commercial projects by 8–10% and for residential projects by 10–15% (Grogan and Angelo, 2005). Cost estimators adjusted escalation factors in bids in anticipation of demand surge (ENR Staff, 2005). The uncertainty in the weeks after Katrina also affected material prices: "While it is too early to determine the full impact of the storm on construction costs, the uncertainty it has stirred up undoubtedly will lead to higher bids for projects just to cover the new level of risk" (Grogan and Angelo, 2005).

Manufacturing capacity and distribution facility damage were expected to affect material prices. Two cement plants in the New Orleans area shut down for two weeks, removing 80,000 tonnes of cement from production, and a manufacturer switched production from siding to oriented strand board in anticipation of the future demand (Grogan and Angelo, 2005). The pre-Katrina construction boom in the United States had encouraged investment in manufacturing facilities, which were expected to meet some of the additional demand for materials. Hurricane damage to the port of New Orleans reduced distribution capacity for materials transported on the Mississippi river; a drought in the Central United States had already increased costs for barge transportation because of delays and higher fees to cover dredging costs (Nicholson, 2005).

The pace and costs of reconstruction after Hurricane Katrina were affected by the availability of labor. By one month after Katrina, a construction management firm expected to pay a 20% premium to attract labor and managers to the affected area (Grogan and Angelo, 2005). The plumbers' union president expected a shortage of plumbers and welders, and he expected higher wages for the available skilled labor (Winston, 2005). Also at this time, construction contractors were able to pass along the higher costs to their clients, and thus the higher costs did not slow the pace of reconstruction (McFall, 2005). One year after Katrina, the pace of reconstruction was limited by the availability of skilled workers, who were themselves limited by the availability of local housing (ENR Staff, 2006). By March 2007, though, delays in securing financing for reconstruction projects meant that the funds to support higher labor wage rates were not available (Buckley, 2007).

Two anecdotes of cleanup efforts at casinos on the Gulf Coast demonstrate why labor costs can be higher after a catastrophe. (John Osteraas relayed both observations to the authors in personal communication.) At one location, there was an attempt to save the undamaged televisions in the hotel by moving them into storage. The additional labor costs to move all the televisions on the site may have been greater than simply replacing them. At another site, there was saltwater intrusion in the electrical panel. The cleanup crew removed the wiring in addition to the panel, but the wiring may not have been similarly damaged. The wiring was cut into six-foot lengths for disposal at a great expense in labor costs (John Osteraas, personal communication, October 2008). Isolated examples such as these suggest that the decisions about the amount of reconstruction work at a property, in hindsight, may not be the most efficient in terms of cost. A quantity other than cost (such as time) may be optimized, or there may not be sufficient available information to optimize efficiency when a decision must be made.

3.9 Events with little demand surge evidence

- A great windstorm affected Northern Europe in January 1362. Robert Muir-Wood provided details to the authors in a personal communication. In England, the price of roofing tiles and the wage of labor to repair roofs increased significantly after the storm. King Edward II reacted by requiring that all prices return to the pre-windstorm levels of December 1361. The penalty for failing to reduce the material and labor costs was quite severe: indefinite imprisonment and seizure of portable personal property (Robert Muir-Wood, personal communication, April 2009).

- After the 1989 Newcastle earthquake, rebuilding costs increased by 35% (ASIC, 2005).

- The 1999 Windstorms Lothar and Martin in France caused up to a 30% increase in loss (Risk Management Solutions, Inc., 2000). RMS identified several contributors to this increase: shortages of roofing materials and workers; insurers' inability to verify the large number of claims; and, under pressure from the French government, insurers' agreements to place a ceiling on deductibles and not require a claim adjustment for losses below a threshold. In an RMS reconnaissance report on the storms, Abraham *et al.* (2000) stated that almost three million claims had overwhelmed the local adjusters, and in response, some insurers publicized that claims as high as €7,620 (US$7,725) would not be verified by an adjuster. Abraham *et al.* (2000) also noted a 300% increase of roofing tile prices in some especially hard hit areas near Paris.

- Dennis O'Brien (personal communication, October 2008) estimated 20–30% demand surge following the 1999 Sydney hailstorm. In the (Sydney) Daily Telegraph, Porter and Melki (1999) reported two separate incidents of high materials prices: one man paid A$5.33 per meter for rope, compared to the regular price of under $1; and another man paid $118 for a tarpaulin that could have been purchased at a local hardware store for $34, a 247% increase. Trute and McMillan (1999) quoted a roof-tiling contractor who described a shortage of tilers, resulting in an expected 25% premium on labor costs for tilers.

- How and Hasson (2006) reported that the 2002 Prague Flood and the 2005 Carlisle Flood caused demand surge "comparable to Hurricane Katrina." They noted that insurance companies incurred additional expenses to import claims adjusters because there was an insufficient number of local adjusters after each event.

- Walker (2005) estimated demand surge of at least 25% after the Canberra bushfires of January 2003. He attributed the increase to a local construction boom, which reduced the capacity of the construction industry to perform repair work. Walker (2005) also reported that there was little demand surge after the 2005 Newcastle earthquake. He cited a recession in the local construction industry and the ready supply of construction materials and labor in neighboring Sydney as explanations for the absence of demand surge.

- At the beginning of the 2005 Atlantic hurricane season, RMS reported that construction costs in Florida were 20–40% above their normal levels (Risk Management Solutions, Inc., 2005). RMS explained the higher costs as resulting from the significant demand for construction materials and labor following the 2004 Atlantic hurricane season. The international demand for plywood, steel, and cement also contributed to the high materials costs in the Southeastern United States.

- After Cyclone Larry in March 2006, the Australian Securities & Investments Commission surveyed insurers regarding the effects of the cyclone on their business, with special interest in documenting underinsurance(ASIC, 2007). The surveys showed that approximately 50% of affected homes were underinsured, and the insurers estimated that construction costs increased by at least 50%.

- After the Summer 2007 flooding in the United Kingdom, RMS noted several factors that would increase losses (Stuart-Menteth, 2007). Reconstruction costs would increase because of clean up of sewage spills and material and labor shortages. Repairs were delayed following both the June and July flooding as a result of a shortage of equipment to dry properties.

