What We Know about Demand Surge: Brief Summary

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Abstract: Demand surge is a process resulting in a higher cost to repair building damage after large disasters than to repair the same damage after a small disaster; this higher cost can be an additional 20% or more. It is of interest to insurers, regulators, property owners, and others. Despite its importance, demand surge has no standard definition or generally accepted predictive theory of its mechanisms and quantitative effects. By studying the circumstances of natural disasters that did and did not cause demand surge, common explanatory themes emerge from these historical events that may describe why and how much losses increase in some disasters. 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. The development of these themes will aid in constructing a mechanistic, empirically supported approach to modeling demand surge. **DOI:** **10.1061/(ASCE)NH.1527-6996.0000028.** *© 2011 American Society of Civil Engineers.*

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Introduction

Demand surge is an issue for individuals and institutions that sustain losses in large-scale 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 to 40% following Hurricane Katrina (Guy Carpenter 2005) to 50% after Cyclone Larry [Australian Securities and Investments Commission (ASIC) 2007]. For specific materials and labor items, news reports have documented price increases of 30% for oriented strand board following Hurricane Katrina (Grogan and Angelo 2005) to a 2,000% increase for securing a tarpaulin to a damaged roof after the 1999 Sydney hailstorm (Sweetman and Morris 1999). The higher repair costs at each property result in a greater loss for an insurer that indemnifies many properties in an affected area. For a single insurer, this 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).

Commercial catastrophe modelers, such as Applied Insurance Research (AIR), EQECAT, and Risk Management Solutions (RMS), develop models of demand surge. One of the writers (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 keep the details private as intellectual property. As a result, there seems to be no independent, public examination of the commercial demand-surge models to test their methods and duplicate their results. The Florida Commission on Hurricane Loss Projection Methodology does assess commercial catastrophe models to approve their use for rate filings in Florida, but the modelers' methodologies remain confidential (Florida Statute 2009). Because these models are proprietary, there is no synergy of the modelers' insights into demand surge.

Demand surge bedevils consumers and those government agencies that serve a consumer-protection role. Since proprietary models are somewhat 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 conflict between insurers, policyholders, and consumer advocates.

This paper develops an understanding of demand surge as a socioeconomic phenomenon associated with large-scale natural disasters. It provides evidence of demand surge as the outpacing of supplies (of reconstruction materials, labor, equipment, financing, or some combination of these) by their respective demands after a natural disaster. This introduction has described the problem. Subsequent sections will discuss some terminology and definitions, followed by descriptions of existing models of insured and economic loss after natural disasters, with particular attention to demand surge. Finally, some common themes of demand overwhelming supply will be distilled from observations of historical natural disasters. These themes provide possible explanations for the mechanics of demand surge, and they inform a quantitative model the writers are now developing. This work does not fully and completely describe and explain the phenomenon of demand surge. Rather, it summarizes the current state of knowledge and collects qualitative evidence for demand surge from historical events. This paper condenses a longer report (Olsen and Porter

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2010), in which the reader can find a more complete discussion of the issues presented in this paper.

Terminology

"Demand surge" has various, imprecise definitions, and the term has various, inconsistent connotations. The basic understanding of demand surge is exemplified by the definition of the Actuarial Standards Board: "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 quantities of materials, labor, and services. In other words, there is no clear distinction between the underlying phenomenon and the metric used to measure the phenomenon.

Other definitions and usages of "demand surge" limit the scope of the term. Consider the following two quotations from the insurance industry literature: "With demand surge, insured losses creep upward due to the increased price of construction materials and labor following large losses such as Katrina and Rita" (Howard 2005); and "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" (Federal Alliance for Safe Homes and The Actuarial Foundation 2006). Here, demand surge refers specifically to temporary increases in materials prices and labor wages following large-scale natural disasters. 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.

Furthermore, there is no consensus on what specific material and labor costs contribute to demand surge. Labor costs are the wages paid to workers in the construction industry. However, to be amenable to study, one 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 or wholesale prices charged by or to the construction industry for the materials required to repair the damage. Again however, the geographic and temporal scope of the products, and which ones, must be crisply defined before it is practical to test any hypotheses about their influence on demand surge.

