

CONSTRUCTION CAPACITY: HOW REGIONAL CONSTRUCTION SUPPLY CHAINS RESPOND TO DISRUPTIONS

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A thesis submitted to the
Faculty of the Graduate School of the
University of Colorado in partial fulfillment
of the requirement of the degree of
Doctor of Philosophy

Department of Civil, Environmental, and Architectural Engineering

2018

This thesis is entitled:

**Construction Capacity:
How Regional Construction Supply Chains Respond to Disruptions**

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ABSTRACT

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Construction Capacity: How Regional Construction Supply Chains Respond to Disruptions

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The U.S. construction industry continues to recover from the global economic recession of 2007-2009 but is but is hampered by regional craft labor shortages and unsteady building material manufacturing output. The availability and efficient use of construction supply chain labor and material resources is critical at the regional level, since smaller geographic scales are more susceptible to labor shortages and inadequate material supply. A lack of regional labor and material availability – the regional construction capacity – often results in project schedule delays and inflated material prices. This dissertation introduces the concept of construction capacity, defined for the first time here as *the maximum building volume a construction industry can supply due to regional supply chain availability of labor and materials*.

To explore how regional supply chain labor and material availability affect construction industry supply and demand mechanisms, this research quantitatively analyzed construction capacity across 179 regions covering the entire U.S. The overarching dissertation research questions asks: *How does regional construction capacity affect the construction industry's ability to respond to unanticipated disruptions of supply and demand?* The methods elaborated in this research contribute to the body of knowledge by: (1) introduces a novel quantitative method for identifying and measuring regional construction capacity, based on unit labor costs and capacity utilization metrics, (2) analyzes how regional construction industry market conditions and socio-economic conditions determine regional construction capacity, and (3) introduces a novel

quantitative model to predict regional post-disaster residential housing reconstruction, based on regional pre-disaster construction capacity. The main theoretical contribution of this work fills the gap in existing literature regarding quantitative, industry-level, and regional construction supply chain performance. This research also adds to the literature regarding the economic performance of regional construction industries, building upon concepts from supply chain theory, economic geography theory, and the economic theory of market-driven resource supply.

ACKNOWLEDGEMENTS

This dissertation has only been made possible through the support of my family and the invaluable guidance and mentorship of my professors and peers at the University of Colorado Boulder. First and foremost, I want to thank my family for supporting my long journey towards a doctoral degree. My father Marion Arneson has always encouraged me to dream big and have ambitious goals, but to remember to keep my feet on the ground. My mother Patricia Arneson's career as a professor and life-long pursuit of learning has inspired my own interest in mentoring students, teaching, and research.

During my first year at the University of Colorado Boulder, I served as a research assistant on a National Science Foundation funded-project examining post-disaster recovery and resilient communities. This study was unique not only for being collaborative and interdisciplinary but was led almost entirely by female engineers and researchers. In particular, I would like to thank the faculty involved in our NSF study for encouraging me to pursue research and supporting my early doctoral studies. This includes: post-doctoral student Derya Deniz, as well as Drs. Shideh Dashti, Abbie Liel, Leysia Palen, Leah Sprain, and my advisor Dr. Amy Javernick-Will.

As I continued my doctoral studies at the University of Colorado, I also worked closely with a group of peers. These fellow students have expanded my understanding of construction industry and disaster management theory and practice and helped improve my research and writing capabilities. This includes the former students who set the standard for me to follow: Drs. Eric Antillion, Arthur Antoine, Wesam Beitemal, Cristina Poleacovschi, Jessica Kaminsky, Kyle Kwiatkowski, Kaitlin Litchfield, Aaron Opdyke, Scott Stanford, Ulises Techera, John Wanburg, and Jeff Walters; my former undergraduate research assistant Whitney Thomas; as well as current students Sarah Al-Haddad, Wael Alruqi, Dylan Hardison, Matthew Sears, and Nicholas Valcourt.

I also need to acknowledge other professors and peers from our department. Over the course of the past year, my colleagues have been a rock of support during the unexpected challenges of graduate school and life, and I owe them a huge debt of gratitude. These people believed me, believed in me, and encouraged me to speak up and be a leader. I am humbled and honored to have worked with Dr. Keith Molenaar, Siddhartha Bhandari, Allie Davis, James Harper, Shaye Palagi, Kimberly Pugel, Andrew Tracy, and Casie Venable.

Additionally, I'd like to thank my committee members: Drs. Ross Corotis, Paul Goodrum, Matthew Hallowell, Leah Sprain, and Amy Javernick-Will. Dr. Ross Corotis provided guidance as an advisor in the U.S. Department of Education's Graduate Assistantship in Areas of National Need (GAANN) fellowship program, which funded the majority of my doctoral studies. Dr. Paul Goodrum and Dr. Leah Sprain supplied important insights into my construction industry and post-disaster communications research, respectively.

Most importantly, I owe thanks to my co-advisors Dr. Matthew Hallowell and Dr. Amy Javernick-Will. You have both shaped my way of thinking and driven me to research the U.S. construction industry in ways I never thought possible in the early days of graduate school. Dr. Hallowell pushed me to have the confidence to believe in my work and capabilities, and to brave the world of quantitative data. Dr. Javernick-Will has continually challenged me to think big ideas and demand more of myself and my research. I also recognize Dr. Javernick-Will for being a role model, advocate, and going above and beyond for her graduate students. Your combined mentorship helped prepare me for the academic job market, and I look forward to being a future colleague while serving as an Assistant Professor of Construction Management at Colorado State University.

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CHAPTER 1 – INTRODUCTION

The U.S. residential construction industry is highly susceptible to disruptions of normal operating conditions at the national level. Over the past two decades, economic downturns and recessions have repeatedly hindered the residential construction sector's ability to generate consistent levels of output, maintain efficient construction industry supply chains, and retain a skilled craft labor workforce (U.S. Bureau of Labor Statistics 2016). Such economic disruptions have typically resulted in long-term reductions in construction labor availability (Henderson 2013) and decreased production and manufacturing of building materials (Haiyan 2009). Post-disruption recovery of residential construction industry labor and material capacity is typically slow, lasting much longer than the recession itself, as highlighted in Figure 1-1.

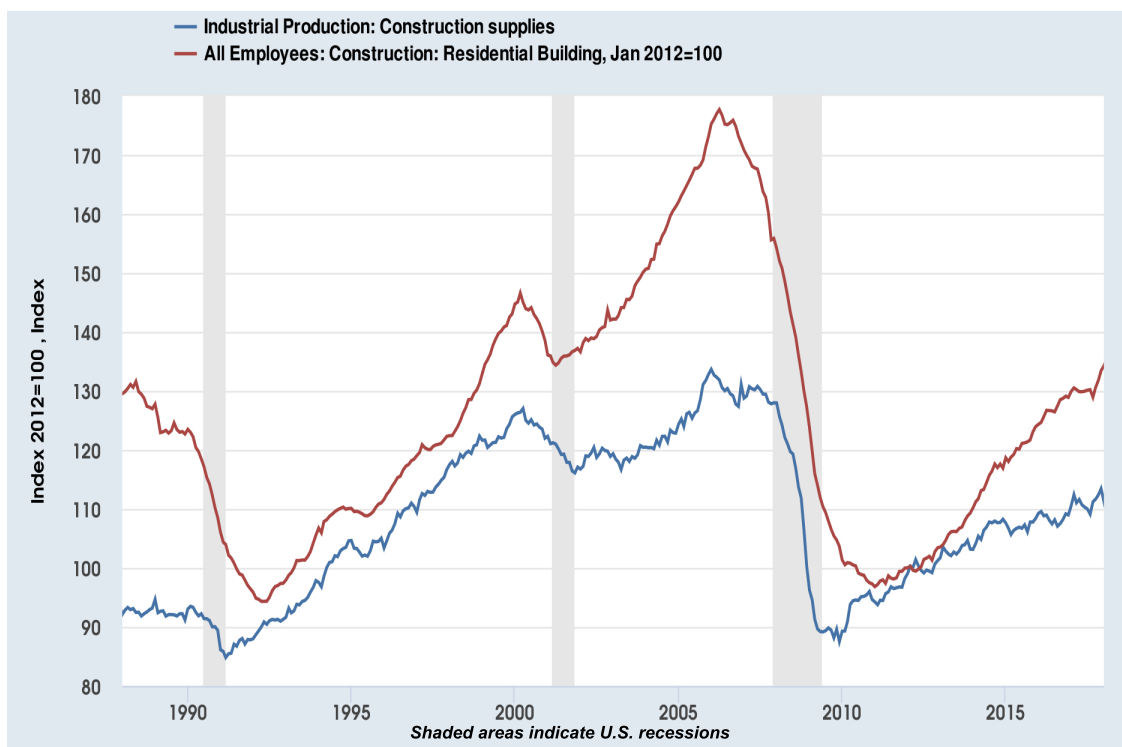


Figure 1-1. U.S. Residential Construction Industry Labor and Material Supply¹

¹ Data Source: (U.S. Bureau of Labor Statistics 2016); Index sets a base year of 2012 = 100

The ability of a regional construction industry to meet the demand for construction services is driven by the availability of construction material and labor resources within the surrounding regional construction supply chain (Arneson et al. 2016; Moon et al. 2015). Supply chains, defined as an integrated series of processes and businesses that work together to provide a forward flow of materials, labor, or services (Chen and Paulraj 2004), facilitate resource sharing within regional construction industries. When supply chains function efficiently, the flow of goods and services are delivered on time, to the correct location, in a cost effective method (Christopher and Peck 2004). However, when supply chains are disrupted, by either man-made or natural hazard events, the effects can be far-reaching.

Disruptions to regional residential construction industries also creates unstable construction resource availability, and access to material and labor resources varies significantly across regions (Sodhi et al. 2012). The residential construction industry and construction supply chains are highly vulnerable to disruptions at the regional level, due to the site-specific nature of the industry (Delgado et al. 2014). Past studies have shown the destabilizing effects of natural disasters (Hwang et al. 2015; Zhang and Peacock 2009), political uncertainty (Aldrich 2012b; Kleindorfer and Saad 2005), terrorist attacks (Kendra and Wachtendorf 2003), and labor shortages (AGC 2017a) to regional industries and supply chains. When unexpected disruptions strike, regional construction supply chains becomes strained and hinder access to labor and material resources (Gosling et al. 2013). A lack of regional labor and material availability – the regional construction capacity – often results in post-disruption inflated material prices (Auernheimer and Trupkin 2014) and delayed project schedules (Vereen et al. 2016). Regional ***construction capacity*** is defined for the first time in this research as ***‘the maximum building volume a construction industry can supply due to regional supply chain availability of labor and materials.’*** I

hypothesize that the amount of regional construction capacity that exists before a disruption occurs determines how well regional residential construction industries meet consumer demand for housing and other construction services after a disruptive event occurs.

While construction supply chain capacity differs between regions, material and labor resource availability is currently only tracked at the national level based on aggregated data for all sectors of the construction industry, and does not reflect regional supply chain variability (Delgado et al. 2016; Porter 2003). This dissertation explores the concept of regional construction capacity, and aims to improve regional responses to disruptive events addressing the following overarching question: *How does regional construction capacity affect the construction industry's ability to respond to unanticipated disruptions of supply and demand?*

Towards this goal, I propose a novel method to define and measure pre-disruption supply chain resources, both labor and materials, which drive the U.S. residential construction market. Through quantitative analysis of publicly available datasets provided by the U.S. federal government, I examine how regional construction industries, and their associated supply chain resources, can meet fluctuating post-disruption residential building demands.

RESEARCH FRAME AND RATIONALE

To provide a clear framework for examining how regional construction capacity hinders or facilitates regional construction industry responses to disruptive events, this dissertation has a defined scope of study. The research delineates: (1) the industry sector affected by disruptions, and (2) the type of disruptive event itself. Specifically, the scope of the dissertation focuses on the role of regional construction capacity in the U.S. residential construction sector (Chapters 2 and 3) after natural disaster events (Chapter 4).

Residential Construction Industry

The residential construction industry is fragmented and spread across geographical areas of the U.S., suggesting a regional perspective provides a more realistic examination of project labor and material availability (Chen and Paulraj 2007). To fully understand how construction capacity varies across regions due to uneven labor and material availability, it is necessary to examine the residential construction industry's supply chain. For example, on a typical residential construction project the end user is the homeowner, who finances and procures the services of a general contractor, generating demand for construction services. On the supply side, material suppliers and building contractors work together to meet end user demand for construction services, as shown in Figure 1-2.

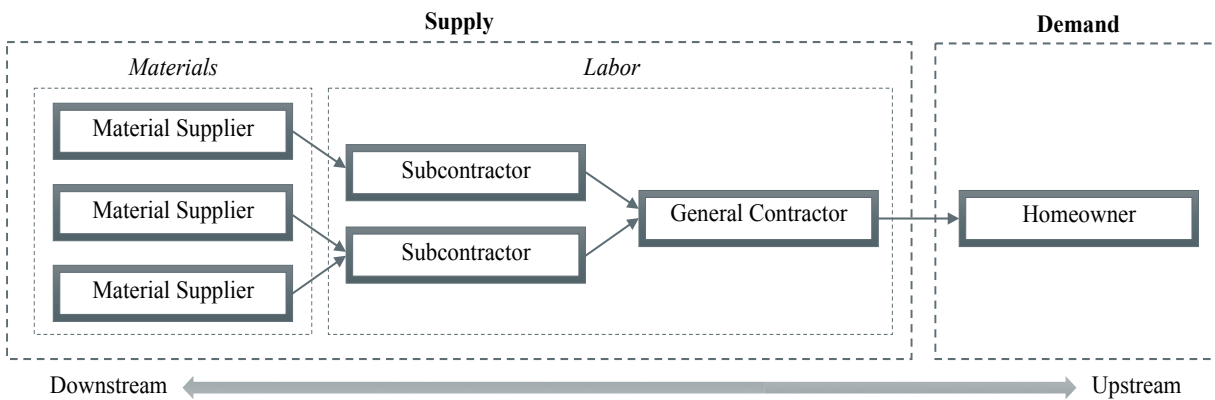


Figure 1-2. *Project-Level Construction Supply Chain*

However, nearly all of the supply chain management literature has focused on project-level supply chains for individual projects and firms, using case study methods. Regional construction supply chain resources are difficult to quantitatively measure due to the complex movement of labor and materials, and are understudied in the field of construction management (Chen and Paulraj 2007). Therefore, advances in quantitatively measuring construction supply chain capacity are still needed to improve our understanding of regional-scale and industry-level supply chains.

Natural Disasters

Disasters are a type of weather-related disruption that can wreak havoc on regional economies and construction industries. Disasters create sudden demand spikes for residential construction, which regional construction industries must supply to facilitate long-term recovery of the region (Kates et al. 2006). The U.S. residential housing stock is particularly vulnerable to disaster events, due to common building materials used in construction and the nature of the U.S. housing market. For example, nearly 90% of the residential building stock in the U.S. is comprised of light-frame wood construction (Ellingwood et al. 2004; Standohar-Alfano and van de Lindt 2015), which is extremely vulnerable to wind loads, flood waters, fire, and other natural hazards. Additionally, the U.S. housing market is driven primarily by private financing and insurance funding after disasters. Although the reestablishment of permanent residential housing is considered critical to regional socio-economic recovery (Cantrell et al. 2012a; FEMA 2009), the existing literature on coordination of post-disaster construction labor and material resources is limited (Gill 2015; Halman and Voordijk 2012).

RESEARCH QUESTIONS

The research presented in this dissertation aims to increase our theoretical and practical knowledge of the interconnected and complex relationships between regional construction capacity, supply chains, and post-disaster reconstruction efforts. A brief summary of the gaps in existing literature and the proposed dissertation research questions can be found in Table 1-1.

In *Chapter 1*, I introduce a novel quantitative method for measuring regional construction capacity, incorporating publicly available datasets from the U.S. Census Bureau and the Bureau of Labor Statistics. To measure regional construction capacity, my research incorporates existing methodology for calculating manufacturing industry labor efficiency and material availability. The

residential housing roofing sub-sector is used to illustrate construction capacity since there is a shortage of roofer labor supply across many regions of the U.S. This research has been submitted to the *ASCE Journal of Construction Engineering and Management*.

In **Chapter 3**, I examine similarities and disparities between regions to understand why the regional construction capacity of the residential construction industry varies across regions and over time. I identify and measure eleven regional indicators that reflect regional construction capacity, residential housing market, and socio-economic conditions found within each of the 179 economic regions of the U.S., as delineated by the Bureau of Economic Analysis (BEA). I follow a multi-step process that: (a) measures annual median values of indicators for the years 2007 and 2012; (b) assess statistical relationships between regional indicators based on correlation analysis; and (c) identifies common indicators of regions with high levels and low levels of regional construction capacity. This research will be submitted to the *Journal of Construction Engineering and Management*.

In **Chapter 4**, I compare how pre-disaster construction capacity affects post-disaster reconstruction of residential housing after natural disasters. I follow a multi-step process that: (a) measures annual regional pre-disaster construction capacity since 2002; (b) calculates annual multi-hazard disaster losses for single-family residential housing based on damage inspections conducted by the Federal Emergency Management Agency (FEMA); and (c) compares pre-disaster construction capacity to post-disaster housing reconstruction progress using a cross-case comparison. This process is completed for each of the 179 economic regions of the U.S. Results will be submitted to the ASCE's *Natural Hazards Review*.

