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HOW CONSTRUCTION CAPACITY AFFECTS POST-DISASTER REBUILDING OF RESIDENTIAL HOUSING

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Abstract: The existing U.S. residential housing stock is increasingly exposed to storm surge and coastal flooding. For example, over 650,000 single-family residential homes were damaged or destroyed following Hurricane Sandy in 2012. The construction industry must meet increased post-disaster demand for construction services to facilitate repair and reconstruction of residential homes damaged by disasters. *Construction capacity*, defined here as the maximum building volume a construction industry can supply with available resources, determines how efficiently residential housing is rebuilt following a disaster. To better prepare for post-disaster reconstruction, this study addresses the question: *how do we measure pre-disaster construction capacity at the state-level, and how does it compare to post-disaster reconstruction?* We analyzed this question for single-family residential housing in the states of New Jersey and New York following Hurricane Sandy. Building on literature from construction supply chain management theory, we: (a) identified construction wholesale trade (material) and residential contractor (labor) establishments within New Jersey and New York; (b) measured state-level pre-disaster construction capacity as the net value of residential construction that can be performed in a given year; (c) calculated post-disaster losses for single-family residential housing based on FEMA damage inspections; and (d) compared pre-disaster construction capacity and single-family residential housing unit counts to post-disaster housing reconstruction progress, using a cross case comparison. Results highlight the extent to which construction resources within New Jersey and New York were capable of meeting post-disaster demand for residential construction. Furthermore, the novel methodology developed and employed can be used to assess whether construction capacity can meet demand following a disaster in other regions.

1 INTRODUCTION

The U.S. consistently ranks in the top five countries most frequently devastated by natural disasters in terms of economic losses (FEMA 2013). Economic losses from individual disaster events now commonly exceed one billion dollars, especially for large atmospheric storm events, such as hurricanes. With rapid population growth and residential development occurring along U.S. coastlines, residential buildings increasingly exposed to storm surge and coastal flooding from hurricanes. Despite the growing vulnerability of the U.S. residential building stock to hurricanes and associated inland flooding, pre-disaster planning and coordination efforts rarely examine the ability of the construction industry to respond to events (Hwang et al. 2015). To facilitate post-disaster repair and reconstruction of residential housing, the construction industry must be capable of meeting post-disaster demand for construction services. Here, we introduce and define the term *construction capacity* as the maximum building volume a construction industry can supply with available resources at a given time. We theorize that construction capacity determines how quickly the U.S. residential housing stock can be rebuilt in a post-disaster setting.

The long-term recovery phase of the disaster cycle, when reconstruction of permanent residential housing takes place, is not well understood (Cantrell et al. 2012). Yet, the reestablishment of permanent residential housing is a critical factor for successful post-disaster recovery, since residential housing comprises 60-70% of the built infrastructure in most communities (Nejat and Ghosh 2016). Additionally, a lack of permanent residential housing can lead to long-term decreases in population, businesses, and social cohesion after a disaster (Hwang et al. 2015). Recently, the Federal Emergency Management Agency (FEMA) developed the first U.S. National Disaster Housing Strategy after the failure of temporary housing options, like the well-publicized 'FEMA trailers,' following Hurricanes Katrina and Sandy (Cantrell et al. 2012; FEMA 2013).

This paper sets a new direction for post-disaster reconstruction in the U.S. by focusing on state-level recovery efforts and the importance of quickly rebuilding permanent residential housing. For the first time, the U.S. government has formally recognized that disaster recovery is often determined by pre-disaster coordination mechanisms, including construction industry material and labor resource availability (Cantrell et al. 2012). Therefore, in order to better understand the role construction capacity plays in post-disaster rebuilding, we seek to address the research question: ***How do we measure pre-disaster construction capacity at the state-level, and how does it compare to post-disaster reconstruction?***