3.10 Events not known to have produced demand surge

3.10.1 1989 Hurricane Hugo

Hurricane Hugo made landfall on the United States mainland at midnight local time on 22 September 1989 near Charleston, South Carolina. The storm was a Category 4 (Saffir-Simpson Hurricane Scale) at the time of landfall, having previously reached Category 5. A National Hurricane Center Preliminary Report attributed forty-nine deaths to the storm, with twenty-one of those on the mainland United States (National Hurricane Center, 1989). In the same report, the American Insurance Association estimated US$3 billion in 1989 value of insured property damage on the mainland United States and expected that figure to rise. The Insurance Information Institute (2009) ranked Hurricane Hugo as the ninth most costly catastrophe in United States history with an insured loss of $4.195 billion in 1989 value, or equivalently $7.284 billion in 2008 value.

Hurricane Hugo is not known to have caused demand surge. In the United States, the phenomenon of demand surge seems to have been widely acknowledged only after Hurricane Andrew in 1992 and the 1994 Northridge Earthquake. (See timeline in Figure 1.) Hurricane Hugo preceded these events by at least three years. Also, in work for EQE International in 1994 and 1995, one of us (Porter) created a demand-surge model based on a comparison of wind vulnerability functions derived from insurance claims data after Hurricane Andrew, versus vulnerability functions based on claims data from Hurricane Hugo and other prior hurricanes in the Eastern United States. (The vulnerability functions referred to here were curves fit to data of property repair cost as a fraction of estimated replacement cost, plotted against estimated peak 3-second gust velocity at 10-meter elevation at or near the affected properties.) The data from Hurricane Hugo were perhaps slightly higher than the curves based on earlier hurricanes, suggesting little if any demand surge. However, in Andrew, losses at moderate wind speeds were significantly above the pre-Andrew curves, implying that significant demand surge occurred following Hurricane Andrew but only slightly if at all following Hugo.

Despite these observations, there are reports of significant increases in the prices of plywood and roofing felt in the few weeks after Hurricane Hugo. In Atlanta, a major distribution center for timber products in the Southeast United States, the price of standard four-ply, half-inch plywood increased 40-80%, and in Charlotte, the price of standard half-inch CDX plywood rose 60-70% (Setzer, 1989). Setzer indicates that these price increases may have been unusually high because of the low inventory before the hurricane. The following summer, two-thirds of South Carolina's construction labor, carpenters, and painters were repairing damage caused by Hurricane Hugo (Carr, 1990). It is unclear why these observed increases in material prices and demand for labor would not cause significant demand surge after Hurricane Hugo.

3.10.2 1989 Loma Prieta Earthquake

At 5:04 p.m. local time on 17 October 1989, thirty-five kilometers of the northern San Andreas fault system ruptured, producing a moment magnitude 6.9 earthquake. Although the epicenter was located 100 km from the major urban centers, most of the casualties and structural damage were in San Francisco and Oakland. There were an estimated US$6 billion of losses in the public and private sectors (Ellsworth, 1990) and an estimated $7 billion in 1989 value of insured and uninsured property damage, or $12.2 billion in 2008 value (Insurance Information Institute, 2009). The significant structural failures were due to problems of soils. Soft soils can amplify ground motion relative to firm soil or rock. Site amplification probably contributed strongly to the collapse of the Cyprus Structure of Interstate 880 in Oakland (Hough *et al.*, 1990). In the San Francisco Marina District and on the perimeter of the San Francisco Bay, soil liquefaction undermined building foundations, causing them to list significantly.[7] The ignitions of thirty-four fires were directly or indirectly attributed to the main shock or aftershocks (San Francisco Fire Department, 1990). Geotechnical failures caused damage to buried water supply pipe needed to fight the fires, which aggravated the fire losses.

[7] Liquefaction is a process in which the soil particles in loose sand or silty soil near the ground surface and beneath a high water table become suspended in water when shaken. The soil loses the ability to carry vertical loads and flows like a liquid. Buildings founded on these soils can sink, tilt, or experience other costly damage.

Like Hurricane Hugo one month earlier, the Loma Prieta Earthquake is not mentioned as a demand-surge event. Unlike Hurricane Hugo, we have not found reports to suggest any change in construction costs. The Loma Prieta earthquake, although certainly dramatic, seems to have caused an insufficient amount of damage to overwhelm the local ability to adjust insurance claims and repair damage, possibly because it was not a direct hit on the highly urbanized portions of the Bay Area.

3.11 Summary

The evidence for demand surge from historical events presented in this section suggest four important points regarding what demand surge is and is not.

1. Demand surge is not a new phenomenon. This section documents evidence for demand surge in fourteenth century England, the 1886 Charleston and 1906 San Francisco Earthquakes, and the present day.
2. Demand surge is not limited to one region or country. We present evidence for demand surge from Australia, the United States, the United Kingdom, and continental Europe. Although evidence of demand surge is most readily available from these territories, the apparent causes and mechanisms of demand surge are not unique to them. Thus there does not appear to be strong reason to exclude the possibility of demand surge in any region of the world.
3. Demand surge is not unique to one or two perils. Rather, it has been observed following cyclones, earthquakes, floods, hailstorms, windstorms, and wild- or bush-fires. The extent of demand surge may be affected by the peril, if a particular material or skill is in short supply. However, the fundamental problem of supplying the demanded services and goods is the same across perils.
4. Demand surge has many and varied causes that depend on the particulars of each event. Since each catastrophe is unique, there is a unique explanation for demand surge in each event. Nonetheless, themes emerge when considering these events together, rather than the isolated incidents they appear to be. We identify and discuss these themes in Section 5.

4 Current demand surge models

Although there is evidence across seven centuries that losses after catastrophes are greater than losses after small-scale disasters, models to describe demand surge have been developed within only the last two decades. The demand surge models that exist capture parts of the phenomenon, but no published model fully describes how much and why losses increase because of the disequilibrium of demand and supply after catastrophes. Perhaps there has not yet been enough knowledge of demand surge accumulated to develop and test a comprehensive model. Until this body of knowledge forms, demand surge models will be incomplete. Nonetheless, existing demand surge models form the groundwork for future model developments. Current models use observations (similar to the ones collected in Section 3) to inform the mathematical frameworks. This section describes these models and their current states of development.