Table 1-1. Research Gaps and Questions

Gaps in Literature	Chapter	Research Question
Limited understanding of how to identify, measure, and compare construction industry outputs or supply chain capacity at a regional scale.	2	<i>How can construction capacity be measured within the U.S., based on regional availability of construction industry labor and materials?</i>
Limited understanding of what conditions within a region lead to uneven levels of regional construction capacity, and why capacity changes over time.	3	<i>Why does the regional construction capacity of the residential construction industry vary over time and across regions?</i>
Limited understanding of how regional construction industries repair/replace damaged houses after disaster events.	4	<i>Does pre-disaster regional construction industry labor and material resource availability, when controlling for federal disaster capital availability, predict post-disaster regional reconstruction of residential housing units?</i>

RESEARCH METHODS

To address the gaps in existing literature and the research questions listed above, regional construction capacity was quantitatively assessed across economic regions of the U.S. The data collection and data analysis methods incorporated in this dissertation are very similar throughout Chapters 2, 3, and 4. I have provided a brief description of these research methods below, as summarized in Table 1-2.

Data Collection

This research utilized construction industry and manufacturing industry data from publicly available datasets published by the U.S. federal government. This included data from the U.S. Bureau of Economic Analysis, U.S. Bureau of Labor Statistics, U.S. Census Bureau, and the Federal Emergency Management Agency.

U.S. Bureau of Economic Analysis (BEA): Chapters 2, 3, and 4

To identify the construction capacity within a regional construction supply chain, the geographical areas of the regions were first established. Although construction supply chain management theory suggests that regional supply chains are the appropriate level to fully understand how the construction industry functions, there was no universal delineation or boundaries to define a ‘region.’ In order to systematically analyze regional construction supply chains in the U.S., this research incorporated pre-established economic and geographic regions developed by the U.S. Bureau of Economic Analysis (BEA). The BEA has designated 179 regional economic regions within the U.S., based on strong linkages between businesses, commuting patterns, shared labor and material markets, and shared economic development trends (Delgado et al. 2016; Porter 2003; U.S. Bureau of Economic Analysis 2016).

U.S. Bureau of Labor Statistics (BLS): Chapters 2, 3, and 4

The BLS tracks industry-level data for all sectors of the U.S. economy, including the construction industry. The BLS collects, analyzes, and publish data relevant to measuring construction capacity, in terms of NAICS manufacturing and employment statistics. BLS data is primarily limited to economic indicators of industry growth and employment, such as: wages, number of employees, and number of establishments. The North American Industry Classification System (NAICS) is used by the BLS to provide data at various industry levels based on (e.g., 2- to 6- digit NAICS code) and different geographical levels (e.g., national, state, and county) (U.S. Bureau of Labor Statistics 2016).

U.S. Census Bureau: Chapters 2, 3, and 4

The U.S. Census Bureau track individual-level and industry level data for geographic regions of the U.S. The Census Bureau primarily tracks annual changes in socio-economic

indicators for the resident population. Some industry-level data, including for the construction industry, is tracked through programs conducted every five to ten years based on NAICS 2- to 6-digit codes (U. S. Census Bureau 2015).

Federal Emergency Management Agency (FEMA): Chapter 4

FEMA is the arm of the federal government tasked with managing and supervising post-disaster recovery efforts in the U.S. FEMA also conducts on-site housing inspections after disaster to determine the damages incurred by residential houses due to disaster events. Additionally, as part of national transparency laws, FEMA is required to track and provide financial assessments of U.S. disaster events at the county-level (Federal Emergency Management Agency 2008).

Data Analysis

Multi-Level Data Analysis: Chapters 2, 3, and 4

Multi-level data analysis has been used throughout this dissertation to aggregate data sources into regional estimates of construction capacity and other construction industry metrics. The need for aggregating data in this method is due to data availability. The most recent and extensive economic data available about the U.S. construction industry and specific sub-sectors of the industry (based on NAICS codes) is from the U.S. Census' Economic Census program. However, the Economic Census is only conducted every five years and provides only state-level information. Regional estimates of construction industry economic data are developed using state-level averages.

Case Studies: Chapter 2

Case study comparative analysis of four regions is used in Chapter 2 to provide in-depth examinations of regional construction capacity metrics for the residential roofing sector. Since Chapter 2 was mostly devoted to the development of the novel quantitative method for measuring

regional construction capacity, the analysis was limited to the four case studies. Case study comparisons also allowed for more in-depth analysis of demographic and socio-economic conditions within each region, which may have affected construction capacity.

Correlation: Chapter 3

Statistical correlation analysis is used in Chapter 3 to explore if existing residential housing market or socio-economic conditions within a given region affect regional construction capacity. The ability of a regional construction industry to generate output, in the form of the net value of construction work put in place minus work subcontracted out, is directly linked to wages and employment. Pearson's r analysis has been conducted in Chapter 3 to examine correlations between regional construction capacity, residential housing market conditions, and socio-economic conditions.

Linear Regression: Chapter 4

Simple linear regressions techniques have been utilized in Chapter 4 to develop a model for predicting post-disaster reconstruction outcomes, based on available labor, material, and capital. Linear regression is used to determine how changes in the independent variables (e.g., regional labor, material, and capital availability) affect the independent variable (e.g., post-disaster housing reconstruction).

GIS mapping: Appendix B

Chapter 3 examines why construction capacity metrics vary across regions and change over time. As part of the early exploratory research into regional construction capacity, geospatial information systems (GIS) were used to map capacity metrics. Since there are 179 BEA economic regions, visualizations of capacity facilitated my understanding of the spatial component of construction capacity. Although the mapping exercises proved extremely useful for my own

understanding of how construction capacity changes over time, the maps were ultimately not included in Chapter 3. However, results of the mapping exercises can be found in Appendix B.

Table 1-2. Data Collection and Analysis Summary

Chapter	Methods	Data Sources
2	Multi-Level Data Analysis	U.S. Bureau of Economic Analysis (BEA) U.S. Bureau of Labor Statistics (BLS)
	Case Study	U.S. Census Bureau
3	Multi-Level Data Analysis	U.S. Bureau of Economic Analysis (BEA) U.S. Bureau of Labor Statistics (BLS)
	Pearson's r Correlation	U.S. Census Bureau
4	Multi-Level Data Analysis	U.S. Bureau of Economic Analysis (BEA) U.S. Bureau of Labor Statistics (BLS)
	Linear Regression	U.S. Census Bureau Federal Emergency Management Agency (FEMA)

DISSERTATION FORMAT

This dissertation follows a journal article format, so that Chapters 2, 3, and 4 are written as standalone journal articles. Each chapter has its own list of references, which are compiled into a complete list presented at the end of this work. The introductions to each chapter, though different, may repeat aspects of the theoretical basis of this work. A summary of gaps in the existing literature that this research aims to fill, plus a list of chapter research questions is provided above in Table 1-1. Additionally, the chapter research methods sections detail similar data collection and data analysis, and there is some duplication of information. A summary of data sources and methods is provided above in Table 1-2. I respectfully request that citations for work published in Chapters 2, 3 and 4 reference final journal articles instead of this dissertation. Over-arching theoretical contributions, practical contributions, and findings are discussed in Chapter 5. Although each chapter has its own list of references, Chapter 6 provides a list of all references used throughout the dissertation. Finally, this dissertation includes appendices that further explain how this final

dissertation research came to be. Appendix A includes a list of publications completed during this dissertation research that complement and expand upon results provided in Chapters 2, 3, and 4. Appendix B provides the GIS mapping outputs that were created as part of the exploratory research into why construction capacity varies across regions.

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CHAPTER 2 - DEFINING AND MEASURING REGIONAL CONSTRUCTION CAPACITY FOR RESIDENTIAL CONSTRUCTION

ABSTRACT

The U.S. residential construction industry is continuing to recover from the Great Recession of 2007-2009 but is hampered by craft labor shortages and unsteady building material manufacturing output. The availability and efficient use of residential construction supply chain labor and material resources is critical at the regional level, since smaller geographic scales are more susceptible to labor shortages and inadequate material supply. This study introduces the concept of construction capacity, defined for the first time here as the maximum building volume a construction industry can supply due to regional supply chain availability of labor and materials. Its use is illustrated with the U.S. residential roofing sector, but it can be applied to other residential construction sectors and other countries. The residential roofing sector is used to illustrate the applicability of the proposed method, since the U.S. is experiencing ongoing roofer craft labor shortages and decreased production of roofing materials since the Great Recession. Building upon supply chain management theory to identify the regional network of labor and material organizations that comprise the residential roofing sector, the research presented here introduces a novel quantitative method for measuring regional construction capacity, based on unit labor costs and capacity utilization metrics, using publicly available datasets. The method elaborated in this paper contributes to the body of knowledge by identifying and measuring regional construction capacity. This allows regional residential construction industries to determine their capacity and the extent to which they can withstand a disturbance or shock.

KEYWORDS: Construction Capacity, Regional Supply Chains, Residential Construction

INTRODUCTION

The U.S. residential construction industry is highly susceptible to unexpected disruptions in normal operating conditions (Halman and Voordijk 2012). Disruptive events, both natural and man-made, often result in sudden demand spikes for residential construction services. As seen with recent hurricanes Harvey and Irma, disruptive events such as natural disasters can destroy large amounts of the existing U.S. residential housing stock, requiring swift repair and replacement of damaged houses. Similarly, many regions of the U.S. are currently vying to be Amazon's secondary national headquarters, but the large influx of tech workers will require the residential construction industry to quickly build thousands of new residential housing units. However, due to the site-specific and local nature of residential construction, the ability of the residential construction industry to meet demand for residential housing is contingent on regional availability of craft labor and building materials (Delgado et al. 2014). Therefore, quantitative measurements of regional-level residential construction labor and material resources are needed to assess the impact of disruptive events on regional residential construction industries.

Although the lack of craft workers and building materials has received attention from researchers and the construction industry, most quantitative studies have focused on a national unit of analysis rather than examine regional industries, resources, or economies (Rojas and Aramvareekul 2003). However, residential construction projects are typically performed at the regional-level (Chancellor and Lu 2016), and it is therefore imperative that construction resource availability is analyzed regionally as well. The site-specific nature of residential construction work necessitates the use of local craft workers and building materials, which the surrounding regional construction industry must have the capacity to provide. Furthermore, durable goods-producing

industries like construction are inherently local industries that rely on regionally available goods, services, and labor (Porter 2003). Importantly, smaller geographic regions are more susceptible to construction supply chain disruptions, labor shortages, and material scarcity (Sodhi et al. 2012; Tserng et al. 2006). Recognizing the importance of regions, the term regional *construction capacity* is introduced here as the maximum building volume a regional construction industry can supply with available resources.

Within this paper, a method is proposed to define and measure regional residential construction industry resources, in the context of available labor and materials. The residential roofing sector is used to illustrate the applicability of the proposed method, but the approach can be used for the broader residential industry, other residential construction sub-sectors, and even in other countries using respective governmental datasets. Reasons why we chose the residential roofing sector for illustration here is the fact that the residential roofing supply chain consists of a labor force working on one specific scope of work while installing one particular building material. Residential roofing material supply chains are particularly vulnerable to sudden demand surge associated with extreme weather events, where demand quickly outpaces the available material supply. Unexpected material demand surge makes it difficult for manufacturers to anticipate demand, often resulting in severe regional shortages of asphalt shingles (Olsen and Porter 2011). In addition, the residential roofing sector has experienced significant craft labor shortages (AGC 2017) and decreased manufacturing and production of roofing materials since the Great Recession (U.S. Census Bureau 2002a; b, 2007).

Access to roofing sector resources has become constrained throughout the U.S. since the Great Recession of 2007-2009, with craft labor shortages and decreased material inventories. In a recent national survey, 41% of construction firms reported difficulty securing roofers for projects

in the past year (AGC 2017a). Craft labor annual average employment within the residential roofing sector has declined by nearly 23% from 2007-2012, similar to the decrease of 26% experienced across all specialty construction trades (U.S. Census Bureau 2002b, 2007). Additionally, the annual growth in manufacturing of non-wood roofing materials (e.g. asphalt shingles) has slowed from about 7% annual growth pre-Recession (2002-2007) to less than 2% annual growth post-Recession (2007-2012) (U.S. Census Bureau 2002a; b, 2007). These construction labor and material shortages are impacting project performance. Karimi et al (2017) found clear statistical evidence that projects experiencing shortages in qualified craft labor also experienced lower productivity and greater schedule overruns. Furthermore, Dai et al. (2009) and Rojas and Aramvareekul (2003) found the lack of available materials are also negatively impacting craft productivity.

Specifically, this study uses quantitative analysis to examine how the residential roofing sector of the U.S. construction industry, and associated regional residential supply chain resources can meet residential roofing sector demands. Supply chains, defined as an integrated series of processes and businesses that work together to provide a forward flow of materials, labor, or services (Chen and Paulraj 2004), facilitate resource sharing within regional construction industries. Construction capacity is limited by the availability of regional construction supply chain resources, such as craft labor and building materials, (Halman and Voordijk 2012; Moon et al. 2015). To study this phenomenon, the research team addresses the research question: ***How can regional construction capacity be measured within the U.S., based on regional availability of residential construction industry labor and materials?***

LITERATURE REVIEW

To efficiently coordinate regional residential construction industry resource supply and demand, it is necessary to have a quantitative measurement of available labor and materials. Building upon concepts from supply chain management theory, a novel method for measuring regional construction capacity is proposed, based on two metrics: *unit labor costs* and *material capacity utilization*. Unit labor costs are routinely used in economic research regarding the European Union to measure and compare industry-level workforce availability and efficiency across member nations (Belke and Dreger 2013). Similarly, unit labor costs are incorporated into this research to measure and compare the economic performance of the residential roofing sector workforce across regions of the U.S. The concept of capacity utilization is often associated with unit labor costs, and is commonly used in the manufacturing industry to measure material supply and demand (Corrado and Matthey 1997). Capacity utilization rates are included in this research to measure the regional availability of residential roofing materials, based on typical regional supply and demand rates.

Supply Chain Management

Within the construction industry, supply chain management theory has been used to explain how the ability of individual firms to supply labor or materials is intrinsically tied to the capacity of a larger network of organizations (Gosling et al. 2013; Moon et al. 2015). This perspective considers supply chains as a series of interconnected business processes that can be documented, measured, controlled, and improved (Saad et al. 2002). However, the industry is fragmented and spread across geographical areas, suggesting a regional perspective provides a more realistic examination of project labor and material availability (Chen and Paulraj 2007). Regional construction supply chains have not been adequately studied due to a lack of available construction

industry-level data and the difficulty of modeling supply chains above the project-level (London and Kenley 2001).

Recently, researchers have started to explore the role of labor and material availability within construction supply chains. For example, Azambuja et al. (2014) found that although industrial construction firms value material supplier coordination, the lack of regional market data about supplier capabilities hinders collaboration between firms. Gosling et al. (2013) indicated that a lack of material supplier coordination results in higher project costs, schedule overruns, and increased uncertainty within construction supply chains. Similarly, Gill (2015) showed that by quantitatively measuring regional availability of construction material resources, residential contractors could better manage unexpected demand for construction services. Therefore, advances in quantitatively measuring construction supply chain capacity are still needed to improve our understanding of regional-scale and industry-level supply chains. Figure 2-1 illustrates the relationships between labor and material supply and demand within an industry-level regional residential roofing supply chain.

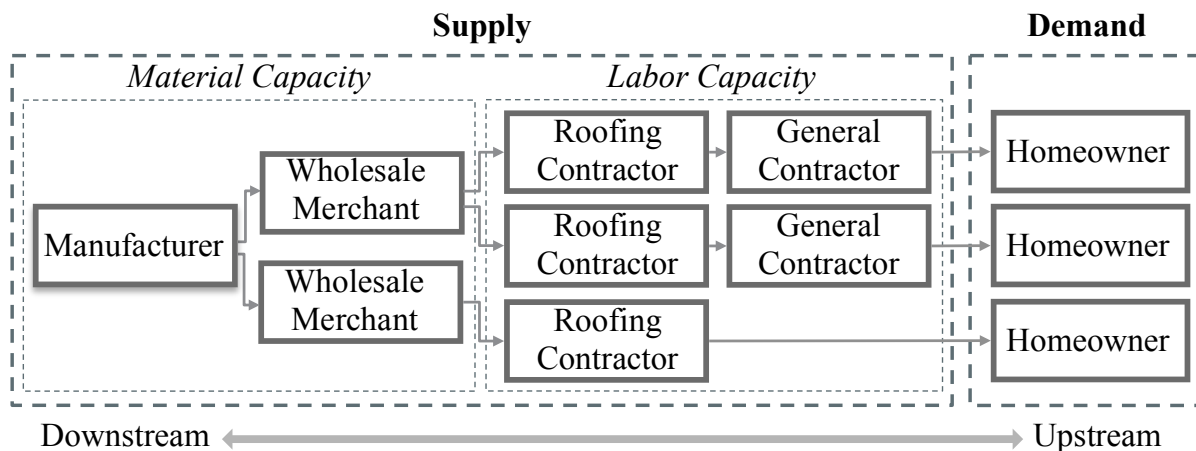


Figure 2-1. Regional-Level Residential Roofing Construction Supply Chain

Unit Labor Costs

Past research has shown that craft labor shortages vary considerably at the regional-level, especially within specific construction sectors (Goodrum et al. 2002). There is an established need for better quantitative labor measurements at smaller geographic scales, in terms of craft labor availability, output capabilities, and efficiency (Rojas and Aramvareekul 2003). Unit labor costs are defined here as labor compensation paid to laborers per value of output produced by said laborers. This ratio is an economic measure of how efficiently the labor workforce can transform raw inputs (e.g., building materials) into finished product outputs (e.g., installed residential roofing) (Pancotto and Pericoli 2014), Equation 2-1.