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, there is no apparent reason to limit the definition to increased materials prices and labor wages when there are other reconstruction resources that may also be in short supply after large-scale natural disasters, such as equipment, financing, and the number of construction contracting firms, which can be the primary provider of labor at reconstruction sites.

"Demand surge" has also been used to explain the difference between an expected, or modeled, loss and the realized, or actual, loss in a large-scale natural disaster. For instance:

> 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 (Munich Re Group 2006).

Using "demand surge" to refer to unexpected losses can obscure alternate explanations for the difference between expected and realized losses. Examples 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 the true values 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" as an underlying but unquantified cause of the observed discrepancy raises the question: 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? Is demand surge a carpet under which we sweep the dust of modeling error?

Most observers' use of "demand surge" is quite general and similar to the definition of the Actuarial Standards Board presented previously. 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 large-scale natural disasters. But additional explanations are offered that augment the limited definition. For example:

> With a major windstorm, overall losses increase not only because of economic shortages in roofing materials and workmen, but because insurance companies are unable to police the volume of claims. [Called "loss-cost inflation" or "demand surge."] For the largest of all catastrophic losses, politicians put pressure on insurance companies to relax their internal rules and fast track the processing and repayment of claims (Risk Management Solutions, Inc. 2000).

In this example, the quote offers increasing material and labor costs first to explain larger losses in large-scale natural disasters and then provides additional, specific explanations. 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, in which repair delays or shortages of alternative facilities inhibit return to normal operations?

Several general definitions or usages of "demand surge" add "services" to the short list of labor and materials to explain higher costs after large-scale natural disasters, but the reference to services is unclear. For example, precisely which services ought to be considered in the following quote: "Demand surge [is] the increase in costs of materials, services, and labor due to increased demand following a catastrophic event" (AIR Worldwide Corporation 2007)? "Services" might refer to expenditures by insurers to claims adjusting firms, or by insurers to construction contracting firms (over and above the contractors' labor and material costs), or by construction

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contracting firms to businesses such as hotels, restaurants, and equipment-rental companies that serve them while they mobilize outside their home market, market their services, or do the repairs.

Since insurance claims include additional living expenses and other time-element losses, and since restoring operations could involve purchases from great distances for company-specific needs, services in this context could mean virtually any expenditure paid to businesses at any distance from the disaster by any insured entity during the life of any time-element claim. These examples indicate that the current understanding of demand surge is not sufficiently developed to easily and routinely specify the geographic, temporal, or sectoral scope of services that contribute to increased losses following large-scale natural disasters.

In addition to "demand surge," there are other terms that refer to the same phenomenon or similar ideas. Two groups have separately offered distinct terminology to identify and explain the increased losses after large-scale natural disasters. Risk Management Solutions proposed "loss amplification" as the increase in loss following large-scale natural disasters that is not adequately modeled by assuming independent losses at exposed properties (Grossi and Muir-Wood 2006). RMS identifies 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"). The same concepts are presented elsewhere by RMS with slightly different names.

Risk Frontiers, formerly the Natural Hazards Research Centre, studies topics of interest to the insurance industry and used the term "postevent claims inflation" to refer to the increase of payments for insurance claims after major disasters (McAneney 2007). They use "demand surge" to refer specifically to the outpacing of supply by the demand for goods and services, which results in higher prices. These terminologies and the accompanying explanations help to define the idea of demand surge, but none provides a precise definition of the phenomena. The same challenges of circumscribing the scope of these terms exists as when this phenomenon is called demand surge.

The writers intentionally do not offer new terminology or a precise definition of demand surge. This work collects and distills anecdotal evidence for demand surge in historic events and proposes hypotheses to explain the phenomenon. Since this paper does not provide—nor have the writers found in published studies—clear evidence for what demand surge is and is not, it seems premature to introduce additional terminology. The existing terminology, flawed as it may be, is sufficient while researchers develop a sound understanding of reconstruction costs after large-scale natural disasters. The writers expect that the knowledge from future work will suggest improved terminologies and precise definitions of the mechanisms that drive the complex phenomenon we currently call "demand surge."