4.1 Commercial catastrophe models

In a broad sense, a catastrophe model is a tool used to provide a quantitative estimate of risk to a single property or a collection of properties, primarily from natural hazards. Typically, a catastrophe model is used to analyze a primary insurer's portfolio, that is, its set of insured properties, also known as a book of business. Modern catastrophe models apply a series of stochastic events (for example, earthquakes in California, flooding in continental Europe, cyclones in Australia, with locations and severities matching an assumed probability distribution) to the exposed properties and calculate the hypothetical loss to the insurer from the assumed events. Reinsurers and reinsurance brokers routinely use the results of catastrophe models to help them price reinsurance for a portfolio.

A catastrophe model can be divided into four parts: hazard, exposure, vulnerability, and loss modules. The hazard module defines a series of events from natural hazards in terms of the event location, intensity, and probability of occurrence. The catastrophe modeler defines this stochastic event set, based on expectations of events in the next few years, and the user typically cannot modify this event set in a commercial model. The exposure module uses the insurer's information about the locations, types, values, insurance deductibles and other insurance parameters, of properties at risk and organizes it in a database for subsequent analysis. The vulnerability module marries the hazard information (be it peak ground acceleration in an earthquake or wind gusts in a cyclone) at each location in the portfolio with the information about the value and vulnerability of the property to the hazard. The output of the vulnerability module is commonly a damage factor for each property in each event.[8] Finally, the loss module converts

[8] Here, damage factor means the repair cost as a fraction of replacement cost, and ranges from 0, meaning undamaged, to 1, meaning totally destroyed. In rare cases losses can exceed replacement cost. The damage factor is sometimes known as the damage ratio.

the ground-up repair costs to a monetary loss to the insurer: the replacement cost of the property multiplied by the damage factor determines the ground-up loss. If applicable, the terms of insurance policies (for example, deductibles and limits) are applied to the ground-up loss to calculate the insured loss at each property. Since there are many sources of uncertainty in a catastrophe model, the calculated loss is uncertain. (See Grossi and Kunreuther (2005) for a more extensive discussion of catastrophe models.)

As frequently employed, the demand surge component of a catastrophe model modifies the calculated ground-up loss for a property. A demand surge factor multiplies the ground-up loss, either at the individual property level or the aggregate portfolio loss level, by a factor, typically between 1.0 and 1.6. Depending on the model, this factor can be based on the expected loss to the insurance industry as a whole or based on additional information, such as the affected region, peril, and type of property. Often, the model end-user can change this factor or turn off the calculation of demand surge as part of the model's options.

4.2 Regional economic and demand surge models

Researchers interested in natural disasters have repurposed regional economic models to study losses in natural disasters. These models distinguish economic sectors as well as the interactions between them, both locally and with other geographic regions. These macroeconomic models are most often used to estimate societal losses as a direct or indirect result of a natural disaster. Here, "loss" refers to the difference in economic output had there been no disaster versus the output following a disaster.

There are two common, and one less common, types of models used to estimate macroeconomic losses in natural disasters. The two major types are input-output and computable general equilibrium models, and the minor type is an econometric model. Each model has its advantages, disadvantages, and limitations. It is generally believed that estimates from input-output models are an upper-bound, whereas estimates from computable general equilibrium models are a lower-bound on economic loss (Okuyama, 2007). However, there have been few attempts to determine the accuracy of these models for loss estimation (Rose, 2004).

Input-output models predict the production of economic sectors for a regional economy. Generally, this type of model is linear and static. Input-output models make clear the structure of an economy and easily incorporate data from engineering studies of damage; however, these models cannot accommodate feedback of price changes, human behavior, constraints on resources, and substitutions (Rose, 2004). They tend to be very high-level, for example, considering the construction sector as a single entity, as opposed to a complex system of local and imported construction workers, construction contracting firms, suppliers of materials and equipment, etc., operating within a social framework of regulators, building officials, insurance companies, etc., under a set of societal norms that can affect pricing and that can vary geographically and in an economic setting that can vary with the business cycle. Nonetheless, several groups have extended input-output models to study: the total economic impact of earthquakes on lifelines in the conterminous United States (Applied Technology Council, 1991); the effect of electrical power disruptions caused by an earthquake (Rose *et al.*, 1997); the effect of transportation and industrial disruptions because of an earthquake (Cho *et al.*, 2001); the effect of lost productive capital and adaptive behaviors on losses from Hurricane Katrina (Hallegatte, 2008); etc.

Computable general equilibrium models also simulate the behavior of an economy but with an emphasis on prices. This type of model includes feedback interactions among economic sectors. Computable general equilibrium models include an input-output model disaggregated with a social accounting matrix (Rose, 2004). The social accounting matrix distinguishes flows in an economy according to socioeconomic groups or institutions. The social accounting matrix can describe the differential impact of a natural disaster on identified economic agents. The computable general equilibrium model overcomes many of the limitations of the input-output model previously described, but computable general equilibrium models are designed for long-term equilibrium analyses (Rose and Liao, 2005). Also, the uncertainties after natural disasters may not allow the optimizing behavior assumed in computable general equilibrium models (Okuyama, 2007). Rose (2004) recommends computable general equilibrium models over input-output when modeling the impacts of natural disasters, except if the recovery period is less than one week. Computable general equilibrium is more data-intensive than input-output, and so it tends to be more costly to apply to natural disasters.

Econometric models describe the high-level operation of regional economies. This type of model utilizes time-series data of significant economic metrics. Unlike input-output and computable general equilibrium models, econometric models can be used for forecasting. However, this type of model is not often used for economic loss estimation because of the large data requirement and difficulties distinguishing losses directly caused by the event from losses caused indirectly (Rose, 2004).

Hallegatte (2008) explicitly included demand surge within an input-output model framework. The study assumed that demand surge is "driven by the unbalance between the large demand in the reconstruction sector and the insufficient production capacity." Commodity prices are assumed to be proportional to the underproduction of the commodity, and wages are assumed fixed when determining profits in economic sectors. In the simulation of post-

Katrina reconstruction in Louisiana, Hallegatte (2008) found the total reconstruction costs to be US$121 billion as opposed to $107 billion assuming pre-Katrina price levels—a 13% increase that the author attributed to demand surge. Although demand surge was included, the purpose of the study was to assess the change in value added to the Louisiana economy because of Hurricane Katrina, considering direct and indirect losses.