Equation 2-1. Unit Labor Costs

$$\text{Unit Labor Costs} = \frac{\text{Labor Compensation (\$)}}{\text{Production Output Value (\$)}}$$

Unit labor costs are a commonly used metric for many goods-producing sectors, to provide insight into the connection between wages, production output, and labor efficiency (Pancotto and Pericoli 2014). The U.S. Bureau of Labor Statistics (2017) tracks national unit labor costs for industries such as mining and manufacturing, but not the construction industry. Research by Dullien and Fritsche (2008) found that unit labor costs vary significantly across regions of the U.S. due to different tax structures, labor availability, and labor specialization within industry sub-sectors. Similarly, Belke and Dreger (2013) found that variances in unit labor costs across regions is more pronounced within industry sub-sectors, especially for cyclical industries such as construction.

Capacity Utilization

As the U.S. industrial and manufacturing sectors have matured, a measurement method was developed to match production capacity (e.g., supply) with customer purchase orders (e.g.,

demand). *Capacity*, defined here as the maximum resource output that can be sustained over time given normal working conditions, is a common measurement of production output used by the federal government and private manufacturing companies (Fevolden and Grønning 2010). The concept of capacity utilization, defined here as the ratio of current output, or demand, to the maximum capacity, or supply, is an indicator of efficient supply and demand relationships (Corrado and Matthey 1997) (Equation 2-2). When current output (demand) exceeds available capacity (supply), capacity utilization rises above 100%. High capacity utilization rates correspond with economic expansion but also indicate a lack of available materials within the supply chain and lead to inflated material costs. When capacity exceeds demand, capacity utilization falls below 100%, indicating a surplus inventory of materials within the supply chain (Mulligan 2016). Past research indicates a capacity utilization rate between 80%-82% is ideal for all industries since it correlates with a lack of material price inflation (Corrado and Matthey 1997).

Equation 2-2. Capacity Utilization

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

Recently, researchers have analyzed capacity utilization rates outside of the industrial and manufacturing industries. In a study on global port congestions, Maloni and Paul (2013) found that an imbalance between volume of shipped goods and capacity of ports leads to high capacity utilization rates above 100% and thus creates schedule delays. Similarly, a study within the electric transmission line industry by Boffa et al. (2015) found that capacity utilization rates below 100% decrease cost to consumers. However, there is a dearth of literature on the use and measurement of capacity utilization in the construction industry, although the importance of capacity utilization is clear, especially at the regional level.

RESEARCH METHODS

The purpose of this research was to develop a method for measuring the regional construction capacity of residential construction sectors. First, regional unit labor costs were calculated. Second, material capacity utilization was calculated. This study examined the roofing sector of the single-family residential construction industry because of ongoing roofer labor shortages (AGC 2017a) and the decline in roofing material production by the manufacturing industry since the Great Recession (U.S. Census Bureau 2002a; b, 2007). The applicability of the method was studied by measuring regional construction capacity within four regions of the U.S.

Data Collection

Quantitative data sets for regional construction industry supply chains were collected from the U.S. Bureau of Labor Statistics (BLS) and the U.S. Census Bureau. Multilevel data analysis was used to estimate regional construction capacity by identifying elements of residential roofing supply chains that influence regional construction industry supply and demand coordination mechanisms.

Residential Roofing Supply Chains

To measure regional construction capacity, organizational relationships within the single-family residential construction industry roofing sector supply chain were identified. Downstream manufacturers in the roof sector transform raw materials into non-wood roofing products such as asphalt shingles. Manufacturers sell and transport roofing products to merchant wholesalers, who in turn buy, store, and sell goods from a physical storefront location. Roofers then purchase roofing materials from merchant wholesalers. Furthest upstream in the residential roofing supply chain are the homeowners, who drive demand for residential roofing and provide project financing.

North American Industry Classification System (NAICS)

Data for roofing craft laborers and material wholesalers was collected based on the North American Industry Classification System (NAICS), which standardizes industry-level statistics and is used throughout the federal government (Office of Management and Budget and Executive Office of the President 2007). For example, a 2-digit NAICS code identifies an industry (e.g., NAICS 23 - construction), while 5-digit codes identify specific sub-sectors (e.g., NAICS 23816 - roofing contractors). Each U.S. establishment, a single physical location at which business is conducted, is also assigned a NAICS code by the BLS and Census Bureau (Office of Management and Budget and Executive Office of the President 2007). The researchers focused on establishments classified as NAICS 23816 – Roofing Contractors and NAICS 4233 – Roofing Merchant Wholesalers. According to the Census Bureau. Establishments classified as NAICS 23816 are engaged primarily in roofing, including new work, remodels, and upkeep (U.S. Bureau of Labor Statistics 2012; U.S. Census Bureau 2012a), and establishments classified as NAICS 4233 are merchants engaged in the wholesale distribution of lumber and other construction materials such as roofing (U.S. Census Bureau 2002b). The federal government’s ‘product and services code’ 10721 (U.S. Census Bureau 2002b), is used to specifically identify sales of non-wood roofing materials such as asphalt shingles, at wholesaler establishments.

Geographical Boundaries of Economic Regions

To systematically analyze construction capacity within regional supply chains, this research incorporated pre-established economic regions developed by the U.S. Bureau of Economic Analysis (BEA) (Johnson and Kort 2004). Figure 2-2 illustrates the boundaries of the BEA economic regions, with the four case study regions from this research marked in gray. There are 179 economic regions designated by the BEA within the U.S., based on business ties,

commuting patterns, and shared economic development trends (Delgado et al. 2016; U.S. Bureau of Economic Analysis 2016). The authors utilized the BEA economic regions for four reasons: 1) they encompass the entire U.S.; 2) they are comprised of aggregated clusters of U.S. counties and thus unlikely to change boundaries over time; 3) each region contains an economic labor market independent of any other labor markets; and 4) the regions have been shown to be statistically likely to share similar economic performance indicators like wages and employment (Porter 2003). Each region is anchored by an urban core that drives regional economic activity, and surrounding counties are grouped into regions based on statistical analyses conducted by the BEA (Johnson and Kort 2004).

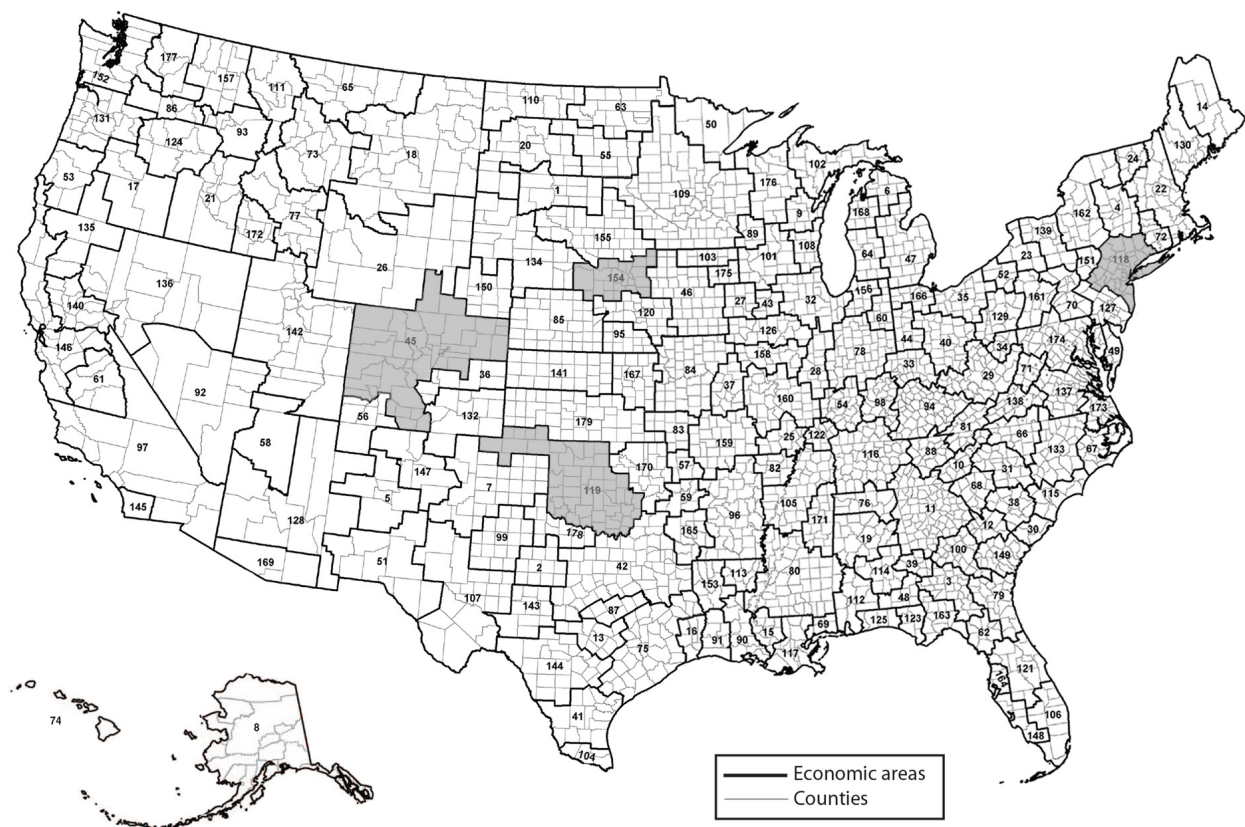


Figure 2-2. U.S. Bureau of Economic Analysis (BEA) Economic Regions

Datasets and Construction Capacity Indicators

Data relevant to measuring regional construction capacity was collected from the U.S. Bureau of Labor Statistics (BLS) and the U.S. Census Bureau, based on NAICS codes. This study used data from 2012, the most recently published construction industry economic indicators available from the federal government, as part of the 2012 Economic Census. Table 2-1 at the end of Chapter 2 provides further information about datasets and construction capacity indicators included in this study.

Construction material demand and production output metrics were collected from the Census Bureau's 2012 Economic Census – Construction Geographic Area Series (U.S. Census Bureau 2012b). There were two state-level capacity indicators collected from this construction series: (a) the cost of materials, components, and supplies (dollar cost of roofing materials purchased by roofers classified as NAICS 23816), and (b) the net value of construction work (dollar value of construction work put in place by roofers classified as NAICS 23816, less work subcontracted out to other firms).

Construction material supply metrics were collected from the Census Bureau's 2012 Economic Census – Wholesale Trade Series (U.S. Census Bureau 2002b, 2012a). There was a single state-level capacity indicator collected from the wholesale trade series, wholesale trade sales (dollar value of non-wood roofing materials sold by merchant wholesaler establishments classified as NAICS 4233). This value was based on the product and services code 10721 for non-wood roofing materials (U.S. Census Bureau 2002b), since over 80% of the existing U.S. residential housing stock was built with non-wood roofing materials (Standohar-Alfano and van de Lindt 2015). There was also one county-level capacity indicator collected from the Census Bureau's

2012 County Business Patterns program, namely the number of merchant wholesaler establishments in each county (NAICS 4233) (U.S. Census Bureau 2012a).

Residential housing construction data was collected from the Census Bureau's 2012 Building Permits Survey (U.S. Census Bureau 2018). There was one county-level capacity indicator collected from this dataset, the number of permitted single-family homes. Additionally, craft labor data was collected from the BLS 2012 Quarterly Census of Employment and Wages program (U.S. Bureau of Labor Statistics 2012). Specifically, there were two county-level capacity indicators used from the BLS quarterly census program: (a) annual average wages paid to roofers, and (b) annual average employment for roofers (NAICS 23816).

Data Analysis

Multilevel data analysis was used to develop construction capacity measurements, using the residential roofing sector as an example, because the BLS and Census Bureau data structure was hierarchical. Since the BEA economic regions were comprised of multiple U.S. counties, this study analyzed construction capacity at the county-level. Although the BLS labor data and some of the Census Bureau's data was available at the county-level, the 2012 Economic Census county-level data was suppressed due to privacy. County-level data was estimated using state-level averages for economic capacity indicators provided in the 2012 Economic Census: the cost of materials, components, and supplies; net value of construction work; and wholesale trade sales. Here, the authors have detailed the methods for measuring construction capacity for the residential roofing sector, within any given BEA economic region.

The first step was to identify the value of non-wood roofing materials roofers purchased within an economic region. The total 'cost of materials, components, and supplies' (\$ USD) for roofers (NAICS 23816) for each state included within the boundaries of the BEA economic region

was first identified. Next, the authors found the ‘annual average employment’ of roofers within every county for the states within the economic region. The authors assumed the state average cost of materials, components, and supplies purchased per employed roofer would be consistent across all counties within a state. Finally, the average cost of materials purchased per roofer for those same states was calculated (Equation 2-3).

Equation 2-3. *Regional Costs of Materials, Components and Supplies*

$$= \sum \left\{ \left[\left(\frac{\text{Cost}_{\text{State}^A}}{E_{\text{State}^A}} \right) \times E_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Cost}_{\text{State}^B}}{E_{\text{State}^B}} \right) \times E_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Cost}_{\text{State}^n}$ = Cost of building materials, components, & supplies purchased by laborers (Stateⁿ total)

E_{State^n} = Annual average employment of laborers (Stateⁿ total)

$E_{\text{State}^n-\text{counties}}$ = Annual average employment of laborers (for Stateⁿ counties within economic region)

In the second step, the authors identified the regional value of construction work installed by roofers in an economic region. First, the total ‘net value of construction work’ (\$ USD) roofers (NAICS 23816) installed in each state located within an economic region was identified. This was the billable work conducted by roofers, based on receipts for labor and materials (U.S. Census Bureau 2012b). Next, the authors found the number of new single-family residential houses that were permitted in all counties located within the economic region. The authors assumed the state average net value of construction work installed per employed roofer would be consistent across all counties within a state. Finally, the average value of residential roofing construction work installed by roofers per permitted single-family house for each state within the region was calculated, as shown in Equation 2-4.

Equation 2-4. Regional Net Value of Construction Work

$$= \sum \left\{ \left[\left(\frac{\text{Value}_{\text{State}^A}}{H_{\text{State}^A}} \right) \times H_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Value}_{\text{State}^B}}{H_{\text{State}^B}} \right) \times H_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Value}_{\text{State}^n}$ = Net Value of construction work installed by laborers (Stateⁿ total)

H_{State^n} = Permitted single-family residential houses (Stateⁿ total)

$H_{\text{State}^n-\text{counties}}$ = Permitted single-family residential houses (for Stateⁿ counties within economic region)

In the third step, the researchers identified the regional wholesale trade sales of roofing materials within a BEA economic region. First, the state total ‘sales’ of non-wood roofing materials (NAICS 4233: product and services code 10721) sold by wholesale trade establishments, for each state located within the boundaries of a region was identified. Next, the authors tallied the total number of merchant wholesale establishments (NAICS 4233) for each county in the region. The authors assumed that the state average wholesale trade sales per wholesale trade establishment would be consistent across all counties within a state. Finally, the average wholesale sales of non-wood roofing materials (\$ USD) per merchant wholesale trade establishment was calculated (Equation 2-5).

Equation 2-5. Regional Wholesale Trade Sales

$$= \sum \left\{ \left[\left(\frac{\text{Sales}_{\text{State}^A}}{W_{\text{State}^A}} \right) \times W_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Sales}_{\text{State}^B}}{W_{\text{State}^B}} \right) \times W_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Sales}_{\text{State}^n}$ = Sales of building materials by wholesalers (Stateⁿ total)

W_{State^n} = Number of Wholesale Trade Establishments (Stateⁿ total)

$W_{\text{State}^n-\text{counties}}$ = Number of Wholesale Trade Establishments (for Stateⁿ counties within economic region)

In the fourth step, regional unit labor costs were calculated, which reflect the cost of labor required to generate output (Pancotto and Pericoli 2014). For this research, unit labor costs were calculated as the inverse ratio of the total 2012 annual wages (\$USD) paid to roofers (NAICS

23816) working in an economic region over the annual value of roofing construction work installed (\$ USD) in that same region during 2012 (Equation 2-6). Therefore, regional unit labor costs measured in this study indicate the economic value of roofing construction work generated within a region for every \$1 of annual wages paid to roofers. For example, a region that recorded unit labor costs of \$10.00 was twice as efficient at transforming raw building materials into installed construction work, compared to a region with a unit labor cost of \$5.00.