2 RESEARCH CONTEXT: HURRICANE SANDY

On October 29, 2012 Hurricane Sandy struck the eastern seaboard of the U.S., killing over one hundred people and causing more than sixty-five billion dollars in damages and economic losses (HUD 2013). We selected Hurricane Sandy as the case study disaster for this research, due to how disruptive the hurricane was to the construction industry, especially along the eastern seaboard of the U.S. New Jersey and New York were two of the most densely populated coastal areas of the U.S. affected by Hurricane Sandy, and both states were declared major disaster areas by the federal government and FEMA. Suburban communities along the New Jersey and New York coastline, containing millions of single-family residential housing, were severely damaged due to wind and flood. In fact, of the approximately 650,000 single-family residential houses that were damaged or destroyed in the U.S. during Hurricane Sandy, over 300,000 homes (47%) were located in either New Jersey or New York (FEMA 2014; HUD 2013).

3 LITERATURE REVIEW

In order to effectively measure and model pre-disaster construction capacity, one must first understand both pre-disaster material and labor availability. Thus, we measure pre-disaster construction capacity using two indicators: *material capacity utilization* and *labor productivity*.

3.1 Capacity and Capacity Utilization

As modern manufacturing and industrial sectors developed after the Industrial Revolution, firms began identifying and measuring material resource supply and demand. The study of production, the economic process of converting inputs into outputs, provided insight into how organizations could utilize existing resources to efficiently produce finished goods (Gill 2015). *Capacity*, the maximum amount of available resources or output available over a specified time period (Gill 2015), is a measurement of production output. *Capacity utilization*, the ratio of production demand to maximum capacity supply (Fevolden 2015), measures the effectiveness of supply and demand relationships, and is shown in Equation 1. Capacity utilization rates above 100% indicate demand for materials exceeds the available supply, while a capacity utilization rate below 100% represents surplus material inventories (Fevolden 2015).

[1] Capacity Utilization = Demand / Supply (Capacity)

However, only minimal research has been conducted to understand the interconnected processes and mechanisms of production within the construction industry (Gill 2015). Historically, the construction industry has relied on best practices and experience in order to manage production (e.g., using contractor labor to convert raw materials into completed buildings), despite the fact that economic models can create a better understanding of how organizations work collectively to complete construction projects (Gill 2015). New quantitative models are needed to measure capacity utilization within the construction industry, in order to increase the effective use of existing resources (Croom et al. 2000).

3.2 Labor Productivity

Historically, it has been difficult to measure labor productivity in the construction industry because there is no single definition or data source. The Bureau of Labor Statistics (BLS) maintains construction industry labor productivity measurements, but uses aggregated productivity rates for all construction sub-sectors (e.g., residential and commercial construction) and only at the national-level (Vereen et al. 2016). However, research suggests that construction labor availability can vary significantly across geographic regions and industry sub-sectors (Goodrum et al. 2002). There remains a need for improved construction labor productivity metrics for narrower geographic regions of the U.S. (e.g., the state-level) and for specific industry sub-sectors (e.g., residential construction).

3.3 Construction Supply Chain Management Theory

Construction supply chain management theory has been used to explain how the network of materials, labor, information, and services within a supply chain affect the logistics of supply and demand. A key concept of construction supply chain theory is that project owners and developers are ‘upstream’ in the supply chain, and their demand for construction services must be met by the ‘downstream’ supply of material and labor (Croom et al. 2000; Gosling et al. 2013; Moon et al. 2015). Researchers typically examine construction supply chains at the individual firm or project-level almost exclusively, with an emphasis on reducing project costs and schedule durations (London and Kenley 2001). However, there has been increasing attention paid to more holistic examinations of supply chain performance (Gosling et al. 2013; Moon et al. 2015). The highly fragmented, yet interconnected nature of the construction industry, suggests a need for industry-level studies of construction supply chains to further investigate how construction industries utilize existing labor and material resources, especially for geographic scales beyond the national-level (Arneson et al. 2016; Gosling et al. 2013; Hwang et al. 2015).

4 METHODS

This research examined how pre-disaster construction capacity affects post-disaster reconstruction of single-family residential housing. Specifically, we studied the state-level, single-family residential construction industry in New Jersey and New York following Hurricane Sandy. To this end, we followed a multi-step process that: (a) identified construction wholesale trade (material) and residential general contractor (labor) establishments within New Jersey and New York state residential supply chains; (b) measured state-level pre-disaster construction capacity in terms of capacity utilization and labor productivity rates; (c) calculated post-disaster losses for single-family residential housing based on FEMA damage inspections; and (d) compared pre-disaster construction capacity and single-family residential housing unit counts to post-disaster housing reconstruction progress using a cross case comparison.