Risk Frontiers, a group of Australian researchers interested in natural hazards and risks, developed a basic model of demand surge, or using their terminology "post-event claims inflation" (McAneney, 2007). Their model uses estimates of total market losses and average loss ratios, disaggregated by "major" and "lesser" population centers. They use historical, insurance industry losses and adjust for changes in population, wealth, inflation, and building codes. This model was an initial attempt to understand how insured losses increase after large-scale disasters.

The Florida Public Hurricane Loss Model predicts losses caused by Atlantic hurricanes and includes a demand surge model. The Florida Office of Insurance Regulation funds the model, and researchers at the Laboratory for Insurance, Economic, and Financial Research at Florida International University lead the model's development. According to the limited available documentation, the demand surge component of the Florida Public Model applies "weighted average demand surge factors" to the loss from each event (Unknown, 2009). The model assumes that demand surge is affected by the insurance coverage (that is, the fraction of properties that are insured for the relevant peril), region, and the total statewide loss without demand surge. This demand surge model "involves examining the gap between forecasted post-storm indices and actual post-storm indices." The researchers validated the model with the following data: construction cost indices for Florida ZIP codes from Marshall & Swift; the household furnishings and operations index of the Consumer Price Index for Miami-Fort Lauderdale; and insured losses caused by Hurricanes Andrew, Charley, and Frances.

As mentioned earlier, one of us (Porter) participated in creating a simple macroeconomic demand-surge model that was incorporated into the EQECAT commercial catastrophe software. In the mid-1990s the group at EQECAT hypothesized that demand surge might result from: opportunistic increases in prices for labor, retail and wholesale materials, and equipment; increased physical damage because of delayed temporary repairs to prevent water intrusion; substitution of heavier materials because of limited supplies, aggravated by damage to local construction materials, and substitution of union for nonunion labor; and increases in effort required to perform repairs because of access difficulties and the need to bring repair resources from greater distances. We created an empirical demand-surge model for United States hurricanes: a factor that is a trilinear function of the ratio of total estimated societal repair cost to the estimated inventory of retail and wholesale construction materials within a given radius of landfall. When the ratio was less than that estimated for Hurricane Hugo, no demand surge was assumed to occur. When the ratio reached or exceeded that of Hurricane Andrew, demand surge was assumed to reach a maximum value. The effects of demand surge at its maximum value were estimated at the per-property level, based on the observed differences between vulnerability functions from Hurricane Andrew claims data and ones based on prior hurricanes in the Eastern United States and Gulf Coast. Separate demand-surge functions were developed for residential and commercial insurance losses. The EQECAT model has subsequently developed, but the details of the changes do not appear to have been published.

5 Common themes of demand surge

Historical natural disasters are deterministic—they are fixed, even if the details of what occurred are not known—whereas future disasters are uncertain. Looking back on a catastrophe, the explanations for local supplies not meeting the demands may be readily apparent. However, predicting the disequilibrium of demand and supply in future large-scale natural disasters can be done only with uncertainty. We expect that, as the understanding of demand surge as a socioeconomic phenomenon improves, predictions about demand surge will become less uncertain.

This section qualitatively describes explanations for the disequilibrium between supply and demand of materials, labor, equipment, and financing after catastrophes. On the whole, these explanations describe cost increases, but there are reasons why these increases may be offset. The observations in Section 3 from historical events form the basis for these generalized explanations. To put some structure to the discussion, we group the explanations into broad themes. We use the word "theme" intentionally to indicate that, in a particular event, the specific expression may be unique, but nonetheless, there is an overarching idea common to demand surge in many past events.

At this qualitative stage of development, we do not indicate the relative significance of each theme. We describe them without assigning more weight to one over another. We suspect that relatively few themes contribute the most explanatory power for demand surge, and the remaining themes exert little if any influence. Our purpose in identifying and describing these themes is to use them as hypotheses to test our understanding of demand surge. We expect to take each in turn and find specific evidence to accept or refute the ability of each theme to explain, and thus predict, demand surge.

5.1 Event definition (A decoy theme)

The language of natural disasters uses a shorthand to reference specific historical events. Often the reference is simply a named event, such as "Andrew" or "Loma Prieta," but the event name may be supplemented with the year and peril, for example "the 1999 Sydney Hailstorm" or the "the 2007 U. K. Flooding." These references conjure images and facts unique to these events and the specific location. An event may have been significant for a developing scientific field (for example, the 1971 San Fernando Earthquake for earthquake engineering) or an event may have been psychologically significant for a region (for example, Hurricane Katrina in 2005 for the United States). These references are a common way to conceptualize an event as a combination of peril, location, and year of occurrence. This standard language immediately suggests characteristics that may inform our knowledge of demand surge. Does the peril affect demand surge? Does the location or year affect demand surge? Based on our current understanding, more fundamental issues may explain and predict demand surge better than the peril, year, and region.

If we understand demand surge as the meeting of demand for materials, labor, equipment, and financing with their supplies, then knowing the peril may not directly provide information on any resulting demand surge. Different skills, materials, and equipment will be in demand depending on the peril. For example, a hailstorm may put roofers and asphalt roof shingles in high demand, but a flood may require a large volume of equipment to dry buildings and large quantities of carpeting and gypsum wallboard for repairs. However, the fundamental problem of supplying the demanded materials, labor, and equipment remains, independent of the peril. If the peril itself does not provide information about demand surge, then data from hurricanes might be combined with data from flood events to predict demand surge after earthquakes.