Equation 2-6. Regional Unit Labor Costs

$$\text{Regional Unit Labor Costs} = \frac{1}{\left\{ \frac{[\text{Regional Annual Average Wages (\$ USD)}]}{[\text{Regional Net Value of Construction Installed (\$ USD)}]} \right\}}$$

In the fifth and final step, the authors measured regional material capacity utilization, which indicates the available material stock inventories within a regional construction supply chain (Mulligan 2016). For the residential roofing sector, capacity utilization was calculated as the ratio of demand over supply for roofing materials (Equation 2-7). First, the researchers identified the previously calculated regional cost of materials, components, and supplies (\$ USD) purchased by roofers (NAICS 23816) within the economic region during 2012. These costs represent the total regional demand for roofing materials generated within the region. Next, the previously calculated volume of regional wholesale trade sales of roofing materials (\$ USD) completed by merchant wholesalers (NAICS 4233) operating in the region during 2012 was identified. This value represents the total available supply, or capacity, of roofing materials available within the region.

Equation 2-7. Regional Capacity Utilization

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

RESULTS

Regional construction capacity is measured using two methods: *unit labor costs* and material *capacity utilization*. Detailed regional construction capacity results are presented in Table 2-2, at the end of Chapter 2.. For this study, the researchers examined the availability and efficient flow of roofing sector labor and material resources within regional single-family residential construction supply chains.

Regional construction capacity results were calculated for the roofing sector within four BEA economic regions: Sioux City, Iowa; Oklahoma City, Oklahoma; Denver, Colorado; and New York, New York. From the 179 total BEA economic regions covering the U.S., site choices were narrowed down based on geography, population density, and urbanization. The U.S. is divided into four geographic regions by the Census Bureau, namely the Midwest, South, West, and Northeast regions. Therefore, the authors selected a BEA economic region from each of the Census Bureau regions to compare and validate smaller-scale BEA regional results with larger economic trends (U.S. Bureau of Economic Analysis 2016). Results of the regional construction capacity analysis are presented here, with regions ordered based on lowest to highest population density.

Sioux City, Iowa Region

The Sioux City, IA BEA region is the smallest of the BEA economic study regions, both in terms of population (about 380,000) and land area (23 counties) (U.S. Bureau of Economic Analysis 2016). The region is anchored by the Sioux City metropolitan statistical area, which drives economic activity in surrounding northeast Nebraska, southeast South Dakota, and northwest Iowa (Delgado et al. 2016).

Unit Labor Costs

There were 24 roofing contractor establishments within the Sioux City, IA region (NAICS 23816) in 2012, which generated over \$25.2 million dollars of installed roofing construction value. This returns a regional unit labor cost of \$6.20, indicating that for every \$1 spent on annual wages for craft laborers employed as roofers in the Sioux City region, those workers generated \$6.20 worth of installed roofing construction value in the region. In contrast, the U.S. national total unit labor costs for roofers is only \$3.70. Therefore, the roofing labor force in the Sioux City region are roughly 67% more efficient at transforming raw materials into finished and installed roofing work, based on prevailing wage rates.

Capacity Utilization

There were 6 merchant wholesale establishments (NAICS 4233) within the Sioux City, IA region in 2012. Those wholesalers sold roofing materials worth over \$25.0 million dollars. Roofer laborers (NAICS 23816) within the region purchased approximately \$12.9 million dollars of those roofing materials. Results show the Sioux, City region has a capacity utilization rate of 52%, indicating that wholesaler capacity far exceeded demand. The regional capacity utilization rate is also substantially less than the 80%-82% net zero inflation range, indicating the region is more likely to experience economic contraction and low demand for roofing project work within the residential sector (Walsh et al. 2004).

Oklahoma City, Oklahoma Region

The Oklahoma City, OK region has a population near 2,125,000 and includes 50 counties (U.S. Bureau of Economic Analysis 2016). The urban core is the Oklahoma City metropolitan statistical area, and the surrounding region covers western Oklahoma, four counties in southwest Kansas, and one county in the Texas Panhandle (Delgado et al. 2016).

Unit Labor Costs

The Oklahoma City, OK region had 194 roofing contractor establishments in 2012. The roofers employed at or subcontractors of these establishments created an installed roofing construction value of approximately \$265.5 million dollars in residential roofing work that year. Results indicate that for every \$1 spent on annual wages for roofers in the Oklahoma City region, roofers generated \$4.50 worth of installed roofing construction value in the region, thereby resulting in a regional unit labor costs of \$4.50. In contrast, the U.S. national total unit labor costs for roofers is only \$3.70. Therefore, roofers within the Oklahoma City region are more efficient at mobilizing labor resources, in terms of local wages paid to complete work, compared to the typical U.S roofer.

Capacity Utilization

In 2012, there were 18 merchant wholesale establishments engaged in roofing material wholesale trade in the Oklahoma City BEA economic region, which sold roofing materials worth over \$114.3 million dollars. However, roofers within the region purchased almost \$135 million dollars of roofing materials in 2012, resulting in a capacity utilization rate of 118%. Since regional capacity utilization is over 100%, this indicates merchant wholesale establishments within the region did not maintain an adequate material inventory and were unable to meet customer demand for roofing materials. While high capacity utilization rates often reflect high demand for construction services (Walsh et al. 2004), they are also associated with longer lead times for materials. Additionally, the regional capacity utilization is well above the stable inflation range of 80% to 82%, which would increase the likelihood of inflated material prices within the region (Corrado and Matthey 1997).

Denver, Colorado Region

The Denver region is the second most densely populated of the BEA study regions, with a 2012 population around 4,265,000 spread across 43 counties (U.S. Bureau of Economic Analysis 2016). The Denver metro area functions as a supply hub for materials and labor, serving surrounding counties in most of western Colorado and parts of southeast Wyoming (Delgado et al. 2016).

Unit Labor Costs

There were 492 roofing contractor establishments in the Denver, CO region in 2012, and over \$598 million of construction value of roofing was installed. Results show a regional unit labor cost of \$3.60, which is very close to the national unit labor costs for the roofing sector (\$3.70). For every \$1 in annual wages paid to Denver region roofers, they install a residential roofing valued at \$3.60 annually.

Capacity Utilization

There were 40 merchant wholesale establishments in the Denver, CO region in 2012. Those merchant wholesale establishments sold nearly \$244.8 million dollars of roofing materials, while roofers located in the region spent over \$342.1 million dollars on roofing materials. Results highlight a capacity utilization rate of approximately 140%, which coincides with increased material prices and delivery delays. The merchant wholesale establishments are unable to meet the demand for materials created by roofers within the region and do not have adequate stock inventories. Essentially some of the roofers in the Denver region are forced to buy from merchant wholesalers located in adjacent regions, to meet project demands.

New York, NY Region

The New York economic region is the most densely populated of the BEA study regions,

with a 2012 population around 19.9 million people spread across 36 counties (U.S. Bureau of Economic Analysis 2016). The region is anchored by the New York City metropolitan statistical area, driving economic activity in nearby northern New Jersey and Pennsylvania, as well as southern New York state and Connecticut (Delgado et al. 2016).

Unit Labor Costs

There were 825 roofing contractor establishments in the New York region in 2012. Roofers located in the region that year generated a construction value of \$935.9 million dollars of installed roofing work. Results highlight a regional unit labor cost of \$3.30. For every \$1 in annual wages paid to New York regional roofers, they install residential roofing valued at \$3.30. These results indicate the regional roofer labor force has similar efficiency, wages, and project demand as found at the national level (Dullien and Fritsche 2008).

Capacity Utilization

There were 146 merchant wholesale establishments within the New York region in 2012. Wholesalers sold roofing materials worth just over 1 billion dollars in the region during 2012, with regional roofers purchasing only about \$450.8 million dollars of those materials. Therefore, the New York region has a capacity utilization rate of only 43%, indicating its regional roofing material supply far outpaces regional demand. Such a low capacity utilization indicates the regional roofing sector is likely experiencing low demand for construction services within the single-family residential construction industry (Walsh et al. 2004).

DISCUSSION

This study highlights the importance of measuring regional construction capacity within four BEA economic regions, using unit labor costs and capacity utilization metrics. Studying construction capacity from a theoretical lens of supply chain management allows us to analyze

networks of existing regional construction resources. However, it is also necessary to understand why construction capacity varies notably across regions.

Why do Differences in Unit Labor Costs Exist among Regions?

A shrinking national construction workforce exacerbates craft labor shortages at the regional level (Goodrum et al. 2002), and this relates to the roofing labor force as well. Between 2008-2012, the U.S. roofing labor force fell nearly 24%, and remains well below pre-Recession employment totals today (U. S. Census Bureau 2015). This research indicates that unit labor costs for the roofing sector of the single-family residential construction industry also vary at the regional level, as highlighted in Table 2-2.

The reason unit labor costs remain relatively stable over time at the national level (Pancotto and Pericoli 2014) despite experiencing pronounced variances at the regional level is likely due to regional economic trends (e.g., unemployment and population growth) and housing market trends (e.g., demand for residential housing and prevailing labor wages). For example, the Sioux City, IA region has the highest unit labor rate of the study regions, generating about \$6.20 of installed residential roofing for every \$1.00 in annual wages paid to roofers working in the region in 2012. The region has been minimally impacted by the Great Recession, in terms of unemployment trends across all industries. Unlike much of the U.S., total unemployment remained stable at about 5% within the region between 2008-2012 (U. S. Census Bureau 2013) and roofer craft labor availability was also steady (U.S. Bureau of Labor Statistics 2010, 2013). However, the region is experiencing a slow but steady population decline that translates into fewer residential homes being permitted and built (U.S. Census Bureau 2016b). The combination of a steady supply of roofer craft labor and a diminishing demand for roofing construction work is likely leading to higher unit labor costs.

In contrast, the lowest unit labor costs were found in the Denver, CO (\$3.60) and New York, NY (\$3.30) regions. Both jumped from approximately 5% total industry unemployment in 2008 to 9% unemployment by 2012 (U. S. Census Bureau 2013), and lost craft workers in the roofing sector (U.S. Bureau of Labor Statistics 2010, 2013). At the same time, population growth and residential housing starts continued increasing in both regions. The decreased availability of roofer craft labor, coupled with an increased demand for residential roofing projects, helped drive down unit labor costs in both regions.

To summarize, higher unit labor costs in the construction industry represent a labor force that can efficiently transform supply chain raw materials into finished building products, with minimal expenditure of labor wages. However, high unit labor costs are associated with high regional labor competition (Belke and Dreger 2013), due to low prevailing wages and lack of demand for construction services. Lower unit labor costs reflect a regional construction industry that is less efficient, requiring more expenditure of labor wages to install finished construction project work. Low unit labor costs are found in less competitive regions, with higher prevailing labor wages due to high demand for construction services.

Why do Differences in Capacity Utilization Exist among Regions?

Although national capacity utilization rates for U.S. industries tracked by the federal government have remained relatively stationary over time (Board of Governors of the Federal Reserve System 2016), capacity utilization rates for industry sectors and smaller geographical regions have proven more volatile (Mulligan 2016). The four BEA economic regions have considerably different capacity utilization rates compared to the U.S. national average (83%) for the single-family residential roofing sector, as shown in Table 2-2.

For instance, capacity utilization rates for the Oklahoma City region (118%) and the Denver region (140%) are well above the national average. Both regions have a high capacity utilization rate, indicating that the demand for roofing materials far exceeds the available supply sold by regional merchant wholesalers. Both regions have experienced population growth significantly higher than the U.S. average between 2002-2012 (U.S. Census Bureau 2016a). While population growth can drive regional economic development, it also strains the local housing market, driving up demand for residential housing (U.S. Census Bureau 2018). Due to the capital investments required, and the cyclical nature of the residential construction industry, the number of merchant wholesale trade establishments supplying roofing materials has not expanded at the same rate as the demand for services in the Oklahoma City and Denver regions. For example, sales of roofing materials in the Oklahoma City region have increased 35% from 2007-2012, much faster than the U.S. national growth in roofing material sales (9%) during that same timeframe (U.S. Census Bureau 2002b, 2007). However, available roofing material inventories decreased 54% in the Oklahoma City region from 2007-2012 (U.S. Census Bureau 2002b, 2007), creating a regional material shortage and a high regional capacity utilization rate.

The other economic regions included in the study have low capacity utilization rates, indicating an inefficient regional roofing material supply chain, such as the New York region (43%) and the Sioux City region (52%). For over a decade, both regions have experienced significantly lower population growth rates than the U.S. average, resulting in a slowdown of single-family residential housing demand (U.S. Census Bureau 2016a; b). At the same time, merchant wholesale trade establishments within both regions have increased material inventories, leading to an overabundance of regionally available roofing materials. For example, sales of roofing materials have risen substantially in the New York and the Sioux City regions since the Great Recession

(U.S. Census Bureau 2002b, 2007). Merchant wholesale establishments in both regions have responded to the growing demand by drastically increasing roofing material inventories. While the total U.S. national roofing material inventory grew 19% between 2007-2012, roofing material inventories increased by 68% in the New York region and 25% in the Sioux City region over that same time period (U.S. Census Bureau 2002b, 2007). Merchant wholesalers likely overestimated the increased demand for roofing materials after the Recession, leading to low regional capacity utilization rates.

LIMITATIONS AND FUTURE WORK

Although this study has collected data regarding regional construction capacity from publicly available sources, not all data was provided at the county-level. To develop aggregate totals for the BEA economic regions, state-level averages were assumed to apply consistently throughout each state to estimate county-level data. Additionally, this research presents an analysis of a single sector of the U.S. residential construction industry, namely residential roofing. Construction capacity findings for the roofing sector should be validated with further studies across a broader range of construction sectors and geographical regions. Future research will measure construction capacity for the residential construction industry across all BEA economic regions. Such measurements will facilitate examinations of how existing regional construction capacity effects residential building after an unexpected demand surge for construction services. Quantitative analysis of pre-disaster regional construction capacity could allow building contractors to better anticipate and meet the needs for residential construction in a post-disaster setting.

CONCLUSIONS

The purpose of this research is to quantitatively assess and measure regional construction capacity, based on the availability and efficiency of labor and material resources within regional residential construction supply chains. Although the U.S. national economy and construction industry have recovered substantially since the Great Recession of 2007-2009, ongoing residential construction craft labor shortages and a lack of available building materials often leads to project schedule delays and cost overruns. The site-specific nature of the residential construction industry suggests a regional scale of analysis of construction capacity is appropriate, especially since craft labor and material inventories vary considerably across regions of the U.S.

A novel quantitative method is developed for identifying and measuring regional construction supply chain resource availability and capabilities. Identification of unit labor costs and capacity utilization rates across four disparate economic regions indicates construction resource availability varies considerably across U.S. regions, especially for industry sub-sectors such as residential roofing. Results highlight the connections between regional economic trends, housing market trends, and unit labor costs. Regions experiencing a competitive roofing sector market typically have a surplus of roofers or a lack of demand for residential roofing construction and repair (often due to larger regional unemployment and population growth trends). Competition then leads to lower prevailing labor wages for roofers and leads to higher unit labor costs. Regions with low roofing sector competition, due to craft labor shortages or high demand for residential roofing project work, are likely to have higher labor wages and therefore lower unit labor costs. Additionally, results indicate capacity utilization rates are dependent on how material manufacturers and wholesale establishments respond to economic disruptions and shifting demographics. In regions with rapid economic expansion, population growth, and new housing

starts, manufacturers and wholesalers are often not increasing material supply fast enough to keep pace with rising demand. This results in high capacity utilization rates. Similarly, manufacturers and wholesalers are often not able to decrease material supply to keep pace with dropping material demand seen in regions facing an economic downturn or stagnating population growth, resulting in low capacity utilization rates.

The main contribution of this work to the body of knowledge is to fill the gap in existing literature regarding quantitative, industry-level, and regional scale construction supply chain performance. These findings indicate construction capacity differs widely across regions, aligning with limited existing quantitative research about the varying economic performance of industries at the regional scale. This research also adds to the literature regarding construction supply chain management theory, by identifying construction capacity as a key component of efficient regional supply chains. Past research has shown that by simply identifying supply chain elements, coordination mechanisms within the supply chain can be improved during economic disruptions. Therefore, quantitative analysis of regional construction supply chain elements, such as residential roofer employment and merchant wholesaler sales, can help contractors better plan for ongoing resource constraints and anticipate demand spikes for construction services.

DATA AVAILABILITY

Data generated or analyzed during the study are available in a repository or at a provided location online (<http://www.colorado.edu/lab/gpo/erin-arneson>). Data were collected from publicly available datasets published by the Bureau of Labor Statistics and the Census Bureau (U.S. Census Bureau 2015; U.S. Bureau of Labor Statistics 2012a; U.S. Census Bureau 2002b, 2012b, 2018).

ACKNOWLEDGMENTS

This research is supported by the Department of Education's Graduate Assistantships in Areas of National Need (GAANN) funding. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agency.