Current Demand-Surge Models

Models to describe how and why losses increase as a result of a large-scale natural disaster have been developed in the last two decades. Current demand-surge models capture parts of the phenomenon, but no published model fully describes how much and why losses increase as a result of the disequilibrium of demand and supply after large-scale natural disasters. Perhaps there has not yet been enough accumulated knowledge of demand surge to develop and test such a comprehensive model. This section describes a sample of the limited documentation of demand-surge models by commercial catastrophe modelers and by professional economists.

Commercial Catastrophe Models

Broadly defined, a catastrophe model is a tool that provides a quantitative estimate of risk to a single property or a collection of properties, usually from natural hazards, and most often for estimating insurance claims for a particular insurance company or reinsurance company in current or future natural disasters. Commercial catastrophe models typically apply a series of stochastic events (for example, earthquakes in California, flooding in continental Europe, cyclones in Australia) to estimate the environmental excitation (shaking intensity, flood depth, windspeed) imposed on a mathematical model of the properties. Then, the model relates intensity of excitation to repair cost normalized by replacement cost (the relationship is called a vulnerability function) to produce an estimate of the damage factor at each property. Multiplying the damage factor by the estimated replacement cost produces an estimate of total repair cost. Applying deductibles and limits to each policy and summing over policies produces an estimate of the total payments the insurer would make to settle claims. Uncertainties in each step are propagated, either through simple Monte Carlo simulation or more-sophisticated variants, to produce a probabilistic estimate of loss, either for single-event scenarios or for suites of possible future events (for example, catalogs of earthquakes).

Building owners routinely use these models to decide how much insurance to buy; insurers use them to help decide what to charge for insurance and how much reinsurance they need; and reinsurers use the results to help them price reinsurance and ensure a reasonable probability of survival. See Grossi and Kunreuther (2005) for a more extensive discussion.

As frequently employed, the demand-surge component of a catastrophe model increases the calculated ground-up loss for a property. (The ground-up loss is the monetary cost to repair damage and continue operations, before applying insurance deductibles, copays, or limits.) A demand-surge factor multiplies the ground-up loss, either at the individual-property level or the portfolio level, by a factor, typically between 1.0 and 1.6. Depending on the model, this factor can be determined on the basis of the expected loss to the insurance industry as a whole or on the basis of 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.

Though unaware of any publication of a commercial catastrophe modeler's demand-surge model, one of the writers (Porter) participated in developing one for EQECAT in the mid-1990s. It has since been enhanced or replaced in some way, but in brief, the early model worked as follows:

1. Regression analysis was used to relate damage factor to environmental excitation for past claims, resulting in vulnerability functions;
2. The regression analysis was performed using data from supposedly non-demand-surge-inducing events and again from an event that supposedly did produce demand surge (Hurricane Andrew);
3. The ratio of the latter to the former was calculated as a function of environmental excitation (windspeed) for broad classes of properties (that is, residential or commercial properties on the Gulf and Atlantic coasts of the United States); and

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4. This ratio was applied at the per-property level, along with a multiplier that reflected the degree to which the event was expected to produce demand surge at a macroscopic level, from nil to 100% of the Andrew-level increase.

In the form of an equation, the model was

$$L = \sum_i V_i y_i(s_i)[1 + P(s_i)G(T)] \quad (1)$$

where L = ground-up loss at the portfolio level; i = index to individual properties in the portfolio; V_i = estimated replacement cost for property i; $y_i(s_i)$ = mean damage factor for property i considering its structure type and given that it is exposed to excitation of intensity s_i; $P(s_i)$ = maximum effect of demand surge on a property when it is subjected to excitation s_i (a property-level effect); and $G(T)$ = degree to which the event as a whole (such as a hurricane) would produce demand surge, given the estimated societal-level total loss T. $P(s)$ might vary from 0 to 0.6, for example, in certain property classes where demand surge can reach 60%, with the lowest effect (0) occurring at low excitation (because damage is so low repairs can wait) or at high excitation (because damage is so severe that no amount of hurry will make a difference). It achieves its maximum value at intermediate excitation, where significant repairs are needed and speed is of the essence. G would vary from 0 (for smaller events like Hurricane Hugo in which the required repairs did not heavily stress available supplies) to 1.0 (for large ones like Andrew). T was parameterized as total estimated repair costs normalized by estimated annual construction contracting revenues of businesses within a given radius of the event's nominal location, such as hurricane landfall. (This model used a radius of 160 km for regions with only one major interstate corridor providing access, and 480 km otherwise.) The model attempted to reflect three hypothesized aspects of demand surge: that repair delays matter only at moderate levels of damage (captured through P); that the ratio of demand to local supplies matters; and that access matters (the last two issues parameterized through T).