Reconstruction financing can depend on the peril. Private property insurers do not indemnify all perils. For example, a standard homeowner's policy covers most fire, wind, and hail damage but not seismic or flood damage. Governments may provide coverage in hazardous areas not served by private insurers. Here, the peril may affect demand surge because the source of reconstruction financing depends on the peril: insurers may be better able to provide immediate funds, whereas a government entity may provide delayed or reduced compensation. For example, under the standard flood insurance policy dwelling form, the United States National Flood Insurance Program pays replacement costs only if: the insured property is a single-family dwelling and the policyholder's principal residence; and the insurance is 80% or more of the full replacement cost or the maximum available (Federal Emergency Management Agency, 2000, pp. 16–18). Otherwise, the NFIP pays actual cash value,[9] except for mobile homes and travel trailers. The NFIP always pays actual cash value for detached garages, personal property, appliances, carpets and pads, outdoor equipment, and property abandoned as debris. Sufficient and immediately available reconstruction financing enables the demand for materials, labor, and equipment. Thus, the demand for materials, labor, and equipment and the supply of financing may provide more fundamental explanations of demand surge after an event than which peril is involved.

The region affected by a disaster may be similarly misleading. The "remoteness" of an area has been suggested to explain some past demand surge events. Isolated populations, such as those in Darwin, Australia, or on Kaua'i Island in Hawaii, may pay significantly more for reconstruction following disasters. However, geographic remoteness may not be a fundamental concern. In terms of demand surge, the ability to supply an affected area determines its "remoteness." In Hurricanes Andrew and Katrina, contractors and materials were also brought into the affected region. The relevant question then is not how far away, but more immediately, at what cost the materials, labor, equipment, and financing can be brought to the affected area. Thus, information on the capacity and costs of transportation and of temporary housing for workers seems more fundamental than distance.

The particular region may also inform an assessment of the pertinent socioeconomic issues for demand surge. Although the demanded materials, labor, equipment, and financing may be available and readily transported, local authorities may restrict the free movement of supplies and prices. Authorities may choose to set prices or place ceilings through anti-price gouging laws. The migration of labor from outside an affected area may be restricted or entirely prohibited. Thus, demand surge may vary by region, not because of physical geography, but rather because of the fundamental questions of physically supplying an area and any restrictions on the flow of those supplies.

Like the peril and region, the year of an event may not be fundamental to demand surge. Rather, the year may be a proxy for issues such as materials supply and the capacities of transportation systems. For example, materials suppliers may now rely on just-in-time-supply chains, rather than inventories. Thus, the reconstruction after recent disasters may be more vulnerable to materials shortages than after disasters of twenty or fifty years ago. In regions with recently well-developed transportation systems, however, the ease of moving materials may offset the problem of smaller inventories. Again, the year *per se* may not provide fundamental information about demand surge.

The sequence, or timing, of events may also not directly affect demand surge. A single event, isolated in time and location from another event, might be seen as a standard disaster to which other disasters can be compared. Thus, it can be used in comparisons with the more unusual catastrophe-following-catastrophes or clustered events. For a

[9] Actual cash value is the cost to replace damaged property at the time of the loss, less the value of its physical depreciation (Federal Emergency Management Agency, 2000, p. 1).

catastrophe following catastrophe, there is the inherent problem of widespread concurrent causation.[10] Insurance adjusters would be asked to distinguish the source of damage, making their work more difficult (and thus more expensive) after a catastrophe following catastrophe than after a single event.

A cluster of events raises additional considerations. At the regional level, the demand following a first event may have exceeded the local supplies, and efforts began to meet this demand. Thus, a second, third, or fourth event may not cause a disequilibrium in supply and demand as large as the original disruption. Also, events subsequent to the first in a cluster may not cause as much damage because many properties have not been repaired after a previous event. In this case, the demand for materials, labor, equipment, and financing may not increase as much after a subsequent event as after a first event.

In summary, the typical characterization of an event according to its peril, region affected, and year of occurrence does not appear to be useful for understanding demand surge. Our current understanding suggests that there are more fundamental questions surrounding the demand and supply of materials, labor, equipment, and financing, which are more directly relevant to a qualitative and quantitative description of demand surge. We discuss these issues in the following sections.

5.2 Amount of repair work

The total amount of repair work in a region partly defines the "demand" of demand surge. Conceptually, the event causes initial damage at a property according to the environmental excitation and vulnerability of each property exposed to loss. Decisions of all stakeholders made before and after the event affect what repairs are done and in what order. Whether the property is insured is a major factor in determining the amount of repair work actually accomplished and how quickly the repairs are effected. The amount of reconstruction work regionally is a sum of the repair work at individual properties. Understanding how much work is done at an individual property informs the understanding of the amount of work regionally.

Individual property owners may attempt to reduce damage to their properties in disasters of any size. A property owner may take measures before the event to prevent damage or make emergency repairs immediately after the event to reduce additional damage. The scale of the disaster, however, may affect these efforts. Damage may accumulate in clustered events, possibly negating any efforts of the property owner. In a catastrophe, properties may be more likely to decay because of neglect (for example, mold can flourish in untended, water-damaged buildings). Properties damaged in a catastrophe may be more prone to additional damage because, for example, local authorities do not allow the population to return soon after the event (as in Hurricane Katrina), or property owners do not have immediate financing for repairs, or temporary patching materials may be in short supply. Thus, the amount of damage at an individual property may be greater because the property was damaged in a large-scale natural disaster.

The level of repair required by building codes, and enforced by the building authority, may also affect the amount of work at a property. The building code in force during the reconstruction period may require a heavily damaged structure to be built to a higher standard than what was required when it was originally built. The rebuilding requirements affect the amount and type of construction materials and the necessary skill of the labor. Although newer building codes tend to become more strict, there can be exceptions: building codes may not be enforced (for example, before Hurricane Andrew (Sirkin, 1995, pp. 6–8)), or the local building department may temporarily suspend certain provisions to allow for speedier recovery (for example, after Hurricanes Iwa and Iniki (Chock, 2005)). Furthermore, insurers or property owners may not have accounted for changes in building code requirements when determining the replacement cost of properties. This is properly a valuation problem for the insurer, but it can masquerade as demand surge in catastrophe models, which usually rely on multiplying a damage factor by (in this case, an erroneously low) replacement cost.

Judgment may also affect the amount and speed of work performed at a damaged property. Contractors and insurance claims adjusters may be pressured to quickly define the amount of work to be done. The adjuster might have a long list of properties to visit, making each loss assessment quickly and carelessly (Thomas, 1976, p. 123). Contractors and claim adjusters may not have enough, or the right, information available about repair work at a property at the time of a repair estimate or claim adjustment. An initial assessment of damage may not identify all damage, and unanticipated damage may be encountered only after demolition and repair work have begun. These types of judgments about the amount of repair work following a catastrophe must be made but may not be fully informed.