Table 2-1. Construction Capacity Dataset Indicators

Dataset	Description	Availability	Capacity Indicators	Details
U.S. Census: Economic Census of the United States (2012)				
<i>Construction: Geographic Area Series: Detailed Statistics for the States: 2012</i>	Only U.S. construction dataset that includes work done by specific industry-level establishments, such as roofing contractors (NAICS 23816).	State-level	1. Cost of Materials, Components, and Supplies 2. Net Value of Construction Work	Costs for materials, components, and supplies used by roofers (NAICS 23816). Value of construction work installed by roofers (NAICS 23816), less work subcontracted out.
<i>Wholesale Trade: Subject Series-Product Lines: 2012</i>	Wholesale trade data (NAICS 42), including sales, receipts, and revenue. Sales by product type, based on 'Product & Services Codes'.	State-level	3. Wholesale Trade Sales	Value of materials sold by wholesale trade establishments, based on receipts and tax filings. Sales only include materials classified as 'non-wood roofing' under Products & Services code 10721.
U.S. Census: County Business Patterns (2012)				
<i>Geography Area Series: 2012</i>	Tracks all U.S. establishments with paid employees, based on NAICS codes.	County-level	4. Number of Establishments - Wholesale Merchants	Number of establishments primarily engaged in merchant wholesale trade (NAICS 423)
U.S. Census: Building Permits Survey (2012)				
<i>Permits by County or Place: 2012</i>	Annual report of permits issued, based on monthly surveys of permit-issuing places.	County-level	5. Number of permitted single-family houses	Number of new single-family housing units authorized by building permits.
U.S. Bureau of Labor Statistics: Quarterly Census of Employment and Wages (2012)				
<i>Private, NAICS 23816 Roofing Contractors, All Counties 2012 Annual Averages</i>	Quarterly count of employment and wages, including annual averages	County-level	6. Annual Average Employment 7. Annual Average Wages	Annual average number of roofers (NAICS 23816) Annual average wages for roofers (NAICS 23816)

Table 2-2. 2012 Regional Construction Capacity: Case Study

Region	Labor Capacity			Material Capacity			
	Value Installed Construction	Annual Average Wages	Unit Labor Costs	Cost of Materials, Components and Supplies	Number of Establishments -Merchant Wholesale	Wholesale Trade Sales:	Capacity Utilization
	Valuer	Wager	$1/(Wager / Valuer)$	CostR	WR	SalesR	CostR / SalesR
Sioux City, IA Oklahoma City, OK Denver, CO New York, NY	\$25,293,214	\$4,083,900	\$6.20	\$12,939,885	6	\$25,026,315	52%
	\$265,458,206	\$58,900,432	\$4.50	\$134,494,295	18	\$114,321,484	118%
	\$598,092,822	\$164,246,724	\$3.60	\$342,103,788	40	\$244,761,690	140%
	\$935,862,051	\$285,392,488	\$3.30	\$450,787,694	146	\$1,055,121,641	43%
U.S. Totals	\$25,235,266,000	\$6,801,373,266,000	\$3.70	\$11,019,762,000	2,825	\$13,232,309,000	83%

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CHAPTER 3 – REGIONAL CONSTRUCTION CAPACITY AND INDUSTRY COMPETITIVENESS

ABSTRACT

The U.S. housing market experienced a severe downturn after the global economic recession of 2007-2009, negatively affecting the residential construction industry and resulting in wage and employment loss. The performance of the national residential construction industry is a composite of varying levels of industry performance at the regional level. Although regional industry performance and competitiveness is highly localized in the construction industry, past research has focused almost exclusively on the national unit of analysis. This research defines residential construction industry performance based on construction capacity metrics: unit labor costs and capacity utilization. Correlation analysis is used to identify relationships between regional construction capacity, and regional residential housing market and socio-economic conditions. Based upon an examination of 179 U.S. regions in both 2007 and 2009, results indicate that wage and employment location quotients affect regional construction capacity and reflect buyer and supplier power dynamics within a region. The study contributes to the body of knowledge of regional construction industry performance and competitiveness, as well as the relationships between unit labor costs, capacity utilization, and industry specialization.

KEYWORDS: Construction Capacity, Competitiveness, and Buyer and Supplier Power

INTRODUCTION

The global economic recession of 2007-2009 had an extremely disruptive effect on the U.S. economy. Due to the strong economic ties between the national economy and the residential housing market, the recession triggered a collapse in new residential housing building and in

existing housing values (Hua 2012). In the five years preceding the recession, median home values in the U.S. jumped 25% and created high demand for residential construction work. Five years after the recession, median home values finally returned to pre-recession values (U.S. Census Bureau 2002b, 2007b, 2012c).

While other industries in the U.S. national economy are experiencing economic recovery and job growth, the U.S. residential construction industry continues to experience labor shortages. This is in part due to how devastated the residential construction industry was compared to other industries. While the U.S. national employment rate for all industries fell -2.9% between 2007 and 2012, employment totals for residential building contractors fell -39.4% (U.S. Bureau of Labor Statistics 2007a, 2012b). Regions of the U.S. where large volumes of residential were being built prior to the recession also experienced higher ratios of displacement of construction and manufacturing industry employees (Leamer 2015). The uneven losses in residential construction industry employment and wages at the regional level during the recession highlight the importance of geographical location in the ability of an industry to respond to sudden economic shocks (Simmie and Martin 2010).

Although the national economy plays a role in the economic performance of regional industries, regions vary considerably in their responses to economic shocks (Simmie and Martin 2010). The performance of the national U.S. construction industry is a composite of very different levels of regional industry and economic performance. Such performance is intrinsically linked with the combination of place-specific conditions that exist within a region (Wolfe and Bramwell 2016). This is especially true for regional construction industries, since they typically: are a local industry that provides services and performs work within the region where firms and employees

are located; do not compete with labor markets in other regions; and the essential drivers of industry economic performance reside within the regions where they are located (Porter 2003).

However, to understand why the economic performance of the residential construction industry is different across various regions of the U.S., it is necessary to clearly delineate construction industry performance. This study uses the concept of construction capacity – the maximum building volume a construction industry can supply due to regional supply chain availability of labor and materials – as the measure of regional construction industry performance. Regional construction capacity is calculated based on two metrics: unit labor costs (e.g., the labor share of the regional value of construction work installed) and capacity utilization (e.g., the share of available supply chain building materials used within the region). Additionally, the authors hypothesize that existing residential housing market and socio-economic conditions within a given region affect regional performance in terms of construction capacity. To address this issue, the research team sought to address the question: ***Why does the regional construction capacity of the residential construction industry vary over time and across regions?***

LITERATURE REVIEW

This research explores why regional construction industries have varying levels of construction capacity, and why construction capacity changes over time within regions. Building upon concepts from economic geography theory, this research examines how existing residential housing market trends and socio-economic conditions within region can affect regional construction capacity metrics.

Economic Geography

Theories within economic geography claim that regional economic performance is a direct result of industry-related and socio-economic conditions within a given region (Doran and

Fingleton 2015). Economic geography theory is typically focused on two key aspects of regional industries: the economic performance and the competitiveness of the industry (Boschma et al. 2017). Regional economic performance is typically a measure of the produced output generated, while competitiveness is a measure of how such performance compares with other regions (Boschma 2004). However, performance and competitiveness of industries at the regional level is not well studied, especially for the construction industry (Flanagan et al. 2007). Empirical research of regional industries, research with large sample sizes, and studies beyond the case study level are still needed (Boschma et al. 2017; Porter 2003).

A key concept of economic geography theory is that regional performance and competitiveness are linked with industry specialization (Boschma et al. 2017). Specialization refers to the spatial concentration of industry resources within a region, and is typically measured as location quotients (Mack and Jacobson 1996). Past research has found that high levels of specialization – location quotients – increase regional economic performance but also vary significantly across regions (Delgado et al. 2014). However, the effect of industry wage and employment location quotients on construction industry performance and competitiveness needs further exploration.

Defining Regional Performance and Competitiveness

Porter's (Porter 1979) seminal 5-Force Analysis is perhaps the best known framework for assessing industry competitiveness. The framework provides a qualitative guideline for assessing industry competitiveness based five indicators: bargaining power of suppliers, bargaining power of buyers, threat of new entrants, threat of substitutes, and rivalry. In terms of the residential construction industry, firms at both the national and regional face similar challenges. The residential construction industry has a high degree of rivalry since unskilled workers can easily

enter the market and low switching costs between contractors. However, buyer and supplier bargaining power varies substantially across regions, and may explain difference in regional economic performance (Porter 2003).

Since regional construction industries consist of numerous firms and individuals that change behavior over time, it is challenging to identify indicators of such change and quantitatively assess their effects on regional economic performance and competitiveness (Storper 2011). Previous research has often limited conceptualizations of performance and competitiveness to focus on a single indicator, such as productivity or profitability (Hassink et al. 2014). However, Flanagan (2007) posits that competitiveness is actually multidimensional and consists of multiple indicators that can be measured and assessed.

Unit Labor Costs

Unit labor costs are the most widely used measure of competitiveness in both economic theory and practical policy decision-making (Belke and Dreger 2013). Unit labor costs are defined as the labor share of the total produced output, and measured as the cost in real wages paid to employees for every one-dollar in output generated those employees (Dullien and Fritsche 2008). Using this definition, residential construction industry competitiveness is a question of wage costs and labor efficiency at transforming raw building materials into finished housing work.

Capacity Utilization

Capacity utilization is a metric that measures the performance of supply chain coordination. It is the ratio of expected demand over maximum supply availability (Fevolden and Grønning 2010). When there is enough supply within the supply chain, capacity utilization is below 100%. Conversely, capacity utilization rates above 100% indicate that demand exceeds supply (Mulligan 2016).

Other Indicators of Performance and Competitiveness

The literature from multiple fields of research have tried to identify, measure, and test indicators of regional performance and competitiveness. In terms of economic indicators, economic geography theory suggests that industry metrics are useful. For example, Porter (2003) examined regional economies of the U.S. between 1990-2000 and found that regional economic performance for any industry relied heavily on: wage, wage growth, and employment totals. Wolfe and Bramwell (2016) compared economic performance of sixteen regions and found that specialization (e.g., location quotients) and demographics were indicators of economic change over time.

For the U.S. residential construction industry specifically, Hua (2012) identified indicators of performance. That research conducted a literature review of economic and social factors linked with demand for residential construction. Using a Stepwise regression method, this study narrowed down the list of statistically significant economic indicators theoretically linked with residential construction. This included: population size, unemployment rate, wages, wage inflation, housing values, and housing value inflation.

Demographics and other social conditions have been recognized as important in understanding why regional industries change over time (Wolfe and Bramwell 2016). Much of the existing literature on links between social and economic indicators is from the field of disaster management. For example, Cutter (2016) has created a system of baseline indicators for regional resilience to disruptions like disasters. This research identifies a number of socio-economic indicators, including: educational attainment, employment, poverty, and residential housing permits.

RESEARCH METHODS

This research focused on why regional construction capacity performance evolves over time and varies across regions, based on regional indicators of residential housing market and socio-economic indicators. regional residential housing market and socio-economic indicators were identified in measured, to compare against regional construction capacity performance and competitiveness.

First, regional residential housing market and socio-economic indicators were selected based on literature regarding the economic performance and competitiveness of regions. It was not possible to characterize all possible indicators that correlate with construction capacity metrics due to limitations of both data and time. Indicators were chosen based on two main considerations: (1) indicator data availability, and (2) indicators have been previously identified as being associated with changes in construction labor and material resource availability. Four indicators were selected to represent the regional residential housing market: industry wages, wages location quotient, industry employment, and employment location quotient. Five indicators were selected to represent socio-economic conditions within the regions: median permit values, population density, poverty rate, unemployment rate, and higher education. A summary of selected indicators can be found in Table 3-1.

Second, regional residential construction industry performance was measured for 179 economic regions defined by the U.S. Bureau of Economic Analysis (BEA), for the years 2007 and 2012. Performance was measured in terms of construction capacity metrics: unit labor costs and capacity utilization. Competitiveness of regional residential construction industries was viewed as the variance in construction capacity across regions of the U.S.

Third, Pearson correlation analysis was run to test for correlation between the regional residential housing market and socio-economic indicators and regional construction capacity performance. Tests were conducted for years 2007 and 2012, as well as for regions with high and low construction capacity. Lastly, Wilcoxon signed-rank tests of medians were used to test for statistical significance.

Data Collection

Data related to the economic performance of regions was collected from publicly available datasets published by the U.S. Bureau of Economic Analysis (BEA), the U.S. Census Bureau, the U.S. Bureau of Labor Statistics (BLS), and the North American Industry Classification System (NAICS). The BEA provided the geographical information used to delineate boundaries of regional economies and regional residential construction sectors. Census Bureau and BLS datasets provided information about indicators of construction capacity, the residential construction sector, and socio-economic conditions within each BEA region included in the study. The NAICS is used by the U.S. federal government to sort data by industry and was utilized in this research to identify Census Bureau and BLS data specific to the residential construction sector. A summary of the regional indicator data utilized in this research, including definitions and data sources, is provided in Table 3-1.

Defining Geographical Regions

To explore how regional residential housing markets and socio-economic conditions affect the regional construction capacity of the U.S. residential construction sector, it was necessary to establish regional geographical boundaries. Regions were delineated using existing U.S. Bureau of Economic Analysis' (BEA) economic regions. The BEA divided the U.S. into 179 economic regions, based on statistical analyses of regional core and periphery market behavior (Johnson and

Kort 2004). Each BEA region is centered around an urban core such as a metropolitan or micropolitan statistical area, and is surrounded by a cluster of peripheral counties (Porter 2003). The urban cores drive economic activity and population growth and all counties within the broader economic region have strong linkages between businesses, common commuting patterns, shared labor and material markets, and shared economic development trends (Delgado et al. 2016). The BEA economic regions were integrated into this research for three key reasons: 1) they incorporate every U.S. county into an economic region; 2) the regional boundaries have remained stable over time; and 3) each region contains an independent labor market that is statistically likely to have a unique combination of economic performance indicators and socio-economic conditions (Delgado et al. 2016).

Inflation Indexes and Wage Deflators

Since the regional indicators of regional construction capacity were collected for years 2007 and 2012, immediately before and a few years after a global economic recession, inflation indexes and wage deflators were used to account for inflation. Inflation index and wage deflator data was collected from two sources: (1) the U.S. Census Bureau Survey of Construction and (2) the BLS Employment Cost Index.

All data measured in dollar values within this study were adjusted for inflation and were reported in 2012 equivalent values. The Census Bureau's Survey of Construction has maintained annual 'Construction Price Indexes' for residential houses under construction (U.S. Census Bureau 2018). This index was used to adjust the median housing values from 2007 to 2012-dollar values. The BLS tracked annual wage inflation, referred to as wage deflators, for a number of U.S. industries such as construction (U.S. Bureau of Labor Statistics 2017a). All wage data from 2007 was adjusted to 2012-dollar values using the BLS wage deflators.

Construction Capacity Indicators

Regional construction capacity conditions were identified using two metrics: (1) unit labor costs and (2) material capacity utilization rates. The regional construction capacity indicators were collected from four programs conducted by the federal government, namely: (1) the Census Bureau's Economic Census, the (2) the Census Bureau's Building Permits Survey, (3) the Census Bureau's County Business Patterns program, and (4) the U.S. Bureau of Labor Statistics' (BLS) Quarterly Census of Employment and Wages.

Unit Labor Costs. Regional unit labor costs for the residential construction sector were defined as the annual wages paid to residential contractors (NAICS 23611) per dollar of net value of construction work installed by those contractors (NAICS 23611) per residential house within a given region. The U.S. Census Bureau describes establishments and employees classified as NAICS 23611 – Residential building construction as primarily engaged in the new construction, repairs, and maintenance of single-family and multi-family residential buildings (Office of Management and Budget and Executive Office of the President 2007).

Annual wage data for residential contractors (NAICS 23611) was provided by the BLS Quarterly Census of Employment and Wages (U.S. Bureau of Labor Statistics 2007b, 2012a). The Census Bureau's Economic Census 'Construction Geographic Area Series' provided the annual net value of construction work put in place by residential contractors (NAICS 23611), less work subcontracted out to specialty trades, for every U.S. state (U.S. Census Bureau 2007c, 2012b). The U.S. Census Bureau's Building Permits Survey program provided the number of residential housing permits issued annually per county (U.S. Census Bureau 2018).

Capacity Utilization. Regional capacity utilization was defined as the cost of materials, components, and supplies purchased by residential contractors (NAICS 23611) over the value of

all building materials sold by wholesalers (NAICS 4233) within a given region. Establishments and employees classified as NAICS 4233 – Lumber and other construction merchant wholesalers as primarily engaged in the wholesale distribution of lumber and wood, brick and stone, roofing, siding, insulation, and other common building materials used in residential construction (Office of Management and Budget and Executive Office of the President 2007).

The Census Bureau’s Economic Census ‘Construction Geographic Area Series’ provided the annual cost of materials, components, and supplies purchased by residential contractors (NAICS 23611) for every U.S. state (U.S. Census Bureau 2007c, 2012b). The Census Bureau’s Economic Census ‘Wholesale Trade Series’ provided the annual value of building materials sold at wholesaler establishments (NAICS 4233) in each state (U.S. Census Bureau 2002b, 2007a). The U.S. Census County Business Patterns program provided the annual average number of establishments engaged in building material wholesales (NAICS 4233) at the county-level (U.S. Census Bureau 2007d, 2012a).