This description leaves out much detail and is limited in too many ways to catalog in a brief space. However, it gives a sense of the simplicity of an early demand-surge model and highlights a few important points: that demand surge has been used to capture past discrepancies between observation and expectation; that at least this model encoded the modeler's unproven hypotheses of a few major mechanisms of demand surge; and that, while hindcasting past losses, it does not provide much explanatory power.

Regional Economic Models Used for Demand Surge

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. They are most often used to estimate societal losses as a direct or indirect result of a natural disaster, where "loss" now 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).

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 were assumed to be proportional to the underproduction of the commodity, and wages were assumed fixed when determining profits in economic sectors (an assumption made to simplify the model, with acknowledgment that in the real world, these calculated profits may be redistributed to the workers, to shareholders and owners, and to future investment). 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 Hallegatte 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 caused by Hurricane Katrina, considering direct and indirect losses.

Florida Public Hurricane Loss Model

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 2009 Florida Commission on Hurricane Loss Projection Methodology submission, the demand-surge component of the Florida Public Model applies "weighted average demand-surge factors" to the loss from each event in the stochastic set (Florida International University 2009). The model assumes that demand surge is affected by the insurance coverage [that is, structure, appurtenant structure, contents, or additional living expenses (ALE)], region of Florida (either "Northeast/North Central," "Northwest," "Central," "South (except Monroe County)," or "Monroe County"), and the modeled total statewide loss without demand surge. The demand-surge factor for structure coverage is

$$F_{\text{structure}} = c + p_1 \ln(L_{\text{state}}) + p_2 \quad (2)$$

where c = parameter; p_1 = parameter with one value for Monroe County and another value for all other regions; p_2 = parameter with a different value for each region; and L_{state} = modeled total statewide loss (an attempt to capture demand). The demand-surge factor for appurtenant structure coverage is the same as the factor for structure coverage. The factor for contents coverage is

$$F_{\text{contents}} = 1 + 0.3(F_{\text{structure}} - 1) \quad (3)$$

and the factor for ALE is

$$F_{\text{ALE}} = 1.5F_{\text{structure}} - 0.5 \quad (4)$$

The researchers used the following data to develop the model's functional form and determine values for the parameters: construction-cost indexes for Florida zip codes from Marshall & Swift/Boeckh (MSB) (for structure coverage); the household furnishings and operations index of the Consumer Price Index for Miami-Fort Lauderdale (for contents); and insured losses caused by Hurricanes Andrew, Charley, and Frances (for ALE). While developing the model, the researchers inferred what the MSB construction-cost index in a region affected by a hurricane would have been if no hurricane had passed, and they assumed that any difference

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between this no-hurricane, inferred value and the with-hurricane, actual value was entirely attributable to demand surge.

Common Themes of Demand Surge

With this background in mind on the nature of the problem and past work to model demand surge, focus now shifts to available historical evidence that can be used to inform a deeper understanding of the mechanisms of demand surge. Past events provide insight into the underlying supply and demand processes that result in higher reconstruction costs. To impose some structure to the discussion, the evidence is grouped into broad themes. The word "theme" is used 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.

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 potentially millions of properties 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.

