Working Paper Proceedings

15th Engineering Project Organization Conference
with
5th International Megaprojects Workshop
Stanford Sierra Camp, California
June 5-7, 2017

Construction Capacity: How Construction Resource Availability Affects Post-Tornado Rebuilding of Residential Housing

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CONSTRUCTION CAPACITY: HOW CONSTRUCTION RESOURCE AVAILABILITY AFFECTS POST-TORNADO REBUILDING OF RESIDENTIAL HOUSING

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ABSTRACT

The U.S. residential housing stock is increasingly vulnerable to wind damage associated with tornadoes, due to a rise in the frequency of tornado disasters and growing suburban development. The construction industry plays a critical role in post-tornado recovery efforts by supplying material and labor necessary for repairing damaged residential houses. The availability of construction resources needed for rebuilding is determined by the network of construction organizations providing materials and labor within construction industry supply chains. This study expands upon the concept of *construction capacity*, defined as *the maximum building volume a construction industry can supply due to regional supply chain availability of material and labor*. The Oklahoma City (OKC) region of the U.S. is used to illustrate how pre-disaster construction capacity influences post-disaster reconstruction of residential housing, since OKC has been struck by multiple tornado disasters since 2002. We employ supply chain management theory to measure pre-disaster construction capacity (e.g., supply) and compare against post-disaster need for construction services (e.g., demand). Pre-disaster regional capacity utilization and labor productivity metrics are used to: (a) measure the maximum supply of construction materials available in a given year; (b) measure the net value of residential construction work the available labor force can install per year; and (c) determine the typical demand for residential housing in terms of permitted single-family houses. The regional pre-disaster construction capacity baseline is then compared with the post-disaster additional demand for construction services, based on FEMA damage assessments. By comparing the pre-disaster regional construction capacity with the post-disaster FEMA assessed losses (both calculated in terms of $USD), we quantitatively measure the discrepancy between regional construction industry supply and demand. Such quantitative assessments of residential construction industries are necessary to improve housing reconstruction work provided by organizations within regional supply chains.

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KEYWORDS

Construction Capacity, Supply Chain Management

INTRODUCTION

Over the past decade, the U.S. has experienced more tornadoes than any other country. Once considered low-probability events, today over 1200 tornadoes form across the U.S. each year, resulting in an average of 110 deaths and economic losses over a billion dollars (Maynard et al. 2013). With growing urban development and suburban sprawl, tornadoes are increasingly more likely to hit densely populated regions and destroy existing U.S. residential housing stock. Wind shears associated with tornadoes can reach over 200 mph, and past assessments of post-tornado communities have highlighted that residential housing is extremely vulnerable to wind damage (Ellingwood et al. 2004; Marshall 2014). Wood-framed construction, which comprises 90% of U.S. residential houses, can begin losing structural integrity at sustained wind speeds as low as 100 mph (Standohar-Alfano and van de Lindt 2015). Thus, the residential housing market can experience significant damage from tornado events.

The reestablishment of permanent residential housing is crucial for post-disaster recovery (Nejat and Damnjanovic 2012), but is hindered by widespread damage commonly seen in regions affected by tornadoes. Past studies have identified the importance of quickly rebuilding after a disaster, with the 2-year post-disaster timeframe given as an important milestone for restoration of permanent residential housing (Olshansky et al. 2012). Similarly, the U.S. Department of Housing and Urban Development (HUD) recently developed formal recommendations for improving post-disaster reconstruction of residential housing (Cantrell et al. 2012). For the first time, the U.S. government has formally recognized that post-disaster residential housing recovery is determined by availability of pre-disaster construction resources. To facilitate post-disaster repair and reconstruction of residential homes, the surrounding regional construction industry must meet increased post-disaster demand for construction services. We theorize that *construction capacity*, defined here as the *the maximum building volume a construction industry can supply due to regional supply chain availability of material and labor*, determines how efficiently residential housing is rebuilt following a disaster. However, regional construction capacity is limited by the availability of construction material and labor resources, and often fails to meet post-disaster demand for construction services. To explore how the capabilities of organizations within residential construction supply chains affect post-disaster rebuilding efforts, the following research question is posed: ***How can pre-disaster regional construction capacity measurements inform post-disaster regional reconstruction capacity?***

POINTS OF DEPARTURE

Pre-disaster construction industry resources can be more efficiently leveraged if the supply of material and labor is coordinated to fulfil post-disaster demand for construction project work. Our study builds upon supply chain management theory to explore construction industry supply and demand coordination mechanisms.