4.1 Data Collection

Publicly available quantitative data sets for single-family residential construction supply chains were collected from the U.S. Census Bureau and FEMA, in order to measure pre-disaster construction capacity and post-disaster damages (FEMA 2014; U.S. Census Bureau 2012a; b; c).

4.1.1 Residential Housing Supply Chains

In order to measure construction capacity for the residential housing sub-sector of the U.S. construction industry, it was necessary to first identify labor and material resources tied to residential construction supply chains. We examined state-level residential construction supply chains for New Jersey and New York. On one end, the supply chain includes manufacturers who transform raw materials into building products that they sell and transport to wholesale trade merchants, who then sell those materials and supplies to residential building contractors. On the other end of the supply chain are homeowners, who provide project financing and hire contractors to build homes.

4.1.2 U.S. Census Bureau Datasets

The U.S. Census Bureau tracks and publishes construction industry economic data necessary for calculating pre-disaster construction capacity and post-disaster residential housing reconstruction trends. The Census Bureau provides detailed economic indicators (e.g., value of construction work completed by contractors and volume of materials bought and sold at wholesaler establishments) for the residential housing construction sub-sector, including information at the state-level. We collected datasets from two Census Bureau programs, the *Economic Census* and the *American Community Survey* and included data from 2012, the most recently available information for both programs (U.S. Census Bureau 2012a; b; c).

The 2012 Economic Census provided economic indicators necessary to measure pre-disaster construction capacity at the state-level. The Economic Census is separated into industry specific data reports. We used *Construction Summary Series* and the *Wholesale Trade Series*, which track industry-level data using the North American Industry Classification System (NAICS). The NAICS assigns 2- to 6-digit codes to all U.S. establishments, with 2-digit codes representing an overall industry (e.g., construction) and 6-digit codes identifying industry sub-sectors (e.g., single-family residential construction) (Office of Management and Budget and Executive Office of the President 2007).

We also used post-disaster housing unit data from the American Community Survey (ACS) 1-year estimates from years 2012-2015. The ACS is a nationwide survey that tracks information regarding the U.S. residential housing stock, including total housing unit counts per state. The ACS supplements data gathered every ten years by the population census, and incorporates data collected by the Census Bureau for the number of residential permits issued each year.

4.1.3 FEMA Assessed Damages

Once a U.S. state has been declared a major disaster, like New Jersey and New York were after Hurricane Sandy, residential homeowners gain access to the FEMA Individual Assistance (IA) post-disaster grant program. FEMA contractors temporarily relocate to affected states, identify all potentially damaged homes, and perform damage inspections for all homes they can gain permission to enter (FEMA 2008). FEMA contractors are trained to identify and record damaged building components that must be repaired or replaced to make a residential house habitable, making it “safe, sanitary, and functional” (FEMA 2008). The value to repair and replace damaged building components is then calculated by proprietary FEMA software, which incorporates national median unit material and labor prices, to determine total damages per residential house. FEMA identified over 300,000 potentially damaged residential houses in New Jersey and New York after Hurricane Sandy, and inspected nearly 175,000 of those homes for damages.

4.2 Data Analysis

A model was developed to identify construction organizations within residential construction supply chains and to measure pre-disaster construction capacity at the state-level. Model results were then compared with actual post-disaster FEMA assessed damages and housing reconstruction data.

4.2.1 Pre-Disaster Construction Capacity

Here, we provide the methods used to identify and measure pre-disaster construction capacity at the state-level for the baseline year 2012, based on two metrics: labor productivity rates and material capacity utilization. We obtained five construction capacity economic indicators from the 2012 Economic Census: *number of single-family residential contractor establishments* (e.g., establishments classified as NAICS 236115 and NAICS 236118); *net value of construction work* (e.g., value of billable work completed by residential contractors); *wholesale trade sales* (e.g., value of building materials sold by merchant wholesaler establishments); *number of merchant wholesaler establishments* (e.g., establishments classified as NAICS 4233); and the *cost of materials, components, and supplies* (e.g., the cost of building materials purchased by residential contractors).