Anecdotes related by construction contractors, claims adjusters, and cost estimators with whom the writers spoke suggest that whether the property is insured strongly affects the amount of repair work actually accomplished and how quickly the repairs are effected. For example, the insurer is sometimes required to pay for repairs that an uninsured property owner might not otherwise elect to pay for. An example is the "reasonably uniform appearance" standard required by insurance regulations in several states, such as the statute in Nebraska that reads: "When a loss requires replacement of items and the replacement items do not reasonably match in quality, color or size, the insurer shall replace all items in the area so as to conform to a reasonably uniform appearance. This applies to both interior and exterior losses. The insured shall not bear cost over any applicable deductible" (Nebraska Administrative Code 2009). Thus, in regions where a substantial fraction of damage is insured, requirements such as reasonably uniform appearance can substantially raise the total amount of repair work actually performed at an insured property when compared with an uninsured property. Thus, the demand for repair services increases, and costs consequently increase as well.

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 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 repairs are delayed by the large scope of damage. For example, mold can flourish in hot, water-damaged buildings when regional electric power is unavailable for an extended period of time. Thus, owners cannot quickly cool and dry buildings. This happened after Hurricane Katrina, for example, at Xavier College in New Orleans, as described in Mosqueda and Porter (2007). In short, 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 building codes tend to become more strict over the years, there can be exceptions; building codes may not be enforced [for example, before Hurricane Andrew (Sirkin 1995)], or the local building department may temporarily suspend certain provisions to allow for speedier recovery [for example, after Hurricanes Iwa and Iniki (Chock 2005)].

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. Adjusters might have a long list of properties to visit, making each loss assessment less thoroughly than they otherwise would in a smaller event (Thomas 1976). Contractors and claims 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 (Tim Wilson, personal communication, July 2008). These types of judgments about the amount of repair work following a catastrophe must be made but may not be fully informed. The pressure of a high volume of repair work seems likely to exacerbate problems of making quick judgments.

Costs of Materials, Labor, and Equipment

Local supplies of materials, labor, and equipment are typically employed first to rebuild after natural disasters. When the local supplies are outstripped by demand, prices rise. Three historical examples touch on price increases for material, labor, and equipment, over several centuries and two continents. See Olsen and Porter (2010) for more examples.

An extratropical cyclone devastated southern and central England on November 26–27, 1703. There was extensive and severe damage to buildings, especially in London and Bristol, contributing to the 480-km-wide damage footprint (Hamblyn 2005). In the immediate aftermath of the storm, prices of materials rose significantly. Defoe (1704) reported that the price of plain roofing tiles rose from 21 shillings per thousand to 6 pounds, 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. Following the immediate rise of prices, they fell. Defoe stated that this fall was not explained by the meeting of demand for roofing tiles with adequate supplies. Rather, property owners and tenants could not pay the heightened costs. The roofs of some properties went unrepaired, 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. Defoe also reported that, after the windstorm, property owners were "fortifying their Houses against the Accidents of Weather by Deal Boards, old Tiles, Pieces of Sail-Cloth, Tarpaulin, and the like." That is, they were substituting any appropriate and available materials to temporarily, if not permanently, repair their buildings.

More recently, the earthquake that occurred north of Charleston, South Carolina, on August 31, 1886, caused extensive destruction in Charleston and created a demand for labor that far exceeded the local supply. Wage rates for skilled and unskilled labor increased dramatically above the preearthquake levels. Seven days after the earthquake, the Knights of Labor union authorized a modest, 50-cent-per-day increase in union wages (News and Courier 1886b). However, skilled and unskilled laborers were actually

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commanding wage rates more than double the preearthquake rates. Union bricklayers would work for no less than US $5 per day, a 67% increase above the preearthquake 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 were actually receiving $6 or $8 per day, a 100–170% increase (News and Courier 1886c).

After the 1992 Hurricane Andrew in South Florida, 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."

Although prices and wages can be understood to result from the meeting of demand with supply, prices are set by individuals, and local culture can play an important role in pricing decisions. In contrast to the Hurricane Andrew equipment example, where the drive to maximize profit seems to have driven up costs, some contractors and laborers elect to provide free or reduced price materials and services, and still others may fix their costs at the preevent levels. One of the writers (Olsen) observed this sense of altruism in interviews of local contractors after the U.S. Midwest floods of June 2008.