SUPPLY CHAIN MANAGEMENT

Supply Chain Management theory has been used in numerous industries to analyze how efficiently raw material inputs are transformed into finished products available to consumers (Veinott 2013). Building on prior literature from supply chain management theory, we postulate that the ability of a firm to provide construction services is inherently tied to a larger network of organizations within the broader construction industry (Arneson et al. 2016; Azambuja et al. 2014). Supply chain management theory has been used to explain how the network of materials, labor, information, and services affects the logistics of supply and demand, but has been studied almost exclusively at the construction firm or project level (Halman and Voordijk 2012). However, regional construction industry supply chains are critical to understanding how the pre-disaster interactions between material suppliers, laborers such as subcontractors and general contractors, and residential homeowners, affect post-disaster reconstruction. The fragmented nature of the construction industry, composed of interconnected organizations spread across numerous geographical regions, leads to competition over limited regional material and labor resources (Azambuja et al. 2014). Advances in quantitatively measuring regional construction resource availability, especially for residential construction industry supply chains, are still needed (Halman and Voordijk 2012).

MATERIAL CAPACITY UTILIZATION

The concept of capacity utilization developed out of the manufacturing industry, which needs to match production supply with end customer demand for material goods. *Capacity utilization*, described here as *the ratio of current output demand to the maximum capacity supply*, is a quantitative measurement of supply and demand relationships and is shown in Equation 1 (Fevolden 2015). When demand exceeds the available capacity within an industry, the capacity utilization rate rises above 100%. High capacity utilization rates indicate the supply chain is unable to meet demand, and often translates into longer material lead times and higher material prices. When capacity exceeds demand within an industry, the capacity utilization rate falls below 100%. Low capacity utilization rates are often an indicator of economic contraction and lead to excess stock inventories (Mulligan 2016; Walsh et al. 2004). The use of capacity utilization rates outside of the manufacturing sector remains sparse, especially within the construction industry.

Equation 1. Capacity Utilization

$$\text{Capacity Utilization} = \frac{\text{Current Output (demand)}}{\text{Capacity (supply)}}$$

LABOR PRODUCTIVITY

Labor productivity has been used to quantitatively measure the efficiency of labor resources across numerous industries. Labor productivity "…can generally be defined as a measure of the efficiency of the industry in exerting labor resources to produce output (measured by physical construction quantities produced)" (Vereen et al. 2016, pg 2). Measuring labor productivity at the industry level for construction industry is difficult due to a lack of available or reliable data, and is often focused on predicting future labor shortages rather than productivity trends over time (Vereen et al. 2016). While the U.S. Bureau of Labor Statistics (BLS) tracks construction industry productivity over time, the data is aggregated for all sub-sectors of the industry (e.g., residential, civil infrastructure, and specialty trade construction) and only available at the national level. However, the literature suggests that sub-sectors of the construction industry, especially at the regional scale, are vulnerable to the effects of labor shortages and productivity fluctuations (Goodrum et al. 2002).

Improved sub-sector construction productivity measurements, especially at the regional scale, are still needed (Rojas and Aramvareekul 2003). Regional construction supply chains have not been adequately studied due to the difficulty of modelling supply chains above the project or singular case study level (O'Brien and Fischer 2000). Advances in quantitatively measuring supply chain capacity and the use of models to improve our understanding of relationships within regional and industry-level supply chains are still needed (London and Kenley 2001).