Once the data were obtained, we identified the number of construction establishments within state-level residential construction supply chains that were involved in building and repairing homes during 2012. Of particular interest were NAICS 236115 – new single-family housing contractors and NAICS 236118 – residential remodelers. These establishments were primarily responsible for construction of new single-family houses and townhomes, as well as additions, alterations, reconstruction, and repair work (U.S. Census Bureau 2012a). With these data, we computed pre-disaster construction capacity through a series of analytical steps.

First, we determined the Net Value of construction work ($ USD) single-family residential contractors (NAICS 236115) and residential remodelers (NAICS 236118) completed at the state-level in 2012. This is the net value of completed project work, less the value of billable work subcontracted out to specialty craft workers, based on labor and material receipts (U.S. Census Bureau 2012a).

Second, we calculated state-level labor productivity rates for the pre-disaster baseline year 2012. We calculated labor productivity as the Net Value of construction work ($ USD) completed per residential contractor establishment. This provided a state-level average labor productivity rate for residential contractors, as shown in Equation 2.

$$[2]\ \text{Labor Productivity} = \frac{\text{Net Value of Construction (\$)}}{\text{Number of Residential Contractor Establishments (\#)}}$$

Third, we identified the number of construction establishments within state-level residential construction supply chains that were involved in the wholesale trade of building materials during 2012. We focused on establishments classified as NAICS 4233 – Lumber and Other Material Wholesalers. These establishments engage in wholesale trade and distribution of "lumber, plywood, millwork, and wood panels; brick, stone, and related construction materials; roofing, siding, and insulation materials; and all other construction materials" (U.S. Census Bureau 2012c).

Fourth, we calculated the volume of wholesale trade sales ($ USD) completed by building material merchant wholesalers (NAICS 4233) at the state-level. Sales included the net value of building materials sold for cash or credit, based on sales receipts and tax filings, and excluded the value of materials returned to the wholesaler (U.S. Census Bureau 2012c).

In the final step, we calculated the cost of materials, components, and supplies ($ USD) purchased by building general contractors (NAICS 236). The cost of materials included the value of building materials purchased by general contractors, which were subsequently installed during the construction, reconstruction, or repair of buildings. This included materials used directly by the general contractor or provided to subcontractors in order to complete the project work (U.S. Census Bureau 2012c). We examined the cost of materials purchased by all building contractor types (e.g., residential and non-residential construction) within the NAICS 236 classification to accurately measure the total demand for building materials generated at the state-level in 2012.

Once the volume of wholesale trade sales and the cost of materials, components, and supplies were measured, we calculated the state-level capacity utilization rate for the pre-disaster baseline year 2012. We calculated capacity utilization as the cost of materials, components and supplies ($ USD) over the value wholesale trade sales ($ USD). This provided a capacity utilization percentage for each state, as shown in Equation 3.

$$[3]\ \text{Capacity Utilization} = \frac{\text{Cost of Materials, Components, and Supplies (\$)}}{\text{Wholesale Trade Sales (\$)}}$$

4.2.2 Post-Disaster Damages and Reconstruction

In this section, we provide the methods for identifying and measuring post-disaster economic damages and reconstruction progress for single-family houses in the states of New Jersey and New York after Hurricane Sandy. After FEMA contractors concluded their on-site inspections of residential houses affected by Hurricane Sandy, as part of the FEMA IA program requirements, the assessed damage value for each home was recorded (FEMA 2008). In order to protect privacy, damages were reported at the state-level for New Jersey and New York. We examined data only for residential homeowners and excluded losses incurred by renters. We then tracked the total: number of potentially damaged homes identified by FEMA, number of homes inspected by FEMA contractors, and the assessed economic value of the damage caused by the hurricane (FEMA 2014). Specifically, the FEMA assessed disaster damages represented the Net Value of construction work that needed to be completed to repair or replace housing units in New Jersey and New York. Additionally, we identified post-disaster single-family residential reconstruction progress that occurred in both states between the end of 2012 and the end of 2015, using housing unit counts provided by the U.S. Census American Community Survey (U.S. Census Bureau 2012b). By tracking the total number of single-family residential housing units within each state, we can calculate the percentage of destroyed housing units that had been replaced.