5.3 Timing of reconstruction

The time when reconstruction begins at a property may affect the final loss. Delayed repairs may be more expensive because of deterioration of, or additional damage to, the property. Also, labor wage rates, contractor overhead and

[10] Concurrent causation results from more than one source of damage to a property. For example, both wind-driven water and rising water can damage a house in a hurricane, but only damage caused by wind-driven water may be covered under a standard homeowners insurance policy.

profit, and materials prices can change during the reconstruction period. These issues may be more significantly affected by the regional factors described in the following paragraphs than by characteristics of the property.

A backlog of properties damaged in a previous event or a construction boom in the region may delay work at a recently damaged property (for example, during the 2004 and 2005 hurricane seasons in Florida (Risk Management Solutions, Inc., 2005)). The organization of the reconstruction effort, if any, may determine the prioritization of work. Contractors may determine a work schedule on a first-come-first-served basis, or they may prioritize work according to potential profit. The government may prioritize the repair of damaged properties, as was the case after the 1999 Sydney Hailstorm (Henri, 2000, p. 17). If the general population evacuated, there may be a delay in reconstruction until there is a critical mass of people. The disruption of electrical power may also affect the timing of rebuilding, unless there are sufficient supplies of portable generators.

Debris removal can be critical before reconstruction can begin at a property. Storm surge in Hurricane Katrina pushed substantial quantities of debris onto properties near the shore along the Mississippi coast, hindering access. In addition to disposing of structural components and building contents, there may be hazardous materials requiring special attention, as was also the case in Katrina. Debris removal may also be hampered by insufficient landfill space.

The efforts of local and national governments may affect the timing of reconstruction. Rebuilding may not begin until the local government allows the release of building permits. For example, as of 30 June 2008 in Cedar Rapids, Iowa—seventeen days after flood-waters crested—the building department was issuing plumbing, electrical, mechanical, and building permits for flood repairs outside the 500-year floodplain only (James Thatcher, personal communication, June 2008). The Cedar Rapids building department expected to release plumbing and electrical permits a few days after this date, but they would not grant building permits until the city decided on a reconstruction plan. For properties in the 100-year floodplain, the city had to consider the guidelines and regulations of the National Flood Insurance Program. As of 30 June, it was not clear whether the city would allow any rebuilding on the 100-year floodplain or adopt the NFIP requirement that properties with damage valued over 50% of the structure's value be rebuilt at least one-foot above the 100-year floodplain. The city recommended that property owners clear debris, dry the structure, and wait for a city council decision. The approach taken in Cedar Rapids suggests that local governments can affect the progress of reconstruction. The municipality may actively influence repairs and rebuilding, or it may passively allow reconstruction to be determined by property owners, financing, and the availability of materials, labor, and equipment. Finally, the building department may be overwhelmed, and permitting and inspections may be delayed (for example, after the 2004 hurricane season in Florida (Weintraub, 2005)).

5.4 Costs of materials, labor, and equipment

The local supplies of reconstruction materials, labor, and equipment are critical to rebuilding after catastrophes. These supplies are the most direct inputs to reconstruction: they physically effect the repair and rebuilding of a city. Thus, materials, labor, and equipment must all be available locally when they are needed.

Establishing the cost of repair materials at a property requires a list of materials, the amounts needed, and unit prices. The specific materials used for repairs may change if the typical materials are not locally available; 5/8-inch plywood may be substituted for standard half-inch plywood if it becomes unavailable. The unit price paid for materials may vary by property. The prevailing materials prices in an affected area are averages and may mask significant price volatility. (For example, Section 3.5 documents several different quotes for 5/8-inch plywood in Central Florida after Hurricane Andrew.) Furthermore, claims adjusters anticipate materials costs by using price lists. Thomas (1976) described how United States insurers handled catastrophe claims circa 1976: "As a result of their experience in numerous catastrophes since the 1930s the insurance companies have formulated *catastrophe plans* to better organize and supervise the handling of claims.... One of the first steps taken by the administrators of a catastrophe plan is to arrange for a conference with local builders and contractors associations to discuss and agree when possible on unit costs for various building items. These unit costs are published and then used as a guide by the adjusters and builders in estimating the losses in the area" (pp. 122, 125). Currently, claims adjusters rely on estimating software to provide price lists for repair materials. Xactware is the leading provider of pricing information for United States insurers, but it cautions the users of its price lists: "Xactware makes every effort to ensure pricing information ... represents market costs at the time of publication. Since actual market prices can vary and may change rapidly, and since many factors can affect the cost of a project (including—but not limited to—labor, equipment, and material costs as well as the rates and application of sales tax), we strongly recommend customers monitor their local markets for any such changes and adjust their estimate pricing as deemed appropriate" (Xactware, 2010). Although collecting material prices to establish the prevailing rates is routine in the construction industry, anticipating material costs at a damaged property after a catastrophe is much more problematic.

The cost of labor has two components: the wage rate and the total amount of work. Meeting the demand for skilled and unskilled labor likely drives the wage rate. According to basic microeconomic theory, if the demand for labor exceeds its supply, and there are no substitutes, the labor force can command a higher wage rate. Immediately after a disaster, there is a great need for labor-intensive clean-up and debris removal, which can be supplied by unskilled and skilled labor. In the following weeks, however, skilled labor tends to become more important, and the type of disaster determines what skills are required. For example, after a major hailstorm, roofers and siding installers will be highly sought after, whereas after a flood, the primary demand may be for flooring and wallboard installers. Certainly, in both examples other trades will be demanded, but nonetheless, certain construction skills will be in greater demand than others. Furthermore, the skills demanded may vary with the progress of reconstruction. Initially, there may be high demand to repair damaged exteriors, such as roofs and siding, to prevent further damage or deterioration. Eventually, interior finishes will be repaired or replaced, requiring the associated skilled labor.