RESEARCH METHODS

The purpose of this research was to explore the implications for the construction industry when a tornado strikes an urban area, damages a significant amount of the housing stock, and requires the existing construction supply base to urgently respond. We compare pre-disaster regional construction capacity, measured in terms of material capacity utilization and labor productivity, with post-disaster demand for construction services. This comparative analysis was conducted for a case study region over a fifteen-year timeframe. Pre-disaster regional construction capacity baselines were calculated at five year intervals (e.g., 2002, 2007, and 2012) based on data availability. Post-disaster building reconstruction demand from tornado disasters was calculated for each baseline (e.g., 2003-2007, 2008-2012, and 2013-2017).

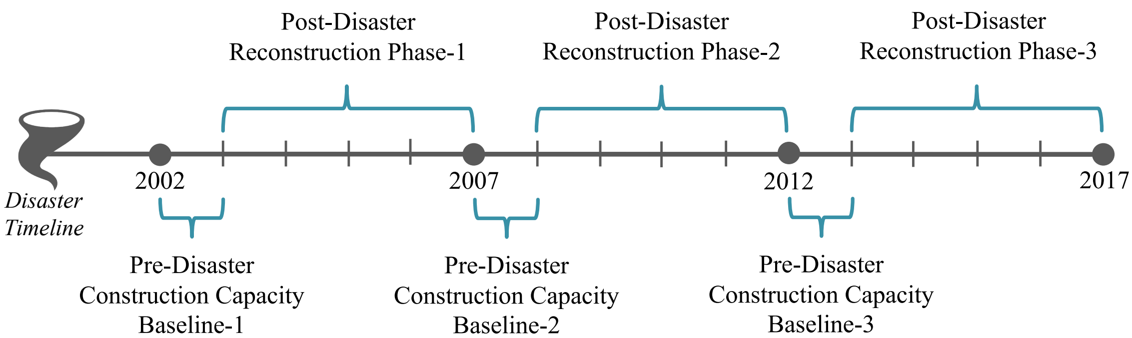

Figure 1. Pre- and Post-Disaster Study Phases

RESEARCH CONTEXT: OKLAHOMA CITY, OKLAHOMA ECONOMIC REGION

To understand regional construction capacity trends and their relationship to post-disaster residential reconstruction, we examine a case study region. Oklahoma City (OKC) is an economic region delineated by the U.S. Bureau of Economic Analysis (BEA), based on strength of business ties, commuting patterns, and economic trends

(Johnson and Kort 2004). The region is anchored by the Oklahoma City metropolitan statistical area, the main source of employment and economic activity for the region, and comprised of 51 counties in Oklahoma, Kansas, and Texas (Delgado et al. 2016). The OKC region provides a unique case study setting to examine the effects of construction capacity on post-disaster reconstruction of residential housing; the region has been struck by multiple tornadoes since 2002, each destroying a substantial portion of the residential housing stock. Since 2002, the OKC region has experienced rapid population growth, fluctuating levels of employment tied to boom and bust cycles of the oil and gas industry, and increasing demand for single-family residential housing construction (U.S. Bureau of Economic Analysis 2016). However, the number of building material wholesale establishments and residential general contractors within the region has not grown substantially.

DATA COLLECTION

Quantitative data sets relevant to pre-disaster regional construction capacity (supply) and post-disaster damages (demand) for residential reconstruction and repair, both measured in terms of U.S. dollars, were collected. Data from the years 2002-2012 were used to identify and measure baseline regional construction industry resource supply and the post-tornado demand for construction services in the OKC region.