Local, state, or national governments may enforce wage or price controls, effectively setting an upper limit on reconstruction costs. Antigouging regulations are fairly common. For example, after the 1995 Hurricane Marilyn in the U.S. Virgin Islands, the local government widely publicized its antigouging position (Murphy 1995). Similarly, there may be trade restrictions on the movement of materials and equipment between regions or on the licensing of out-of-state contractors, effectively making supplies from outside the affected area, if allowed, more expensive.

Reconstruction Timing

Regional factors may contribute to repair delays at an individual 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, as suggested by Risk Management Solutions, Inc., (2005) for repairs from the 2004 and 2005 Florida hurricane seasons. 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 1999). If the general population were evacuated, there may be a delay in reconstruction until there is a critical mass of people to finance, permit, perform, and inspect the repairs.

Debris removal can be critical before reconstruction begins at a property. Storm surge in Hurricane Katrina pushed substantial quantities of debris onto properties near the shore along the Mississippi coast, hindering access (see, for example, Mosqueda and Porter 2007). In addition to disposing of structural components and building contents, there may be hazardous materials requiring special attention, as was the case in several New Orleans hospitals observed after Hurricane Katrina (Arendt and Hess 2006).

The efforts of local and national governments may also affect the timing of reconstruction. Rebuilding may not begin until the local government allows the release of building permits. For example, as of June 30, 2008, in Cedar Rapids, Iowa—seventeen days after floodwaters 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 (NFIP). As of June 30, 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 at more than 50% of the structure's value be rebuilt at least 0.3 m 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. The aftermath of the 2004 hurricane season in Florida is an example (Weintraub 2004/2005).

Contractor Fees

Typically in developed countries, construction contractors perform the repairs. In such cases, contractors' fees contribute to the costs of reconstruction. In the aftermath of a large-scale natural disaster, there may not be a competitive environment for contractor services. Contractors typically increase overhead and profit as a buffer against risk. Greater uncertainties in material and labor costs and availabilities, as well as uncertain site access, will result in greater repair costs. For example, the uncertainty in the weeks after Hurricane Katrina affected reconstruction bidding: "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).

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. The supply of contractors may be affected by the local supply and by the willingness and ability of outside contractors to travel to the affected area.

Postcatastrophe increases in contractor profit margins are perhaps intuitive but difficult to document and quantify. One piece of evidence is a Federal Emergency Management Agency review of contract modifications awarded by the City of New Orleans to inspect and repair storm drains after Hurricane Katrina. The city allowed the contractor a 13% profit margin retroactively for work that had been performed previously by subcontractors: work that was contracted without competition, price analysis, or monitoring of billing accuracy (Lankford 2006). In another post-Katrina example, the Federal Aviation Administration allowed nominal profits of up to 15% for contractors providing response and recovery services, often without supporting evidence of subcontractor quotes, possibly because "contract administration resources were stretched quite thin and, understandably, … the top priority was to provide transportation to deliver goods, equipment, and services as quickly as possible to those in need of assistance." A profit margin of 10% is considered appropriate by several federal agencies, and FAA

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acquisition policy and contract terms require subcontractor quotes (Leng 2007).

General Economic Conditions

This paper has discussed issues specific to material prices, labor wage rates, equipment costs, and contractor profit, but these may in turn be affected by the general state of the economy. A predisaster 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. Walker (2005) described two examples:

> After the Newcastle earthquake there was very little demand surge because the building industry in New South Wales was in recession, and there was sufficient surplus capacity of building tradesmen and supplies available just down the road in Sydney to maintain a competitive building environment. The Canberra bushfires in January 2003 resulted in much less damage than the Newcastle earthquake but they occurred during a building boom when there was no spare capacity in New South Wales, with the result that the demand surge was very significant—possibly of the order of 25 percent or more.

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.

The 2005 Hurricane Katrina provides an example of increased costs resulting from the prevailing economic conditions. The pre-Hurricane 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).

Insurance Claims Handling and Decisions of an Insurance Company

There are several ways that an insurer can handle the large volume of claims after a large-scale natural disaster. An insurer may decide not to verify claims under a certain value, as for example, after the 1999 Windstorms Lothar and Martin in France (Risk Management Solutions, Inc. 2000). 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 insurer.