5 RESULTS

Pre-disaster construction capacity is measured as the composite of labor productivity and capacity utilization. We calculated construction capacity for the residential construction industry sub-sector at the national-level and within the states of New Jersey and New York. We then compared construction capacity results with post-disaster FEMA damage assessments and housing unit reconstruction.

5.1.1 Pre-Disaster Construction Capacity – Labor Productivity

Pre-disaster labor productivity rates are critical, as they determine how quickly residential contractors can mobilize state resources in a post-disaster setting and begin the process of rebuilding homes. We calculate labor productivity, at both the national and state-level, as the Net Value per residential building contractor establishment (Table 1). For example, there were 108,235 residential contractors (NAICS 236115 and NAICS 236118) operating in the U.S. in 2012, and they created approximately $62.4 billion dollars Net Value of construction work. This indicates that the U.S. national-level annual labor productivity was $576,505 per residential contractor establishment in 2012. Additionally, we measured labor productivity rates in New Jersey and New York, two states with extensive residential housing damages due to Hurricane Sandy. There were 3,440 residential contractor establishments located inside New Jersey in 2012, and they installed over $2.0 billion dollars Net Value of construction work. This generates a labor productivity rate of $601,365 per residential contractor establishment. The state of New York had 9,651 residential contractors in 2012, and they created over $4.8 billion dollars Net Value, which generates a labor productivity rate of $504,265 per residential contractor establishment.

Comparison of annual labor productivity rates for residential contractors, at the national and state-level, allows us to understand how effectively labor resources are being utilized within a defined geographic area. For example, New Jersey had a higher residential contractor labor productivity rate than New York and the U.S. average. This indicates that residential contractors in New Jersey were more efficiently completing building projects on an annual basis. In contrast, the low labor productivity rate for New York indicates that residential contractors were significantly less efficient in utilizing their available workforce to complete residential housing projects.

Table 1: 2012 Pre-Disaster Construction Capacity – Labor Productivity

Location	Net Value Construction *($ USD)*	Contractor Establishments *(Total #)*	**Labor Productivity Rate** *(Net Value/ Contractor Establishment)*
New Jersey	$2,068,695,000	3,440	$601,365
New York	$4,866,655,000	9,651	$504,265
U.S. Totals	$62,398,058,000	108,235	$576,505

*Includes establishments classified as NAICS 236115 or NAICS 236118

5.1.2 Pre-Disaster Construction Capacity – Capacity Utilization

Here we measure and compare capacity utilization rates at the U.S. national-level and at the state-level for New Jersey and New York (Table 2). For example, the U.S. national residential construction industry has a 2012 pre-disaster capacity utilization rate of 86.6%, representing excess building material inventories within the national supply chain network (Fevolden 2015). Similarly, New Jersey has a capacity utilization rate of 86.9%. Demand for building material generated by building contractors (NAICS 236) located and operating within the state does not exceed the available supply. In contrast, New York has a capacity utilization rate of 124.5%, signifying demand for building materials generated within the state far exceeds the available material supply.

Table 2: 2012 Pre-Disaster Construction Capacity – Capacity Utilization

Location	Cost of Materials, Components, & Supplies *($ USD)*	Wholesale Trade Sales *($ USD)*	**Capacity Utilization** *(Cost Materials/ Wholesale Sales)*
New Jersey	$3,441,000,000	$3,961,886,000	86.9%
New York	$8,343,926,000	$6,699,996,000	124.5%
U.S. Totals	$117,449,856,000	$135,688,498,000	86.6%

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

5.1.3 Post-Disaster Damages and Reconstruction

Pre-disaster construction capacity affects whether state-level residential construction industries, and the associated supply chains that facilitate access to construction resources, have enough available labor and materials to quickly rebuild permanent single-family residential housing in a post-disaster setting. Here, we measure the post- Hurricane Sandy demand spike for residential construction services in terms of economic damages, as assessed by FEMA (FEMA 2008, 2014) and highlighted in Table 3. Additionally, we track the progress of single-family residential housing reconstruction after Hurricane Sandy, based on state-level housing unit counts (U.S. Census Bureau 2012b).