PRE-DISASTER CONSTRUCTION CAPACITY

Pre-disaster data regarding supply chains in the OKC economic region, including material and labor availability, were collected from publicly available national databases (U.S. Census Bureau 2012a; b; c, 2013). Specifically, the U.S. Census Bureau collects, analyzes, and publishes data relevant to measuring construction capacity, in terms of NAICS manufacturing and employment statistics, at various industry levels (e.g., 2- to 6- digit NAICS codes) and geographical levels (e.g., national, state, and county). We collected datasets from three programs conducted by the U.S. Census Bureau, namely: the *Economic Census program, County Business Patterns program,* and *American Community Survey* (ACS). This involved identifying construction capacity indicators within the broader OKC region, such as: the number of single-family residential general contractor establishments and the Net Value ($USD) of yearly construction work installed by those firms (e.g., NAICS 236115 – Residential General Contractors and NAICS 236118 – Residential Remodelers); value ($USD) of construction materials, components, and supplies purchased by general contractors (e.g., NAICS 236 – Building General Contractors); the number of merchant wholesaler establishments and the value ($USD) of all building materials sold by those firms (e.g., NAICS 4233 – Lumber and Other Construction Materials); as well as the number of new residential permits issued annually.

POST-DISASTER CONSTRUCTION DEMAND

Housing data indicating post-disaster construction demand for single-family residential housing was collected from publicly available datasets produced by the Federal Emergency Management Agency (FEMA*) Individual Assistance program* (FEMA 2014). The FEMA Individual Assistance program is a federal disaster grant program geared towards homeowners. Following any federally declared major disaster, trained FEMA agents inspect all single-family residential homes they can gain access to, and document physical damages. Damage reports are processed at FEMA headquarters to estimate the economic cost of such damages, referred to as FEMA verified loss (FVL). FEMA FVL is the estimated financial value required to make a damaged home "safe, sanitary, and functional" (FEMA 2008). FVL is the minimum dollar amount required to make a residential home *habitable* again, including the cost of construction materials and labor.

DATA ANALYSIS

We measured pre-disaster regional construction capacity in the OKC region for three baseline years (2002, 2007, and 2012) based on two metrics: *material capacity utilization* and *labor productivity*. Then, we compared the pre-disaster construction capacity with post-tornado demand for construction services in the OKC region.

PRE-DISASTER CONSTRUCTION CAPACITY

Multilevel data analysis was used to develop estimates for pre-disaster regional construction capacity because the Census Bureau data structure was hierarchical. Since the OKC region is comprised of multiple U.S. counties, we collected and analyzed data at the county level where possible. However, the Economic Census data was only available at the state level. Since the OKC region is comprised of counties in three states (Kansas, Oklahoma, and Texas), we measured the state level averages for economic construction capacity indicators (e.g., cost of materials, components, and supplies; wholesale trade sales; and net value of construction work) for those states. Then, we estimated county level data based on individual state averages. Here, we show the steps for calculating the OKC regional construction capacity indicators, using a mix of state and county level data. This process was repeated for each pre-disaster construction capacity baseline year.

First, we calculated the total annual 'cost of materials, components, and supplies' (\$USD) purchased by building contractors (NAICS 236) in the OKC region, as shown in Equation 2. Cost of materials refers to the value of building materials purchased to complete the construction of residential buildings (e.g., regional building material demand).

Equation 2. OKC Region Cost of Materials, Components & Supplies

$$= \Sigma \left\{ \left[\left(\frac{Cost_{KS}}{B_{KS}} \right) \times B_{KS\text{-}counties} \right] + \left[\left(\frac{Cost_{OK}}{B_{OK}} \right) \times B_{OK\text{-}counties} \right] + \left[\left(\frac{Cost_{TX}}{B_{TX}} \right) \times B_{TX\text{-}counties} \right] \right\}$$

Where:

KS = Kansas; OK = Oklahoma; and TX = Texas

$Cost_{KS/OK/TX}$ = *Cost of building materials purchased by building contractors (State total)*

$B_{KS/OK/TX}$ = *Number of Building Contractor Firms (State total)*

$B_{KS/OK/TX\text{-}counties}$ = *Number of Building Contractor Firms (for State counties within region)*

Second, we calculated the total annual sales ($USD) of building materials sold by wholesale trade establishments (NAICS 4233) in the OKC region, as shown in Equation 3. Wholesale trade sales represents the availability of material stock inventories within the supply chain (e.g., regional building material supply).