Residential Construction Industry Indicators

Regional residential construction industry indicators were identified using four metrics: (1) industry wages, (2) a wage location quotient, (3) industry employment, and (4) an employment location quotient. All regional residential construction industry indicators were collected as county-level data from a single program, namely: (1) the BLS Quarterly Census of Employment and Wages (U.S. Bureau of Labor Statistics 2007b, 2012a).

Socio-Economic Indicators

Regional socio-economic conditions were identified using five metrics: (1) median residential permit value, (2) population density, (3) poverty, (4) unemployment, and (5) higher education. Regional socio-economic indicators were collected as county-level data from two

programs, namely: (1) the Census Bureau’s American Community Survey (ACS), (2) the Census Bureau’s 2010 census, and (3) the Census Bureau’s Building Permits Survey.

The ACS ‘2012 5-Year Estimates’ and ‘2007 3-Year Estimates’ datasets provided county-level metrics regarding poverty, unemployment, and higher education (U.S. Census Bureau 2002b, 2012c). The Census Bureau’s 2010 census ‘Population, Housing Units, Area, and Density: 2010 – County,’ the ACS ‘2012 5-year Estimates,’ and the ACS ‘2007 3-Year Estimates’ datasets provided county-level metrics about population density (U.S. Census Bureau 2002b, 2012c, 2018). The Census Bureau’s Building Permits Survey provided county-level data about the annual valuations of residential permits (U.S. Census Bureau 2017b).

Data Analysis

Multilevel data analysis was used aggregate state-level and county-level data for each BEA region. Regional-level data was then used to identify and measure: construction capacity indicators; residential construction industry indicators; and socio-economic indicators. Data was analyzed for years 2007 and 2012.

Construction Capacity Indicators

The first step was to measure regional indicators of construction capacity, unit labor costs and capacity utilization. Both of these metrics are measured using data from the Census Bureau’s Economic Census, which provides the most detailed economic information available about the U.S. construction industry from the federal government but is only available at the state-level. Thus, regional measurements were estimated using state-level averages, and the assumption that residential construction industries within each region performed consistently throughout the region.

Unit Labor Costs. First, the annual ‘net value of construction’ work (\$ USD) installed by residential contractors (NAICS 23611) within each U.S. state was identified. Second, the number

of residential housing permits issued annually per county was identified. Third, Regional-level net value of construction work was estimated using state-level averages. The authors assumed that the average net value of construction installed per permitted residential housing unit would be consistent within each U.S. state, as shown in Equation 3-1. Fourth, the annual regional wages paid to residential contractors (NAICS 23611) was measured, based on aggregate county-level data. Lastly, regional unit labor costs were measured as the ratio of wages paid to residential contractors over the annual regional net value of construction work installed by those contractors within a given BEA region, as shown in Equation 3-2.

Equation 3-1. Regional Net Value of Construction Work

$$= \sum \left\{ \left[\left(\frac{\text{Value}_{\text{State}^A}}{H_{\text{State}^A}} \right) \times H_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Value}_{\text{State}^B}}{H_{\text{State}^B}} \right) \times H_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Value}_{\text{State}^n}$ = Net Value of construction work installed by laborers (Stateⁿ total)

H_{State^n} = Number of permitted residential housing units (Stateⁿ total)

$H_{\text{State}^n-\text{counties}}$ = Number of permitted residential housing units (for Stateⁿ counties within economic region)

Equation 3-2. Regional Unit Labor Costs

$$\text{Regional Unit Labor Costs} = \frac{\text{Annual Regional Wages (NAICS 23611)}}{\text{Annual Regional Net Value of Construction}}$$

Capacity Utilization. First, the annual regional cost of materials, components and supplies (\$ USD) purchased by residential contractors (NAICS 23611) within each U.S. state was identified. Second, the county-level annual number of employed residential contractors (NAICS 23611) was identified for every state. Third, these two metrics were employed to calculate the regional cost of materials, components, and supplies, as shown in Equation 3-3.

Equation 3-3. Regional Cost of Materials, Components and Supplies

$$= \sum \left\{ \left[\left(\frac{\text{Cost}_{\text{State}^A}}{E_{\text{State}^A}} \right) \times E_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Cost}_{\text{State}^B}}{E_{\text{State}^B}} \right) \times E_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Cost}_{\text{State}^n}$ = Cost of building materials, components, & supplies purchased by laborers (Stateⁿ total)

E_{State^n} = Annual average employment of laborers (Stateⁿ total)

$E_{\text{State}^n-\text{counties}}$ = Annual average employment of laborers (for Stateⁿ counties within economic region)

Fourth, the annual regional value of wholesale trade sales (\$ USD) within each state was identified (NAICS 4233). Fifth, the county-level annual number of operating wholesale establishments was identified for each state. Next, the regional wholesale trade sales were estimated, as shown in Equation 3-4. Lastly, regional capacity utilization was calculated, as highlighted in Equation 3-5.

Equation 3-4. Regional Wholesale Trade Sales

$$= \sum \left\{ \left[\left(\frac{\text{Sales}_{\text{State}^A}}{W_{\text{State}^A}} \right) \times W_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Sales}_{\text{State}^B}}{W_{\text{State}^B}} \right) \times W_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Sales}_{\text{State}^n}$ = Sales of building materials by wholesalers (Stateⁿ total)

W_{State^n} = Number of Wholesale Trade Establishments (Stateⁿ total)

$W_{\text{State}^n-\text{counties}}$ = Number of Wholesale Trade Establishments (for Stateⁿ counties within economic region)

Equation 3-5. Regional Capacity Utilization

$$\text{Regional Capacity Utilization} = \frac{\text{Annual Regional Cost of Materials, Components, and Supplies}}{\text{Regional Annual Wholesale Trade Sales}}$$

Residential Construction Industry Indicators

In the second step, residential construction industry indicators were measured, including: industry wages, the wages location quotient, industry employment, and the employment location quotient.

Industry Wages. First, the annual average regional wages paid per residential contractor (NAICS 23611) was identified for every county within each of the 179 BEA regions. The combined average of the county-level data was used to calculate regional construction industry wages per employee, as shown in Equation 3-6.

Equation 3-6. Regional Indicator Average Value

$$= \sum \left\{ \frac{\text{Indicator}_{\text{County}^A} + \text{Indicator}_{\text{County}^A} + \dots \text{Indicator}_{\text{County}^n}}{n} \right\}$$

Where:

Indicator = County-level indicator value

Countyⁿ = County within a region with a total of n counties

Location Quotient -Wage. Second, the location quotient for wages was calculated. The location quotient quantifies how concentrated residential construction industry wages were within a given region, as compared to the nation, as shown in Equation 3-7.

Equation 3-7. Regional Location Quotient - Wages

$$\text{Regional Location Quotient} - \frac{\text{Wages}}{\text{Wages}} = \frac{\left(\frac{\text{Regional Wages (Construction)}}{\text{Regional Wages (All Industries)}} \right)}{\left(\frac{\text{National Wages (Construction)}}{\text{National Wages (All Industries)}} \right)}$$

Industry Employment. Third, the annual regional number of employees working in the residential construction industry (NAICS 23611) was identified for every county in the BEA economic regions. The aggregated totals of the county-level data was used to calculate the total regional employment numbers, as shown in Equation 3-8.

Equation 3-8. Regional Indicator Total Value

$$= \sum \left\{ \text{Indicator}_{\text{County}^A} + \text{Indicator}_{\text{County}^A} + \dots \text{Indicator}_{\text{County}^n} \right\}$$

Where:

Indicator = County-level indicator value

Countyⁿ = County within a region with a total of n counties

Location Quotient - Employment. Lastly, the location quotient for employment was calculated. The location quotient quantifies how concentrated residential construction industry employment were within a given region, as compared to the nation, as shown in Equation 3-9.

Equation 3-9. Regional Indicator Total Value

$$\text{Regional Location Quotient – Employment} = \frac{\left(\frac{\text{Regional Employment (Construction)}}{\text{Regional Employment (All Industries)}} \right)}{\left(\frac{\text{National Employment (Construction)}}{\text{National Employment (All Industries)}} \right)}$$

Socio-Economic Indicators

In the third step, regional values for the selected socio-economic indicators were calculated. Data was available at the county-level for each of the socio-economic indicators, namely: median permitted housing unit values, population density, poverty rate, unemployment rate, and higher education levels. The combined average of the county-level data was used to calculate the regional averages for each indicator, as shown in Equation 3-6 above.

Correlation Analysis

In the fourth and final step, a series of bivariate (Pearson) correlation tests were conducted. First, the indicator data points were tested for normality, variances, and outliers. The data was found to be bivariate normal, with no skewed indicator data, and few outliers. Therefore, the Pearson correlation test was deemed appropriate.

Second, a correlation matrix was created for the two regional construction capacity metrics, four indicators of the regional residential housing market, and the five socio-economic indicators. Regional indicator values from all 179 BEA economic regions in 2007 and 2012 were analyzed. Third, a separate correlation analysis test was conducted for the two construction capacity indicators (e.g., unit labor costs and capacity utilization) and the other nine indicators for the year 2007 and 2012, as shown in Table 3-3. To interpret the effect size of the correlation coefficients,

this research incorporated guidelines from Evans (1996), where: r values of 0.30-0.39 are ‘weak’, r values of 0.40-0.59 are ‘moderate’, and r values equal to or above 0.60 are ‘strong.’

Fourth, the differences between the median indicator values from 2007 and 2012 were compared to test for statistical difference, using a Wilcoxon signed-rank test. This test was selected to test for statistically similar distributions of the median regional indicator values in 2007 and 2012. Lastly, a Wilcoxon signed-rank test was conducted to test for statistically similar distributions of the median regional indicator values in high construction capacity and low construction capacity regions in 2007 and 2012. Regions that outperformed the median national construction capacity for both labor and material metrics (e.g., lower unit labor costs and lower capacity utilization rates) were classified and sorted as ‘high capacity’ regions. Regions that underperformed the median national construction capacity for both labor and material metrics (e.g., higher unit labor costs and higher capacity utilization rates) were classified and sorted as ‘low capacity’ regions.

RESULTS

The purpose of this research is to identify why the construction capacity of regional residential construction industries varies over time and across regions. This research examines indicators of construction capacity in the 179 BEA economic regions of the U.S. in years 2007 and 2012. The data provides a snapshot in time of regional residential construction industry performance, right as the economic recession of 2007-2009 began and a few years after the industry began recovering. Pearson correlation analyses have been conducted to test for correlation between each of the construction capacity, residential housing market, and socio-economic indicators. Wilcoxon signed-rank tests are performed to test for statistically significant differences

in a regional indicator over time or across regions. A brief summary of the indicators examined are provided in Table 3-1.

Examining all regions in both years 2007 and 2012 collectively, as shown in the correlation matrix in Table 3-2, there are only two indicators with statistically significant correlations with at least a weak correlation relationship. In terms of unit labor costs, both the location quotient for wages ($r = 0.31, p < 0.001$) and the location quotient for employment ($r = 0.39, p < 0.001$) have a positive but weak correlation. Additionally, the location quotient for wages ($r = 0.53, p < 0.001$) and the location quotient for employment ($r = 0.52, p < 0.001$) have a positive and moderate correlation with capacity utilization.

As regional wage and employment location quotients increase (e.g., increased concentration of residential construction industry wages and employment within a region), unit labor costs and capacity utilization rates also increase. In other words, the more concentrated the residential construction industry's wages and employment are within a given region, the more labor compensation is required per dollar of net value in construction work installed (e.g., higher unit labor costs) and less building material inventory will be available within the regional supply chain (e.g., higher construction capacity). Thus, higher wage and employment quotients are correlated with decreased regional residential construction industry competitiveness and lower wage and employment quotients are correlated with decreased regional residential construction industry competitiveness. However, the combined regional data from both 2007 and 2012 may be obscuring trends and changes occurring over time and across regions.

Regional Construction Capacity Changes Over Time

Examining the 179 BEA economic regions separately for years 2007 and 2012, the correlation data provide insight into regional construction capacity changes over time. The

descriptive statistics (e.g., the minimum, median, and maximum) values for the regional indicators in both 2007 and 2012 show that construction capacity metrics, residential housing market indicators, and socio-economic indicators shifted as well.

Comparing correlation results between regional indicators and construction capacity metrics from both 2007 and 2012 reveals that both the location quotient for wages and the location quotient for employment had statistically significant and weak to moderate positive correlation with unit labor costs and capacity utilization, per Table 3-3. Therefore, in both 2007 and 2012, higher wage and employment location quotients were again correlated with less competitive unit labor costs and capacity utilization metrics. However, the strength of the correlations for the wages location quotient and the employment location quotient varies between 2007 and 2012.

Additionally, performing the Pearson correlation test separately for regional indicators in 2007 and 2012 showed the relationship between higher education and construction capacity. Specifically, the higher education indicator has a statistically significant but weak positive correlation with capacity utilization in 2007 ($r = 0.34, p < 0.001$) and 2012 ($r = 0.32, p < 0.001$). Increases in the regional median percentage of the population with an Associate's or other college degree correlates weakly with less building material availability within the regional supply chain (e.g., higher construction capacity). In other words, higher levels of regional educational attainment are weakly correlated with decreased regional residential construction industry competitiveness.

Results also indicate a statistically significant change in regional construction capacity metric, as well as regional residential housing market and socio-economic indicators over time, as highlighted in Table 3-4. For example, the medians of 2007 regional unit labor costs and the medians of 2012 unit labor costs are \$0.13 and \$0.17, respectively. This represents over a 30% in

unit labor costs between 2007 and 2012. To test if this change is statistically significant, a Wilcoxon signed-rank test was conducted. The Wilcoxon signed-rank test indicates that the medians of 2007 regional unit labor costs are statistically significantly lower than the medians of 2012 unit labor costs ($p < 0.0001$). In fact, all of the construction capacity metrics and regional indicators experienced statistically significant change between 2007 to 2012, with the exception of the median wage and labor location quotients.

Regional Construction Capacity Changes Across Regions

To explore why regional construction capacity varies across regions of the U.S., this research focused on ‘high capacity’ regions and ‘low capacity’ regions. Regions that outperformed the national median values for construction capacity (e.g., lower unit labor costs and lower capacity utilization rates) were classified as high capacity regions. Regions that underperformed the national median construction capacity values (e.g., higher unit labor costs and higher capacity utilization rates) were classified as low capacity regions. Findings are presented in Table 3-5.

Results show that the median values for all indicators vary across high and low capacity regions in 2007 and 2012. The Wilcoxon signed-rank test was performed to compare the median values of regional construction capacity, residential housing, and socio-economic indicators in high and low construction capacity regions for both 2007 and 2012. The difference in medians between high and low construction capacity regional indicators is statistically significant for all indicators except population density and the unemployment rate. To summarize, regions with the highest regional construction capacity had statistically lower median values for indicators of the residential housing market (e.g., low total wages and employment totals, as well as lower concentrations of regional wages and employment compared to the nation). In terms of socio-

economic indicators, high construction capacity regions had statistically higher medians for home values and poverty rates, but statistically lower medians of resident with a higher education.

DISCUSSION

This research highlights the differences in the regional construction capacity of the residential construction industry, from 2007-2012 and across the 179 BEA economic regions of the U.S. Regional construction capacity for the residential construction industry is measured using two key metrics: unit labor costs and capacity utilization.

Current literature on the competitiveness of regions is beginning to study the individual components and indicators of unit labor costs, such as: wages, employment, and location quotients (Delgado et al. 2016; Doran and Fingleton 2015). Additionally, the majority of the existing economic geography literature clearly states that lower unit labor costs represent the increased competitiveness of a region or industry (Dullien and Fritsche 2008; Pancotto and Pericoli 2014), and that lower capacity utilization rates drive economic growth (Ženka et al. 2014). Governmental policy in both the U.S. and the European Union has historically aimed to lower unit labor costs to improve the economic performance and competitiveness of regional industries (Delgado et al. 2014; Mack and Jacobson 1996).

However, the authors posit that our understanding and use of unit labor costs and capacity utilization must be interpreted a bit more broadly for industries that are highly location dependent like residential construction. Returning to Porter's (1979) 5-Force Analysis framework, there are two key competitive forces that tend to be uneven across regions: buyer power and supplier power (Porter 2003).

High Construction Capacity Regions and Buyer Power

Regions with high levels of construction capacity in the residential construction industry (e.g., lower unit labor costs and lower capacity utilization rates than the national median) have statistically smaller wage and labor quotients than regions with low construction capacity. Construction firms and employees in high construction capacity regions are typically more efficient at utilizing labor wages in the transformation of raw building materials into finished residential housing output (e.g., the net value of construction installed), and traditional economic literature would classify such regions as highly competitive (Flanagan et al. 2007; Turok 2004).

However, such efficiency and competitiveness come at the expense of construction workforce wages and bargaining power within the regional market. Regions with high construction capacity have statistically lower annual wages per employee, population density, and median permit values for residential housing units than found in low capacity regions. Since population is the largest single determinant of housing demand (Hua 2012), high construction capacity regions presumably have low housing demand. Low demand and low wages create a highly competitive market for residential construction industries within high capacity regions (Porter 2003, 1979), and residential home buyers can push for lower bid prices. Ultimately, regions with high construction capacity in the residential construction industry can be viewed as having high buyer power.