Within New Jersey, FEMA IA on-site inspectors identified over $705 million dollars in damages for residential single-family homes after Hurricane Sandy. This represents the sudden post-disaster demand for additional Net Value of construction work that must quickly be completed within the state. With a 2012 pre-disaster state Net Value of just over $2.0 billion dollars, the post-disaster need for reconstruction and repair work from Hurricane Sandy increases annual residential construction demand within New Jersey by 34.1%. The average residential contractor in New Jersey is only able to install $601,365 of Net Value (pre-disaster labor productivity) within the state each year. Based on the state labor productivity rate, New Jersey will require approximately 1,170 additional residential contractor establishments to provide construction services in the state, to repair and replace all damaged residential houses within one year. Without a massive influx of residential contractor labor into New Jersey, existing residential contractors within the state will need more than one year to repair and replace residential homes damaged or destroyed by Hurricane Sandy. This emanates from the post-disaster housing unit counts for single-family residential houses in New Jersey between 2012-2015. Directly prior to Hurricane Sandy, there were nearly 1.92 million single-family residential housing units located within New Jersey. A year later, the state contained 15,838 fewer single-family homes. By the end of 2015, New Jersey still needed to reconstruct over 10,000 single-family residential houses to return to 2012 pre-disaster housing counts.

In the state of New York, FEMA inspectors found nearly $1.5 billion dollars in damages for single-family residential houses due to Hurricane Sandy. New York has a 2012 pre-disaster state Net Value of nearly $4.9 billion dollars. The FEMA assessed damages represent a 30.2% sudden demand spike for residential construction services due to Hurricane Sandy. The typical residential contractor in New York generates $504,265 Net Value construction work annually within the state. Based on this labor productivity rate, New York requires approximately 2,910 additional residential contractor establishments to enter the state-level construction supply chain, to replace damaged single-family housing units within one year. Without a huge increase in labor availability or productivity, New York will need more than one year to repair and replace the damaged single-family residential housing stock. Prior to Hurricane Sandy, there were approximately 3.4 million single-family residential housing units located in New York. A year after the disaster, there were 17,185 fewer housing units existing within the state. However, by the end of 2015 the New York residential construction industry had to reconstruct less than 900 single-family residential housing units to restore the total housing unit count back to pre-disaster levels.

Table 3: Single-Family Residential Housing Counts and Damages

Location	2012 Single-Family Housing Units *(Total #)*	2013 Single-Family Housing Units *(Total #)*	Damaged Homes Identified by FEMA *(Total #)*	FEMA Assessed Damages *($ USD)*
New Jersey	1,919,531	1,903,693	150,243	$705,097,172
New York	3,411,632	3,394,447	152,805	$1,468,436,200

*Based on data from the *American Community Survey* 1-year estimates and *FEMA IA program*

6 DISCUSSION

Our results indicate that construction capacity, measured in terms of labor productivity and material capacity utilization, varies significantly between states. We originally hypothesized that state-level pre-disaster construction capacity determines how quickly post-disaster single-family residential reconstruction occurs. However, our study findings appear, at first glance, to be counterintuitive. For example, New Jersey's pre-disaster construction capacity suggests the state-level construction industry was more efficient than neighboring New York. The high labor productivity rate for residential contractors indicates single-family homes were being built quickly. A lower capacity utilization rate shows building material availability, which can help to absorb the impact of post-disaster demand shocks within the state supply chain (Fevolden 2015; Gill 2015). Yet, New Jersey has taken longer than New York to reconstruct damaged or destroyed single-family residential housing after Hurricane Sandy.