Equation 3. OKC Region Wholesale Trade Sales

$$= \sum \left\{ \left[\left(\frac{Sales_{KS}}{W_{KS}} \right) \times W_{KS\text{-}counties} \right] + \left[\left(\frac{Sales_{OK}}{W_{OK}} \right) \times W_{OK\text{-}counties} \right] + \left[\left(\frac{Sales_{TX}}{W_{TX}} \right) \times W_{TX\text{-}counties} \right] \right\}$$

Where:

KS = Kansas; OK = Oklahoma; and TX = Texas

$Sales_{KS/OK/TX}$ = *Sales of building materials by wholesalers (State total)*

$W_{KS/OK/TX}$ = *Number of Wholesale Trade Firms (State total)*

$W_{KS/OK/TX\text{-}counties}$ = *Number of Wholesale Trade Firms (for State counties within region)*

Third, we calculated the annual net value of construction work installed ($USD) by residential contractors and remodelers (NAICS 236115 and 236118) in the OKC region, as shown in Equation 4. Net value refers to the total billable work performed by residential contractor establishments within the region (e.g., regional labor supply).

Equation 4. OKC Region Net Value of Construction Work

$$= \sum \left\{ \left[\left(\frac{NV_{KS}}{H_{KS}} \right) \times H_{KS\text{-}counties} \right] + \left[\left(\frac{Sales_{OK}}{H_{OK}} \right) \times H_{OK\text{-}counties} \right] + \left[\left(\frac{Sales_{TX}}{H_{TX}} \right) \times H_{TX\text{-}counties} \right] \right\}$$

Where:

KS = Kansas; OK = Oklahoma; and TX = Texas

$NV_{KS/OK/TX}$ = *Net Value construction work completed by residential contractors (State total)*

$H_{KS/OK/TX}$ = *Number Permitted Single-Family Houses (State total)*

$H_{KS/OK/TX\text{-}counties}$ = *Number Permitted Single-Family Houses (for State counties within region)*

Lastly, using the economic indicators calculated in the previous steps, we measured pre-disaster regional construction capacity in terms of two metrics: material capacity utilization and labor productivity. Literature from the manufacturing sector has defined capacity utilization as the ratio of demand to supply (Fevolden 2015). For the OKC region single-family residential housing sector, we calculated capacity utilization as the ratio of material demand (e.g., cost of materials, components and supplies, as shown in Equation 2) over the material supply (e.g., wholesale trade sales, as shown in Equation 3). OKC regional labor productivity was calculated as the output produced by residential contractors within the region. Specifically, we calculated the average Net Value of construction work generated by each residential contractor establishment within the region.

POST-DISASTER CONSTRUCTION DEMAND

The FEMA Individual Assistance program dataset contained all U.S. disaster declarations since the 1950s. First, we narrowed our search of FEMA disaster declarations to natural hazard events classified as 'major disasters'. Only major disasters have been associated with large scale housing damages, triggered FEMA housing inspections, and generated FEMA verified loss (FVL) assessments for residential housing. Second, we limited major disaster declarations to only those including damages from tornado events. Third, we narrowed the geographic scale of the tornado disasters to only include those in Kansas, Oklahoma, and Texas (states containing counties in the OKC region). Last, we aggregated tornado FVL data from each county within the OKC region, to develop a regional FVL for each post-disaster study phase (e.g., 2003-2007; 2008-2012; and 2013-2017).

RESULTS

Regional pre-disaster construction capacity is measured for the OKC region using two metrics: *capacity utilization* and *labor productivity*, as shown in Table 1 and Table 2. We calculated construction capacity within the OKC region for three baseline years. Those capacity measurements were then compared against the sudden demand spikes for construction services generated by tornado events, calculated in terms of FEMA FVL, for three post-disaster reconstruction phases (Figure 1).