Additionally, wage and labor location quotients have the strongest statistically significant correlation of all indicators examined in this study, for both years 2007 and 2012. High construction capacity regions have statistically lower wage and employment location quotients than other economic regions included in this study. Therefore, low regional wage and employment location quotients can be used to identify regions with high buyer bargaining power.

Low Construction Capacity Regions and Supplier Power

Regions with low levels of construction capacity in the residential construction industry (e.g., higher unit labor costs and higher capacity utilization rates than the national median) have statistically larger wage and labor quotients than regions with high construction capacity. High regional location quotients are positively correlated with unit labor costs and capacity utilization and are indicative of low construction capacity regions.

Construction firms and employees in low construction capacity regions are typically less efficient at utilizing labor wages in the transformation of raw building materials into finished residential housing output, but that is because the workforce can demand higher wages. Regions with low construction capacity have statistically higher annual wages per employee, population density, and median permit values for residential housing units than found in high capacity regions. A large population generating high demand for residential housing (Hua 2012) enables construction industries to bargain for higher wages. Such conditions create positive regional environment for construction firms to earn better wages and have a large available workforce to draw upon for project work. Therefore, regions with low construction capacity in the residential construction industry can be viewed as having high supplier power.

LIMITATIONS AND FUTURE WORK

There are limitations to this research that need mentioning. First, construction capacity is measured in the form of unit labor costs and material capacity utilization. The Census Bureau's Economic Census data is only provided at the state-level. Aggregate regional construction capacity measurements are based on a combination of county-level estimates based on state-level averages. Second, there is no consensus definition of competitiveness or a set list of indicators to for testing changes in regional economic performance or competitiveness over time. Additionally, the only

two regional indicators with a moderate or higher correlation with unit labor costs and capacity utilization are the location quotients for wages and employment.

CONCLUSIONS

Although the U.S. national economy and residential construction industry have recovered substantially since the global economic recession of 2007-2009, regional residential construction industries have not recovered equally. The purpose of this research is to analyze why regional construction capacity metrics change over time and vary across geographical regions of the U.S. To explore changes in regional construction capacity metrics, this study examined correlations between indicators of both the residential housing market performance and indicators of socio-economic conditions.

There is a growing body of literature claiming that regions are a critical resource of competitive advantage. However, few existing models for measuring regional competitiveness account for the complexity and location-specific nature of the construction industry (Boschma 2004). The main contribution of this work to the body of knowledge is to fill the gap in the existing literature regarding quantitative, industry-level assessment of construction industry performance and competitiveness at the regional scale. This research adds to the limited economic geography literature by using quantitative data beyond case studies and theoretical models. Results of the correlation analysis highlight how regional variations of residential housing market and socio-economic conditions correlate with changes in regional construction capacity. The findings show that as regional wage and employment location quotients increase (e.g., increased concentration of residential construction industry wages and employment within a region), unit labor costs and capacity utilization rates also increase. In other words, the more concentrated the residential construction industry's wages and employment are within a given region, the more labor

compensation is required per dollar of net value in construction work installed (e.g., higher unit labor costs) and less building material inventory will be available within the regional supply chain (e.g., higher construction capacity). Thus, higher wage and employment quotients are correlated with decreased regional residential construction industry competitiveness and lower wage and employment quotients are correlated with decreased regional residential construction industry competitiveness.

This research also provides a practical contribution in terms of identifying indicators correlated with regional construction capacity, competitiveness, and buyer and supplier power dynamics. Currently the only publicly available program with detailed economic data for the U.S. construction industry and industry sub-sectors is the Census Bureau's Economic Census. However, the Economic Census is only conducted every five years and data is only available at the state-level. However, results of this research indicate a statistically significant and moderate positive correlation between wage and employment location quotients and regional construction capacity metrics. Therefore, low location quotients can be used to identify regions with high construction capacity and high buyer power. Conversely, high regional location quotients can be used to identify regions with low construction capacity high supplier power. This practical implications of these findings deal with data availability. The U.S. Bureau of Labor Statistics tracks wage and labor location quotients annually at the county-level for many sub-sectors of the U.S. construction industry.

ACKNOWLEDGMENTS

This research is supported by the Department of Education's Graduate Assistantships in Areas of National Need (GAANN) funding. Any opinions, findings, and conclusions or

recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agency.

DATA AVAILABILITY STATEMENT

Data generated or analyzed during the study are available in a repository or at a provided location online (<http://www.colorado.edu/lab/gpo/erin-arneson>). Data were collected from publicly available datasets published by the U.S. Bureau of Economic Analysis, the U.S. Census Bureau, and the U.S. Bureau of Labor Statistics (BLS).

Table 3-1. Indicator Descriptions

Description	Description ^a
Unit Labor Costs	Annual average cost of construction labor (\$USD wages) per unit of construction industry output (\$USD annual Net Value construction installed). Sources: <i>Census Bureau Economic Census, Census Bureau Permits Survey, Bureau of Labor Statistics (BLS) Quarterly Census of Employment</i>
Capacity Utilization	Percentage of building materials sold annually by wholesalers (NAICS 4233) within a region that are used by residential contractors (NAICS 23611) to build houses. Sources: <i>Census Bureau Economic Census, Census Bureau County Business Patterns, BLS Quarterly Census of Employment</i>
Industry Wages ^b	Annual average wages (\$USD) paid per residential construction (NAICS 2361) employee within a region. Source: <i>BLS Quarterly Census of Employment</i>
Location Quotient - Wages ^b	Ratio of regional residential contractor wages (NAICS 23611) compared to national Source: <i>BLS Quarterly Census of Employment</i>
Industry Employment	Regional residential construction industry employment concentration compared to national employment concentration (#) Source: <i>BLS Quarterly Census of Employment</i>
Location Quotient - Employment	Regional residential construction industry employment concentration compared to national employment concentration (#) Source: <i>BLS Quarterly Census of Employment</i>
Median Permit Value ^b	Annual regional median residential permitted housing unit value (\$) Source: <i>Census Bureau's Building Permits Survey</i>
Population Density	Annual regional resident population per regional square mile (#) Source: <i>Census Bureau's American Community Survey</i>
Poverty Rate	Annual regional poverty rate (%) Source: <i>Census Bureau's American Community Survey</i>
Unemployment Rate	Annual regional unemployment rate for all industries (%) Source: <i>Census Bureau's American Community Survey</i>
Higher Education	Annual percentage of regional residents with an education level of an Associate's degree or higher (%) Source: <i>Census Bureau's American Community Survey</i>

a: Measurement methods used to calculate regional indicator values are outlined in detail in the Data Analysis section of this manuscript.

b: All 2007 dollar values (\$ USD) were adjusted for inflation to reflect 2012 dollar values (\$ USD), using inflation indices.

Table 3-2. Correlation Matrix

<i>Indicators (n = 358)</i>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
<i>Construction Capacity</i>											
(1) Unit Labor Costs	1.00										
(2) Capacity Utilization	0.14*	1.00									
<i>Residential Construction Industry</i>											
(3) Industry Wages	0.11	0.25*	1.00								
(4) Location Quotient - Wages	0.31*	0.53*	0.43*	1.00							
(5) Industry Employment	0.23	0.17*	0.59*	0.21*	1.00						
(6) Location Quotient - Employment	0.39*	0.52*	0.24*	0.95*	0.19*	1.00					
<i>Socio-Economic Conditions</i>											
(7) Median Permit Value	0.22*	0.26*	0.45*	0.44*	0.62*	0.49*	1.00				
(8) Population Density	0.21*	0.03	0.50*	0.08	0.67*	0.04	0.47*	1.00			
(9) Poverty Rate	-0.20*	-0.13*	-0.08	-0.07	-0.19*	-0.14	-0.40*	-0.17	1.00		
(10) Unemployment Rate	-0.15*	-0.29*	-0.03	-0.11	0.03	-0.11	-0.03	0.05	0.39*	1.00	
(11) Higher Education	0.19*	0.34*	0.19	0.37*	0.30*	0.45*	0.64*	0.11	-0.59	-0.26*	1.00

Note: Indicator definitions are provided in Table 1.

*Correlation significant at $p < 0.001$ (two-tailed)

Table 3-3. Regional Indicators of Construction Capacity (2007 and 2012)

	Minimum	Median	Maximum	Unit Labor Costs	Capacity Utilization
2007 Regions (n = 179)					
Unit Labor Costs	\$0.03	\$0.13	\$0.59	1.00	
Capacity Utilization	19%	65%	322%	0.14	1.00
Industry Wages	\$22,400	\$37,300	\$73,200	0.11	0.25*
Location Quotient - Wages	0.23	0.74	3.36	0.31*	0.53*
Industry Employment	71	1,846	66,060	0.23	0.17
Location Quotient - Employment	0.22	0.83	3.04	0.39*	0.52*
Median Permit Value	\$58,000	\$107,600	\$390,000	0.22	0.26*
Population Density	1/mile ²	77/mile ²	1,265/mile ²	0.21	0.03
Poverty Rate	5.7%	10.8%	33.8%	-0.20	-0.13
Unemployment Rate	2.4%	4.8%	9.9%	-0.15	-0.29*
Higher Education	26.9%	43.3%	62.7%	0.19	0.34*
2012 Regions (n = 179)					
Unit Labor Costs	\$0.05	\$0.17	\$1.30	1.00	
Capacity Utilization	8%	42%	191%	0.26*	1.00
Industry Wages	\$22,200	\$35,700	\$65,400	0.01	0.09
Location Quotient - Wages	0.25	0.85	2.62	0.25*	0.54*
Industry Employment	68	1,200	51,461	0.12	0.10
Location Quotient - Employment	0.21	0.89	2.47	0.35*	0.58*
Median Permit Value	\$62,400	\$116,100	\$419,400	0.15	0.31*
Population Density	1/mile ²	80/mile ²	1,305/mile ²	0.06	0.03
Poverty Rate	9.8%	15.8%	36.9%	-0.08	-0.22
Unemployment Rate	3.2%	8.4%	14.6%	0.01	-0.12
Higher Education	33.4%	51.7%	67.6%	0.08	0.32*

* Correlation significant at p < 0.001 (two-tailed)

Table 3-4. Median Indicators 2007 and 2012

	2007 Median Value	2012 Median Value	Difference in median	p-value
	<i>(n = 179)</i>	<i>(n = 179)</i>	<i> Δ% </i>	
Unit Labor Costs	\$0.13	\$0.17	30.3%	<0.0001
Capacity Utilization	65%	42%	23.0%	<0.0001
Industry Wages	\$37,300	\$35,700	4.3%	<0.0001
Location Quotient - Wages	0.74	0.85	14.9%	0.0939
Industry Employment	1,846	1,200	35.0%	<0.0001
Location Quotient - Employment	0.83	0.89	7.2%	0.4307
Median Permit Value	\$107,600	\$116,100	7.9%	<0.0001
Population Density	77/mile ²	80/mile ²	3.7%	<0.0001
Poverty Rate	10.8%	15.8%	5.0%	<0.0001
Unemployment Rate	4.8%	8.4%	3.6%	<0.0001
Higher Education	43.3%	51.7%	8.4%	<0.0001

Note: Wilcoxon signed ranks test, with a 95% confidence interval

* significant at $p < 0.0001$ (two-tailed)

Table 3-5. High and Low Construction Capacity Regions

<i>Indicators</i>	2007				2012			
	Median Value _(H) (n = 47)	Median Value _(L) (n = 45)	Difference in median Δ%	p-value	Median Value _(H) (n = 41)	Median Value _(L) (n = 41)	Difference in median Δ%	p-value
Unit Labor Costs	\$0.09	\$0.16	77.8%	<0.0001	\$0.13	\$0.24	84.6%	<0.0001
Capacity Utilization	46%	93%	47.0%	<0.0001	30%	62%	32.0%	<0.0001
Industry Wages	\$33,900	\$42,000	23.9%	<0.0001	\$33,000	\$38,700	17.3%	<0.0001
Location Quotient-Wages	0.53	1.19	124.5%	<0.0001	0.64	1.16	81.3%	<0.0001
Industry Employment	1,226	3,667	199.1%	<0.0001	762	1,739	128.2%	<0.0001
Location Quotient-Employment	0.63	1.17	85.7%	<0.0001	0.67	1.22	82.1%	<0.0001
Median Permit Value	\$96,800	\$142,100	46.8%	<0.0001	\$98,800	\$160,700	62.7%	<0.0001
Population Density	57/mile ²	101/mile ²	77.2%	0.0473	58/mile ²	89/mile ²	53.4%	0.0473
Poverty Rate	12.6%	9.4%	3.2%	<0.0001	17.0%	14.2%	2.8%	<0.0001
Unemployment Rate	5.2%	4.7%	0.5%	0.0018	8.5%	8.3%	0.2%	0.0018
Higher Education	38.7%	47.5%	8.8%	<0.0001	49.1%	56.0%	6.9%	<0.0001

Note: Median Value_(H) = High Construction Capacity Region, and Median Value_(L) = Low Construction Capacity Region

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CHAPTER 4 – PREDICTING POST-DISASTER RESIDENTIAL HOUSING RECONSTRUCTION BASED ON MARKET RESOURCES

ABSTRACT

Multiple billion-dollar disaster events occurred throughout 2017, illustrating the increasing vulnerability of the U.S. residential housing stock to widespread damages associated with disasters. Although the U.S. construction industry plays a critical role in the reconstruction of residential housing after disasters, the industry is constrained by regional availability of labor, material, and capital resources. However, there are few quantitative assessments of why post-disaster reconstruction does not occur consistently across regions. This research introduces a quantitative model to predict regional post-disaster levels of reconstruction, based on the annual average percentage change in the number of residential housing permits issued two years before and after a disaster event. Results from an analysis of 204 regions affected by disasters between 2007 and 2013 indicate that pre-disaster construction labor availability has a statistically significant and positive effect on post-disaster reconstruction of residential housing. Surprisingly, pre-disaster construction material resources and post-disaster capital availability have minimal effect on reconstruction and are not statistically significant. The study contributes to the body of knowledge of post-disaster reconstruction by using economic theory of market-driven resource supply to determine driving factors that prevent or enable residential housing reconstruction following a disaster.

KEYWORDS: Reconstruction, Market Resources, and Residential Housing

INTRODUCTION

Disasters in 2017 severely affected the existing U.S. residential housing stock, resulting in more than 5.1 million damaged or destroyed housing units and nearly 3.3 billion dollars in direct housing damages (FEMA 2018a). The majority of built infrastructure within the U.S. is classified as residential, and the swift reconstruction of permanent residential housing is considered a crucial component of broader post-disaster economic recovery and stability (Rathfon et al. 2013). In fact, a lack of post-disaster residential housing reconstruction within two years after a disaster has been found to lead to long-term decreases in population (Olshansky 2006) and social cohesion (Aldrich 2012a), as well as loss of business establishments and associated government tax base (Godschalk 2003) in areas devastated by disasters.

In the past decade, the U.S. federal government has also taken note of the importance of permanent residential housing reconstruction after disasters. The Federal Emergency Management Agency (FEMA) introduced major housing policy changes in the U.S. National Disaster Housing Strategy in 2009, based on lessons learned in the field. The failure of temporary housing solutions, such as the well-publicized ‘FEMA trailers’ after Hurricane Katrina, led the federal government to reassess the U.S. post-disaster housing assistance process and shift focus to permanent reconstruction options (FEMA 2009). This policy change became evident with the massive permanent housing reconstruction efforts implemented after Hurricane Sandy (Nejat et al. 2016). The national disaster housing strategy sets a new direction for post-disaster reconstruction in the U.S. by focusing on two key aspects of post-disaster recovery: (1) the importance of quickly repairing and replacing damaged permanent residential housing, and (2) the role of resource availability at the regional level (FEMA 2009).

Rapid reconstruction of permanent residential housing is constrained by the availability of three post-disaster regional resources: labor, material, and capital (Dormady et al. 2017; Rose and Liao 2005). Residential homeowners typically seek to rebuild their houses and progress ‘back to normal’ quickly, generating a sudden post-disaster demand spike for residential construction services (Jha et al. 2010). Since residential housing reconstruction is typically implemented and managed at the regional level (Cantrell et al. 2012), the availability of regional resources plays a crucial role in post-disaster housing rebuilding. To meet this demand, the surrounding regional residential construction industry must have enough labor and material capacity and homeowners need an adequate supply of capital to finance the repairs or rebuilding of their residential property (Comerio and Blecher 2010). The combination of construction industry resource availability and financial capital availability may explain why some regions are better able to cope with major economic disruptions such as disasters (Diodato and Weterings 2015).

Despite widespread recognition of the importance of post-disaster reconstruction of housing, including restoration of economic and social stability (Aldrich 2012b; Jha et al. 2010), there is a lack of quantitative studies that investigate why post-disaster housing reconstruction progresses at varying rates across geographical regions (Olshansky et al. 2012; Zhang and Peacock 2009). Although resource management in the construction industry is well studied, the majority of this literature focuses on resource procurement and scheduling during normal operating conditions (Chang et al. 2011). In contrast, few studies have empirically examined the role construction industry resources play in post-disaster reconstruction, especially in countries with mature construction markets such as the U.S. (Stevenson et al. 2010). Given the important role of resources for recovery, a research study was designed to answer the following research question:

Does pre-disaster regional construction industry labor and material resource availability predict

post-disaster regional reconstruction of residential housing units? Given the possible external influence of capital availability, the authors sought to explore this question while controlling for the magnitude of federal disaster grants.