Ultimately, disaster recovery is not carried out consistently across the U.S. by the federal government, but rather implemented by each individual state (FEMA 2013; HUD 2013). State-level decisions dealing with the residential housing reconstruction process, as well as how disaster funding is made available to homeowners, affect when construction industry supply chain resources can be utilized. For example, New Jersey required homeowners to use pre-approved building contractors to perform residential housing reconstruction work, to receive public disaster financial assistance. Project bid estimates had to be reviewed and approved by the state housing recovery officials before work could begin (FEMA 2013; HUD 2013). New Jersey homeowners that did not hire pre-approved contractors were often not eligible for state-funded disaster grants and loans. Despite the efficient pre-disaster construction capacity within the state, homeowners were forced to wait on funding before they could utilize state-level supply chain resources, slowing down the entire reconstruction process.

At the same time, New York opened state finances to subsidize single-family residential reconstruction and later asked to be reimbursed by the federal government (HUD 2013). This allowed New York homeowners to quickly hire residential contractors from across the entire Northeast region. Although New York's pre-disaster capacity utilization was over 100%, indicating material demand exceeded supply, residential contractors could purchase building materials within New Jersey where there was excess inventory. With homeowners in both New Jersey and New York competing for the same finite construction labor and material resources, New York homeowners had an advantage in the residential reconstruction process by hiring residential contractors earlier.

7 CONCLUSIONS

Economic losses associated with hurricanes are rapidly increasing in the U.S., in part due to rising levels of urbanization along the Atlantic Ocean coastline (FEMA 2013; HUD 2013). Despite the increasing vulnerability of the U.S. residential building stock to hurricane related storm surge and coastal flooding, minimal research has examined how pre-disaster construction industry resources affect post-disaster rebuilding of residential houses. To address this gap, our research explores how pre-disaster construction capacity affects post-disaster reconstruction of single-family residential housing in New Jersey and New York following Hurricane Sandy. *Construction capacity*, defined here as the maximum building volume a construction industry can supply due to supply chain availability of labor and materials, is measured in terms of labor productivity and capacity utilization.

Results indicate that pre-disaster labor productivity and capacity utilization vary significantly at the national and state-level, especially within the residential construction sub-sector. Prior to Hurricane Sandy, New Jersey had an excess supply of building materials within the state-level supply chain (e.g., capacity utilization below 100%) while demand for building materials far outpaced supply in the state of New York (e.g., capacity utilization above 100%). New Jersey also had a more efficient labor productivity rate than both New York and the national average for residential contractor establishments. However, a year after Hurricane Sandy, reconstruction of single-family homes lagged in New Jersey in comparison to New York. The reason for the delay is likely twofold: New Jersey had stricter regulations that required pre-approved residential building contractors perform reconstruction work, and homeowners often could not collect disaster funding through the state until their reconstruction paperwork was officially approved. Although comparison of state-level pre-disaster construction capacity and post-disaster reconstruction trends provides insight into how supply chain resources affect disaster recovery, more research is needed. Our study examines only a two-case cross comparison for a single disaster event. Future work will explore how construction supply chains cross state boundaries and how construction capacity can be measured at a smaller regional scale.

Our research adds to the limited construction supply chain management literature by identifying construction capacity as an important indicator of efficient construction supply chains. Disruptions to existing constructions supply chains, such as major disaster events, can cause sudden spikes in demand for construction services which strain existing labor and material resources. Using a novel measurement method, our study is one of the first to quantitatively analyze a construction industry sub-sector (e.g., residential construction) at the national and state-level, or to quantitatively measure increased construction demand due to a disruption within a state-level construction supply chain. In terms of practical implications, this study provides a measurement method that can assist in pre-disaster preparedness planning between state-level government agencies and the construction industries responsible for post-disaster reconstruction of residential houses. Although the construction industry's critical role in repairing and replacing residential houses destroyed by natural disasters is well acknowledged, there remains a lack of pre-disaster coordination between local governments, homeowners, and the construction industry. Through identification and measurement of pre-disaster state-level construction supply chain resources, this research seeks to start a dialogue between stakeholders that will ultimately coordinate residential reconstruction efforts after future disaster events.

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