PRE-DISASTER CONSTRUCTION CAPACITY

Material capacity utilization rates are a measurement of the effectiveness of supply and demand relationships created by the complex network of organizations within supply chains (Gill 2015). Results for the OKC region indicate that material capacity utilization rates varied significantly over time. For example, in 2002 the wholesale trade establishments within the OKC region sold building materials worth over $434.2 million dollars. However, the general contractor establishments in the OKC region purchased over $579.3 million dollars of building materials during that same year. Similarly, wholesalers sold $616.5 million dollars of building materials in the OKC region in 2007, but did not keep up with regional demand of over $934.0 million dollars of construction materials generated by contractor purchases. Thus, the demand for building materials generated by contractors in 2002 and 2007 far outpaced the supply provided by wholesalers, generating capacity utilization rates of 133.4% and 151.5%, respectively. Capacity utilization rates well above 100% reflect an inefficient flow of material resources within the regional residential construction supply chain, and typically cause material price inflation and longer lead times (Mulligan 2016; Walsh et al. 2004). General contractors would have been forced to purchase building materials from other wholesalers outside of the OKC region to keep up with project demands in both 2002 and 2007.

In contrast, the value of building materials purchased by OKC general contractors dropped from 2007 to 2012. This resulted in significantly less demand for materials, with general contractors purchasing just over $735.8 million dollars of building materials in 2012. At the same time, wholesale establishments increased their supply base and sold sell over $865.9 million dollars of building materials, creating material capacity utilization of 85.0%. Capacity utilization rates well below 100% indicate an excess stock inventory within the supply chain. To have sold such a high volume of building materials during 2012, wholesalers in the OKC region must have sold building materials to general contractors from adjacent regions.

Table 1. OKC Pre-Disaster Construction Capacity: Material Capacity Utilization

Baseline Year	Cost of Materials, Components & Supplies *($ USD)*	Wholesale Trade Sales *($ USD)*	**Material Capacity Utilization** *(Cost of Materials/ Wholesale Sales)*
2002	$579,383,057	$434,222,348	133.4%
2007	$934,060,242	$616,500,000	151.5%
2012	$735,875,936	$865,928,098	85.0%

*Includes establishments classified NAICS 236 (Cost Materials) and NAICS 4233 (Wholesale Sales)

Pre-disaster labor productivity rates also provide insight into the available construction capacity within the OKC region from 2002-2012. Within the OKC region, both the total net value of construction work performed by residential contractors and the average net value per residential contractor establishment increased between 2002 and 2012. However, the total number of residential contractor organizations within the OKC region has been gradually decreasing since 2002.

Table 2. OKC Pre-Disaster Construction Capacity: Labor Productivity

Baseline Year	Net Value Construction *($ USD)*	Contractor Establishments *(Total #)*	**Labor Productivity Rate** *(Net Value/ Contractor Establishment)*
2002	$272,532,767	596	$457,270
2007	$349,069,592	574	$608,135
2012	$483,977,734	533	$908,026

*Includes establishments classified as NAICS 236115 or NAICS 236118

POST-DISASTER CONSTRUCTION DEMAND

Post-disaster demand for single-family residential construction services is determined by FEMA FVL economic loss estimates. Such losses represent the net value of construction services ($USD) required to repair and replace residential housing to a habitable status. Results indicate that single-family residential housing damages associated with tornado events in the OKC region varied significantly over time, as shown in Table 3. For example, no major tornado disasters struck the OKC region between 2003-2008. Thus, there was no added strain added to the baseline construction capacity year 2002. However, two major tornado disasters hit the OKC region between 2008-2012, resulting in over $22.1 million dollars of tornado-related damages to single-family residential housing. These losses represent a 2.4% increase in demand for construction services that construction organizations within the OKC region must supply. Similarly, three major tornado disasters struck the OKC region between 2013-2017, generating over $54.1 million dollars of residential housing damages. Such losses represent a 7.4% increased demand for construction services compared to the 2012 construction capacity baseline year.