Regarding the typical procedure of verifying the claim with a claims adjuster, the characteristics of the adjuster or the methods used 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). Also, evaluating partial damage is more difficult than a total loss. Some policies and events require the adjuster to distinguish the cause of damage, and making these distinctions can require special expertise. A person unfamiliar with the type of damage may not properly adjust the claim. For example, an adjuster from a seismically inactive area may be unable to distinguish foundation cracks caused by settling versus those caused by an earthquake. (For that matter, claims adjusters from seismically active California can have the same problem.) An adjuster may not be able to distinguish damage caused by a previous event from normal wear and tear.

Claims adjusters anticipate materials costs and labor wage rates by using price lists. Thomas (1976) described how U.S. 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." Currently, many adjusters use software to estimate reconstruction costs. Xactware (2010) is the leading provider of pricing information for U.S. 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.

An adjuster unfamiliar with any pricing software may use it inappropriately (Postava 2008). The data contained in the software may be for repair under ordinary conditions, and may be inappropriate for estimating losses in large-scale natural disasters. The adjuster may not know how to properly account for rebuilding after a large-scale natural disaster.

After natural disasters, insurance companies may make decisions that affect their loss. 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 its 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 large-scale natural disaster is on the border of what is and is not demand surge. In this instance, the writers 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.

Many of these insurance-related demand-surge issues were documented after the 1906 San Francisco earthquake and fire. The earthquake struck the San Francisco Bay area on April 18, 1906, and the last fire was extinguished four days later. Between 300 and 400 insurance claims adjusters, both local and from across the United States, handled the large volume of claims on insurance

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policies. G. H. Marks of the London Assurance Corporation described the task of adjusting insurance claims after the earthquake and fire (Marks n.d.). According to the standard procedure, claims on insurance policies should be verified. However, the earthquake and fire in San Francisco made this a nearly impossible task. Complete destruction of the sites erased any evidence for the adjusters; there were no neighbors or acquaintances of the claimant who could verify the claim, nor could the original purchase be verified by the retailer or wholesaler. Marks further noted that every insurance company had lost most or all of their records in the fire. Thus, the insurance companies could rarely verify that they even covered the loss that was being claimed.

Some properties were indemnified by several companies. In the months following the disaster, insurance companies tried to develop a common approach to adjusting and settling these claims. At a general meeting of the insurers on June 12 in Oakland, California, across the Bay from San Francisco, 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 insured loss when the cause of damage—either earthquake or fire—was unclear. (Standard insurance policies excluded earthquake damage but covered fire damage. The insurers estimated that 25% of the damage in San Francisco was caused by the earthquake shaking and 75% by the fire.) Although otherwise supporting the work of the General Adjusting Board, 35 companies decided not to reduce payments to their policyholders. On June 21, 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. In its concluding report of December 31, 1906, the Committee of Five, which reviewed claims on the policies of the Thirty-Five Companies, made recommendations to the companies on how to better handle claims after future disasters (Hosford et al. 1906). The committee recognized the unprecedented and difficult task faced by the insurance industry after the 1906 San Francisco disaster. 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. 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?

In addition to issues under their control, insurers faced pressure from their clients, competition, and the government. The General Manager of Munich Re noted that, "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). 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.

U.S. courts ultimately ruled on disputes over fire following earthquake exclusions in typical insurance policies. On October 5, 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 Court reasoned that, since the insurers wrote their policies, any ambiguity in the policy language should favor the policyholder. A decision of the Second Circuit Court of Appeals on November 13, 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).

Summary

The evidence for demand surge from historical events suggests four important points regarding what demand surge is and is not.

1. Demand surge is not a new phenomenon. This paper has offered evidence for demand surge in early 18th-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. There is evidence for demand surge from the United States, the United Kingdom, Australia, 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 (Olsen and Porter 2010). 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 large-scale natural disaster 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.

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, and there are 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. This paper identified the following themes: total amount of repair work; timing of reconstruction; costs of materials, labor, and equipment; contractor overhead and profit;

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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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