The workforce for reconstruction following a catastrophe can be a mix of native and visiting labor. Reconstruction efforts may rely initially on the local labor supply, since it is already on site and familiar with the local situation. However, this local labor may be augmented by outside labor if there appears to be sufficient demand. The local labor supply may be reduced because of evacuation or the widespread destruction of housing.

Although we can understand prices and wages as the result of meeting demand with supply, disasters can change how individuals set their prices or wages. Some people elect to provide free or reduced price materials and services. Others may fix their costs at the pre-event levels, as one of us (Olsen) observed after the United States Midwest floods of June 2008. Some may choose to maximize their profit. The relative mix of these approaches to setting costs may vary by geographic region. Profit-taking may be socially unacceptable in some communities, whereas it is condoned in others.

Local, state, or national governments may enforce wage or price controls, effectively setting an upper-limit on reconstruction costs. Anti-gouging regulations are fairly common. For example, after the 1995 Hurricane Marilyn in the United States Virgin Islands, the local government widely publicized its anti-gouging position (Murphy, 1995). Similarly there may be trade restrictions on the movement of materials and equipment between regions, effectively making their transport, if allowed, more expensive.

5.5 Contractor fees

Typically in developed countries construction contractors perform repairs to damaged buildings. In such cases, contractors' fees contribute to the costs of reconstruction. In the aftermath of a catastrophe, there may not be a competitive environment for contractor services. The total number of contractors may be affected by the local supply and by the willingness and ability of outside contractors to travel to the affected area. Contractors may change their bidding strategies or their rates for overhead and profit margins. Some contractors may seek the highest margins, whereas others may not change their rates. Contractors typically increase overhead and profit as a buffer against risk, so the more uncertain material and labor costs and availability, site access, etc., the greater will be the repair costs.

A government may also constrict the supply of contractors by prohibiting free movement into an affected area. For example, Florida requires that contractors be registered with the local jurisdiction or certified by the state (Florida Statute, 2009b, §489.117). Following the 2004 Hurricanes Charley and Frances, Governor Jeb Bush allowed local building departments to issue temporary, local specialty licenses "for the repair and installation of roofs made of wood shakes, or asphalt or fiberglass shingles" to ensure sufficient supply of roofers (Bush, 2004). Applicants for these licenses must also provide proof of workers' compensation compliance, and public liability and property damage insurance coverage. (Broward, Miami-Dade, and Palm Beach Counties decided not to issue specialty licenses (Building Code Compliance Office, 2006).) By establishing licensure, workers' compensation, and insurance requirements, the State of Florida attempts to restrict the labor supply to qualified contractors. One likely result of limiting the supply of labor is an upward pressure on contractor fees.

5.6 General economic considerations

Sections 5.4 and 5.5 raise issues specific to material prices, labor wage rates, equipment costs, and contractor fees, but the general state of the economy may affect these as well. The economic situation before an event may affect the costs of materials and services. A pre-disaster construction boom may increase costs to rebuild damaged properties because contractors are already in high demand. A lull in construction increases the supply of available contractors, and thus competition may keep costs low. In addition to the local demand and supply of materials, labor, equipment, and financing, the national and international supplies may also influence the local costs. In the immediate aftermath of an event, speculation or panic buying may increase the volatility of reconstruction costs, and this uncertainty may raise costs because suppliers require a premium to cover their risks.

During the reconstruction phase, government and private sector responses may also affect construction costs. Costs may be reduced because of the availability of free or reduced-price services. Governmental or non-governmental aid or supplies may also be available, offsetting any inflated pricing. Low interest government loans may allow reconstruction that otherwise would have been delayed or cancelled. (The converse can be seen in New Orleans after Hurricane Katrina, when the lack of government financing delayed some repairs (Walsh, 2006).)

5.7 Insurance claims handling

There are several ways that an insurer can handle the large volume of claims after a catastrophe. An insurer may decide not to verify claims under a certain value, as noted regarding the 1999 Windstorms Lothar and Martin in France. An insurer may have a preexisting agreement with a contractor stipulating material and labor costs and a margin for overhead and profit. Most commonly, an insurer sends a claims adjuster to the property to identify the damage and estimate the loss. For the same damage at, and policy conditions for, a property, each of these insurance claims handling methods may result in a different loss to the insurance company.

Regarding the typical procedure of verifying the claim with a claims adjuster, the characteristics of the adjuster or his methods may affect the loss as well. A well-trained and experienced adjuster tends to adjust claims lower than an inexperienced adjuster, for the same damage (Kirk Beatty, personal communication, May 2009). A person unfamiliar with the type of damage may not properly adjust the claim. The adjuster's employment may affect his adjustments: an adjuster employed by the insurance company may be more motivated to control the insurer's costs than would an independent adjuster. An adjuster may not be able to distinguish damage from a previous event or from normal wear and tear. Some policies and events require the adjuster to distinguish the cause of damage (for example, earthquake shaking versus long-term foundation settlement), and making these distinctions can require special expertise. Also, evaluating partial damage is more difficult than a total loss.

Currently, many adjusters use software to estimate reconstruction costs. An adjuster unfamiliar with the software may use it inappropriately (Postava, 2008). The data contained in the software may be designed for repair under ordinary conditions, and thus be inappropriate for estimating losses in catastrophes. The adjuster may not know how to properly account for rebuilding after a catastrophe.

The insurance adjusters may be pressured or influenced while making their adjustments. The adjuster may have to handle an unusually large number of claims in a short period of time. The property owner may pressure an adjuster to close a claim or reconsider her adjustment. The insurance company may provide guidance to the adjuster regarding the unique conditions of the event, for example, the prevailing material and labor costs, which likely affects what the adjuster assumes in her estimates of insured losses.

5.8 Decisions of an insurance company

After catastrophes, insurance companies may make decisions that affect their losses. Insurers have faced pressure from several sources in the aftermaths of past disasters, including their clients, competition, and local and national politicians. The judiciary can also influence insurers' decisions through decided or anticipated judgments on insurance disputes. An insurance company may decide to pay for damage it deems excluded in the policy or not enforce multiple deductibles in clustered events. These types of payments may be at the discretion of the insurer and made to avoid costly litigation or maintain a good public image. Depending on its market segment and business model, an insurer may take great effort to minimize the loss paid on each claim, or promptly pay claims on its policies with little verification, or take a path between these extremes.