Table 3. OKC Post-Disaster Tornado Single-Family Residential Housing Damages

	Post-Disaster Phase #1 (2003-2007)	Post-Disaster Phase #2 (2008-2012)	Post-Disaster Phase #3 (2013-2017)
FEMA verified losses For tornado-damaged residential houses	$0	$22,176,186	$54,103,169
Increased Net Value demand for construction (compared to baseline)	0%	2.4%	7.4%

DISCUSSION AND CONCLUSION

Economic losses associated with disasters are growing in the U.S., due to expanding suburban housing development and population trends. When tornadoes strike areas containing large numbers of residential housing units, catastrophic losses caused by a disaster can outstrip the capacity of the existing supply base. *Construction capacity*, defined here as *the maximum building volume a construction industry can supply due to regional supply chain availability of material and labor*, is quantitatively measured in terms of material capacity utilization and labor productivity. Despite increasing vulnerability of the U.S. single-family residential housing stock to tornado disasters, minimal research has examined how pre-disaster construction material and labor resource availability affect the construction industry's ability to rebuild houses after a disaster. To address this gap, our research explores how pre-disaster construction capacity measurements inform post-disaster reconstruction capacity.

In terms of practical implications, we measure pre-disaster regional construction capacity for three baseline years (2002, 2007, and 2012) in the Oklahoma City (OKC) region. Results indicate material capacity utilization can fluctuate significantly over relatively short periods of time. For example, in baseline years 2002 and 2007, material capacity utilization rates were far above 100% (133.4% and 151.5% respectively). Since the OKC region was unable to meet demand for materials during those baseline years, the region was exceeding vulnerable to disruptions from disasters. Homeowners with disaster housing damages would likely encounter delays and increased material prices. In contrast, the 2012 construction capacity baseline year had less than 100% capacity utilization (85.0%), and the excess material inventory could work as a type of shock absorber for the supply chain in case of a disaster. The rapid decrease in capacity utilization seen in 2012 reflects the challenges of coordinating material supply and demand for the construction industry. While residential housing projects require quick acquisition of materials to complete contracted work in real time, the availability of material inventories lags building trends. For example, wholesaler establishments require significant capital investment to create physical storefront locations and warehouses to store material inventories. Such investment is typically only greenlighted after long term building growth within a region.

The OKC region also saw an increase in labor productivity over time. Ostensibly, increased productivity may indicate a more efficient use of labor resources within the region over time, but it may also be an indicator of future labor shortages. The existing residential labor force has been forced to produce more net value of work to keep pace with regional demand, but may not be able to continue such productivity gains if the number of contractor establishments continues to fall. Even if regional contractors could maintain labor productivity trends, tornadoes generated additional demand in OKC during the 2008-2012 and 2013-2017 post-disaster study phases. Homeowners likely had to wait for the existing backlog of project work to be completed by construction organizations within the regional supply chain before their homes could be repaired after tornado disasters.

Our research adds to the limited supply chain management literature by identifying critical categories of construction organizations within residential construction supply chains. Disasters such as tornadoes can exacerbate existing material and labor shortages within regions, straining the capacity of the U.S. construction industry to meet demand for residential construction services. By measuring pre-disaster construction capacity, construction organizations within supply chains can begin to identify regional vulnerability to disruptive events.

FUTURE WORK AND LIMITATIONS

To develop regional level construction capacity measurements, county level data was required since the OKC region consists of 51 counties across three states in Kansas, Oklahoma, and Texas. However, much of the publicly available datasets about the U.S. construction industry are only provided at the state level. Thus, we assumed that material and labor providing establishments within individual states will have similar production output.

Future work will seek to explore a broader range of hazard types, for other sectors of the construction industry such as heavy infrastructure. This research is limited to a broad examination of a single sub-sector of the U.S. construction industry, namely the single-family residential housing sector, in a single case study region. Additionally, further research is needed to analyze component parts of construction industry supply chains, to discover if there are specific elements that have greater influence on the larger supply chain construction capacity, including: subcontractors or specialty trades (e.g., roofers, utility line workers); types of materials (e.g., concrete, roofing, electrical wiring); or project management coordination (e.g., building permits, approval process). These possible pinch points within the supply chain may hinder the ability of the construction industry to efficiently mobilize construction resources after disruptive events such as disasters, and need to be examined in more detail.

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