This issue of insurers' decisions in the aftermath of a catastrophe is on the border of what is and is not demand surge. In this instance, we understand demand surge to be the demand for reconstruction financing conflicting with the limited supply from insurers. These decisions may affect the limits to this supply.

6 Conclusions

There are several, inconsistent definitions of demand surge, none of which is sufficiently precise to define a clear phenomenon. "Demand surge" has been used to refer specifically to the increase of materials prices and labor wages. Other sources expand this definition to include specific causes of higher costs, for example, construction and insurance services and the expansion of insurance coverage. Still other sources understand demand surge to be the difference between the expected (or modeled) loss versus the actual loss. Without a standard, precise definition, there is confusion about demand surge as a socioeconomic phenomenon, as well as various metrics of demand surge.

Historical events provide anecdotal evidence for demand surge. In any particular natural disaster, there is a specific and unique explanation of demand surge. Considering many past large-scale disasters, common themes emerge as plausible explanations for why demand surge happens. We identify the following themes: total amount of repair work; timing of reconstruction; costs of materials, labor, and equipment; contractor overhead and profit; the general economic situation; insurance claims handling; and decisions of an insurance company. These themes are qualitative, proposed explanations for demand surge, and thus, they are also hypotheses to be tested in future work. The development of these themes provides a novel, mechanistic approach to the demand surge problem.

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A Appendix

From Hosford *et al.* (1906, pp. 24–25):

> It is utterly impossible for one who was not in San Francisco during the busy days and nights immediately following April 18th to comprehend the enormous amount of work attending the formation of some general plan of action to be adopted by the companies in the settlement and adjustment of their losses which would meet with universal approval. Particularly so was this the case in view of the uncertainty of the attitude of many of the companies before knowing the real facts and the securing of their records to find out just where they stood. In the list of 1,337 losses ("Exhibit B") accompanying this report, therefore, no adequate conception can be made of the enormous amount of detail work involved. The Committee of Five, however, believe that the companies which they represented will be satisfied with the results achieved. But the Committee of Five wish to state to the 35 Companies generally that had concerted action been taken by the companies prior to July 10, 1906, the date of the opening of the Committee of Five's offices in the Ferry Building, or nearly three months after the happening of the disaster, much better results could have been shown, and at a less expense, besides creating a better feeling amongst policy-holders, which at that time would have facilitated adjustment and probably resulted in savings to the companies, for, in the excited state of mind of the people of San Francisco following the calamity that had befallen them, in addition to the heavy loss already sustained, was added the uncertainty of what the insurance companies would do and created local sentiment against insurance companies generally, and the fire insurance companies in particular, which was hard to overcome and made the work of adjustment for the Committee much more difficult than would have been the case had unanimity of action been arrived at by the companies earlier. Public sentiment, however, changed rapidly after the organization of the Committee of Five, when it was found that that was not an organization for delaying adjustments, but rather to complete them and approve for payment all losses immediately after adjustment. Very little difficulty was thereafter experienced and confidence in the companies was, to a great extent, re-established.
>
> Despite the unsettled and excited conditions prevailing, and the dissatisfaction engendered and fostered in certain directions, the Committee of Five found claimants generally to be fair, patient and honest, the exceptions emphasizing the rule. The people of San Francisco, in common with the companies, lost enormously by this unparalleled catastrophe, and it is equally creditable to the companies and their assured that the heavy losses sustained have been disposed of within a reasonable time and upon honest and mutually satisfactory terms. If some companies have acted badly the Committee of Five feel sure that the people will be sufficiently discriminating in their judgment not to hold all the companies responsible; and the experience of the Committee shows that there was not a greater amount of fraudulent claims presented than is to be found under normal conditions in any big city.
>
> It was found, however, that policy-holders generally prepared their statements of claims hastily in order that their proofs of loss could be filed within the time prescribed by the policy conditions because of the refusal, at the outset, by many companies to extend the time for the rendering of such proofs; and it has been generally stated that proofs of loss for nearly 95% of the losses had been filed prior to June 18, 1906. The fact that in those cases where the books of account were not destroyed in the fire but could not be gotten out of the vaults, safes, etc., where they were deposited for many weeks after the fire made it almost impossible for assured to accurately prepare their statements within the sixty days prescribed in the policy conditions. Therefore, doubtless, many claimants innocently exaggerated their statements in their haste to file them with the companies; and there was no way of determining which claims were so submitted, and those which were not, without the services of an expert accountant to give the necessary time to carefully examine the books of account of the assured. Of course, where the books of account were destroyed services of this character were not required. There are two cases in particular, however, which came before the Committee of Five's attention where the employment of expert accountant's services in examining assured's books of account showed the wisdom of this action, the reduction in the amount claimed in these cases amounting to nearly $100,000, which would seem in itself sufficient justification for the employment of expert accountant's services, and raises the question whether there were not many more such cases which could have been discovered if the companies had united upon the employment of a force of accountants to do this class of work in conjunction with the adjustments at the beginning, thereby giving more time to the adjusters to pursue their part of the wok in the multitude of losses which had to be handled, whereas, as a rule, but little time could be given to the matter of examination of accounts by the adjusters themselves. These remarks need in no way be regarded as a criticism of the prerogatives of the adjusters nor their ability to do the work of accounting themselves, but rather as a suggestion that sufficient time could not be given by them under the circumstances to make such an examination of the books of account of the assured as could have been done by expert accountants especially employed for that purpose in the same way and for the same reasons as are expert builders, machinists, electricians, and

other “specialists” who are usually employed by the companies in an advisory capacity to their adjusters.

It is true that the companies were overwhelmed with the enormous number of claims submitted to them and which could not be disposed of within sixty days after they were filed; and, in fact, required many months longer in order to do so, and under the circumstances it has been questioned as to whether under the terms and conditions of the policy any company was entitled to deduct discounts for immediate payment of losses in view of the lapse of so great a time in the taking up of the adjustments by the companies themselves, except where these voluntary discounts were conceded by the assured in consideration of an immediate settlement of their claim with the idea, presumably, of avoiding closer investigation of the claim and the possible discovery of further damage to the property from causes other than by fire and which up to that time had not been developed.