LITERATURE REVIEW

To facilitate swift post-disaster reconstruction of residential housing there must be an adequate supply of labor, material, and capital resources within the disaster affected region. This research analyzes the relationship among regional labor, material, and capital resource availability (e.g., predictor variables) and post-disaster residential housing reconstruction (e.g., outcome variable). Building upon recent housing reconstruction literature, post-disaster residential housing reconstruction outcomes are measured as the change in the annual average number of permits issued for residential housing units in the two years before and after a disaster event.

Residential Reconstruction Predictors and Outcomes

Post-disaster residential housing reconstruction is often a top priority for both governmental agencies and homeowners, but is hampered by a lack of adequate construction industry and financial resources (Chang et al. 2011). For example, Zhang and Peacock (2009) found that uneven levels of residential housing reconstruction after Hurricane Andrew were linked to pre-disaster construction industry labor and material resource availability. Chang-Richards et al. (2017) also identified residential construction labor shortages as a critical constraint in reconstruction processes after the 2011 Christchurch earthquakes. Similarly, a lack of pre-disaster material availability led to post-disaster reconstruction delays following the 2008 Wenchuan earthquake (Chang et al. 2010). In terms of financial capital availability, access to post-disaster financing from the federal government improved housing reconstruction outcomes after the 1994

Northridge and 1999 Taiwan earthquakes (Wu and Lindell 2003), as well as the 2009 Australia bushfires (Chang-Richards et al. 2013).

However, despite such studies linking post-disaster reconstruction with labor, material, and capital resource availability, the overwhelming research focus to date has been case studies of individual disaster types and locations (Cutter et al. 2014; Olshansky et al. 2012). Few researchers have conducted quantitative assessments of the effect of resource availability on post-disaster reconstruction, especially for multiple hazard types across a range of geographies. Conducting these studies requires selecting an appropriate timeframe and measurement of residential reconstruction.

Reconstruction includes the flurry of construction activity that escalates within a compressed timeframe after a disaster (Olshansky et al. 2012). Past studies have identified the need to quickly repair and replace damaged housing after a disaster, with the two-year post-disaster timeframe noted as an important milestone (Lindell and Prater 2003; Wu and Lindell 2003). For example, Zhang and Peacock (2009) found that damaged houses typically regained their pre-disaster appraised values within two years after Hurricane Andrew. Similarly, Rathfon et al. (2013) discovered that approximately 90% of post-disaster housing reconstruction work ever finished was completed within two years after Hurricane Charley. Thus, this study frames the timeframe for post-disaster residential housing reconstruction as the two year period after a disaster occurs.

Post-disaster residential reconstruction includes the amount of housing repairs and replacement that occur after a disaster. However, measuring post-disaster reconstruction is complicated by the fact that there is no consistent unit of analysis. One proposed quantitative measurement of housing reconstruction is the number of permits issued after a disaster (Wu and Lindell 2003). Permits represent the intent of a property owner to repair or rebuild a damaged

residential housing unit. Within the U.S., permits can be used as a measure of reconstruction since permits are legally required to begin construction work and typically result in completed projects. For example, nearly 99% of single-family residential permits issued in the U.S. result in completed housing projects (U.S. Census Bureau 2018). Permits have been used by Stevenson et al (2010) to measure post-disaster housing reconstruction progress after Hurricane Katrina by examining relationships between pre-disaster housing units, disaster damages, and the number of permits issued. Rathfon et al. (2013) have also used the number of post-disaster housing permits issued as an indicator for the speed of housing reconstruction after Hurricane Charley.

Reconstruction Resources in a Market Economy

The U.S. is one of the world's most mature market economies, a system where supply and demand mechanisms control the production of goods and services. Market economies are found in capitalistic and developed nations, where coordination of resource supply and consumer demand is left to the market with limited government intervention (Simmie and Martin 2010). The role of market economy dynamics in post-disaster reconstruction cannot be overstated. In contrast to developing nations, which often rely on donor-driven resources, developed nations with mature construction sectors, like the U.S., rely on market-driven resource supply to meet post-disaster residential housing reconstruction demand (Chang-Richards et al. 2013). Demand for post-disaster reconstruction of privately owned housing must therefore be met by the supply of resources within the surrounding regional market economy (Dormady et al. 2017).

Recent literature has identified resource availability in regional market economies as a crucial requirement for improving post-disaster reconstruction output and timeframes (Holguín-Veras and Jaller 2012; Hwang et al. 2016). Resources necessary for housing reconstruction include the existing regional residential construction labor force and building materials (Chang-Richards

et al. 2017; Rose and Liao 2005). Homeowners also require readily available capital resources to quickly secure and purchase construction labor and materials after a disaster. Countries with market economies tend only to assist housing reconstruction efforts by providing capital resources. For example, the U.S. government facilitates post-disaster housing reconstruction by providing homeowners with capital resources, in the form of FEMA disaster recovery grants (Federal Emergency Management Agency 2008). The challenge of sourcing adequate construction labor and material resources for housing reconstruction projects is left to the regional market economy to sort out.

Previous research has highlighted the influence of regional labor, material, and capital resource availability on housing reconstruction in market economies (Zhang and Peacock 2009). Regional labor and material shortages have been shown to lead to post-disaster delayed project schedules (Chang-Richards et al. 2017; Holguín-Veras and Jaller 2012) and material price inflation (Chang-Richards et al. 2013; Hwang et al. 2016). There is little quantitative research, however, about why housing reconstruction progresses differently across various geographic regions. Advances in quantitatively understanding the effect of resource availability within a market economy on post-disaster housing reconstruction outcomes therefore is still needed (Comerio and Blecher 2010).

RESEARCH METHODS

The purpose of this research was to measure the extent to which regional post-disaster levels of reconstruction for residential housing units can be predicted from pre-disaster regional construction labor and material resource availability. A multi-step scoping process was performed to identify: 1) U.S. regions affected by disasters between 2007 and 2013, based on per capita residential housing damages; 2) pre-disaster regional construction labor availability; 3) pre-

disaster regional building material availability; 4) post-disaster regional capital availability; and 5) post-disaster housing reconstruction outcomes, based on the change in annual number of permits issued before and after a disaster.

First, the study scope was limited to regions that experienced widespread residential housing damages from disasters that occurred between 2007 and 2013. This range of disaster events was chosen to provide consistent coverage of residential construction industry labor and material availability data, post-disaster capital availability data, and reconstruction permit data. Second, pre-disaster regional labor availability was measured as the net value of residential work installed per permitted house. Third, pre-disaster regional material availability was measured as the ratio of building material wholesales to building material purchases. Fourth, post-disaster regional capital availability was measured by disaster damages covered by federal disaster grants. Fifth, post-disaster residential housing reconstruction outcomes were measured as the difference in the annual average number of residential housing permits issued during the two years before a disaster occurred (e.g., pre-disaster phase) and the two years after the disaster event (e.g., post-disaster phase).

Data Collection

Data related to the U.S. construction industry labor and material availability and federally declared disasters were collected from publicly available programs and datasets published by the U.S. Bureau of Economic Analysis, the U.S. Census Bureau, the U.S. Bureau of Labor Statistics, and the Federal Emergency Management Agency. The North American Industry Classification System (NAICS), which standardizes industry-level statistics and is used throughout the federal government (Office of Management and Budget and Executive Office of the President 2007), was used to identify residential construction industry data related to labor and material metrics. A

summary of the regional labor, material, and capital data used in this study can be found in Table 4-2 at the end of Chapter 4.

Regional Boundaries

To analyze the effect of regional labor, material, and capital resource availability on post-disaster regional reconstruction of residential housing units, the authors used pre-established geographical regions defined by the U.S. Bureau of Economic Analysis (BEA). The BEA has divided the U.S. into 179 economic regions, based on statistical analyses of economic development trends, strength of business and trade transactions, and workforce commuting patterns (Delgado et al. 2016; Johnson and Kort 2004). Each BEA region is anchored by a metropolitan or micropolitan statistical area, serving as a population and business hub that drives economic activity in surrounding cities and counties (Johnson and Kort 2004). The BEA economic regions were selected because they: a) consist of aggregated clusters of U.S. counties and thus provide coverage for the entire U.S.; b) have maintained consistent geographical boundaries over time; and c) are statistically likely to contain an independent labor market with unique economic performance indicators (Porter 2003; Johnson and Kort 2004). The boundaries of the BEA economic regions indicate independent labor markets since 4% or less of the labor workforce in any given region commutes out to an adjacent region (Johnson and Kort 2004), suggesting low interregional mobility of workers within the residential construction industry.

Pre-Disaster Regional Labor Metrics

The authors measured pre-disaster regional labor availability as the annual net value of construction installed by residential contractors (NAICS 23611) per permitted residential housing unit. The researchers collected two residential construction labor metrics: (1) the annual value of

construction work installed by a regional residential construction workforce, and (2) the annual number of residential housing permits issued.

Establishments and employees classified as NAICS 23611 – Residential Building Construction were included, which the Census Bureau describes as primarily engaged in the construction, remodeling, and renovation of single-family and multi-family residential buildings (Office of Management and Budget and Executive Office of the President 2007). Labor metrics were collected from two programs conducted by the U.S. federal government, namely: (1) the U.S. Census Bureau’s Economic Census, and (2) the U.S. Census Bureau’s Building Permits Survey.

The U.S. Census Bureau’s Economic Census program is only conducted every five years, so data were collected and analyzed from the most recently published datasets from years 2002, 2007, and 2012. The Economic Census’ *Construction Geographic Area Series* provided one state-level residential construction labor metric, the annual net value of construction work put in place by residential contractors (NAICS 23611), less work subcontracted out to specialty trades (U.S. Census Bureau 2002a, 2007a, 2012a). The U.S. Census Bureau’s Building Permits Survey program provided one county-level metric, the number of residential housing permits issued annually, which was tracked from 2005-2015 (U.S. Census Bureau 2018).

Pre-Disaster Regional Material Metrics

Pre-disaster regional material availability were measured as a ratio of supply to demand. The value of building material wholesales conducted at wholesale establishments (NAICS 4233) within a given region represented the regional supply of materials. The cost of materials, components, and supplies purchased by residential contractors (NAICS 23611) within a given region represented the regional demand for materials. A 1:1 supply to demand ratio resulted in 100% material availability within a region. In regions where annual supply exceeded demand,

material availability was above 100%, and below 100% in regions where supply could not meet demand for building materials. Four residential construction material metrics were collected and included in the analysis: (1) the annual value of building material wholesales, (2) the annual average number of wholesale establishment operating within the region, (3) the annual cost of materials, components and supplies purchased by residential contractors, and (4) the annual average number of employed residential contractors.

To identify regional building material metrics, the researchers focused on establishments classified as NAICS 4233 – Lumber and Other Construction Materials Merchant Wholesalers. The Census Bureau describes such establishment as primarily engaged in the merchant wholesale of materials used in construction, such as: lumber, plywood, brick, stone, roofing, siding, insulation, gypsum board, windows and doors, and other common building materials (Office of Management and Budget and Executive Office of the President 2007). Material metrics were collected from three programs conducted by the U.S. federal government from the years 2002, 2007, and 2012, namely: (1) the U.S. Census Bureau’s Economic Census, (2) the U.S. Census Bureau’s County Business Patterns program, and (3) the Bureau of Labor Statistics’ (BLS) Quarterly Census of Employment and Wages.

The Economic Census’ *Wholesale Trade Series* provided one state-level material metric: the annual value of building material wholesale trade sales generated by merchant wholesaler establishments (NAICS 4233) (U.S. Census Bureau 2002b, a; c, 2007b; a, 2012a). The Economic Census’ *Construction Geographic Area Series* provided one additional state-level residential material metric: the annual cost of materials, components, and supplies purchased by residential contractors (NAICS 23611) in order to build new or replace existing housing units (U.S. Census Bureau 2002a, 2007a, 2012a).

The U.S. Census County Business Patterns program provided one county-level labor availability metric: the annual average number of establishments engaged in building material wholesale activity (NAICS 4233) (U.S. Census Bureau 2002d, 2007c, 2012b). Although other federal agencies such as the BLS track the number of wholesale establishments, the authors used the County Business Patterns data because it had more detailed establishment counts at the county-level. Another county-level material metric was collected from the BLS Quarterly Census of Employment and Wages program: the annual average number of employed residential contractors and builders (NAICS 23611) (U.S. Bureau of Labor Statistics 2002, 2007a, 2012a).

Post-Disaster Regional Capital Metrics

The authors measured post-disaster regional capital availability based on disaster damage coverage. To assess regional damage coverage, the ratio of federal disaster grants awarded by the Federal Emergency Management Agency (FEMA) for reconstruction was compared to the FEMA assessed value of residential housing damages. The researchers collected two county-level metrics relevant to disaster events: (1) the total value of housing assistance grants paid to residents after the disaster, and (2) the annual damages to residential buildings caused by disasters (FEMA 2018b). Disaster data were collected from the FEMA Individuals and Households Program for all U.S. regions affected by federally-declared disasters between 2007 and 2013. The value of disaster grants (\$ USD) were limited to funds specifically designated for repairing and replacing damaged residential housing. The total damages (\$ USD) were based on in-person assessments conducted by trained FEMA housing inspectors, who attempt to inspect all residential housing units in counties included in federal disaster declarations.

Post-Disaster Regional Reconstruction Outcomes

Reconstruction outcomes were measured as the difference in the annual average number of residential housing permits issued during the two-years before a disaster occurred and the two-years after the disaster event. Permit data were collected for the years 2005-2015 from the U.S. Census Bureau's Building Permits Survey (U.S. Census Bureau 2018). The two-year timeframe was selected for this research since nearly all required permits are issued and reconstruction work completed within two years of a disaster (Rathfon et al. 2013; Wu and Lindell 2003). The two-year pre-disaster phase served as a baseline indicator for the typical number of residential housing projects the regional construction industry completed to meet normal levels of consumer demand. The two-year post-disaster phase indicated if the regional residential construction industry was able to meet increased post-disaster demand for housing. Regions with higher levels of labor, material, and capital resource availability were expected to swiftly begin reconstruction of residential housing, resulting in an increased annual average number of permits issued in the post-disaster phase.

Data Analysis

A multilevel data analysis was used to aggregate state-level and county-level data into regional estimates for: pre-disaster construction labor and material resources; FEMA assessed residential housing damages; post-disaster federal disaster grant assistance provided by FEMA; and post-disaster reconstruction outcomes.

Disaster Regions

The first step was to identify the BEA regions that had experienced large-scale disaster events and associated residential housing losses between 2007 and 2013. To do this, all major disasters declared by FEMA during that time frame were recorded because major disasters are

associated with high concentrations of residential housing damages per capita (Federal Emergency Management Agency 2008). FEMA’s *Individuals and Households Program* data were used to calculate the total annual damages to residential housing units per U.S. county, from 2007-2013. Second, these county-level data were aggregated for all multi-county BEA regions, to measure the annual residential housing damages per region. This regional aggregation resulted in 327 BEA regions that had been affected by federally declared disasters between 2007 and 2013. Finally, the study was limited to disaster regions that had damages of at least \$1.41 per capita, based on damage assessments from FEMA and the Census Bureau population estimates. FEMA designates U.S. states as eligible for federal disaster assistance based on per capita damages, with the \$1.41 per capita figure the set rate from 2016 (FEMA 2017). This resulted in a total of 204 BEA disaster affected regions remaining for inclusion in the study, henceforth referred to as ‘BEA disaster regions.’

Pre-Disaster Regional Labor Availability

In the second step, the authors measured pre-disaster regional labor availability based on the annual ‘net value of construction’ work (USD) installed by residential contractors (NAICS 23611) per permitted residential housing unit. First, the regional-level annual net value of construction work installed was calculated for all BEA disaster regions in the non-disaster baseline years 2002, 2007, and 2012, as shown in Equation 4-1.

Equation 4-1. *Regional Net Value of Construction Work*

$$= \sum \left\{ \left[\left(\frac{\text{Value}_{\text{State}^A}}{H_{\text{State}^A}} \right) \times H_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Value}_{\text{State}^B}}{H_{\text{State}^B}} \right) \times H_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Value}_{\text{State}^n}$ = Net Value of construction work installed by laborers (Stateⁿ total)

H_{State^n} = Number of permitted residential housing units (Stateⁿ total)

$H_{\text{State}^n-\text{counties}}$ = Number of permitted residential housing units (for Stateⁿ counties within economic region)

Second, the regional-level average annual net value of construction work installed was estimated for all BEA disaster regions for years 2003-2006 and 2008-2011. Since net value of construction work is only tracked by the Economic Census every five years, the regional net value of construction was assumed to follow a consistent annual change trajectory between Census Bureau data collection years.

Lastly, the pre-disaster annual regional labor availability for all BEA disaster regions was calculated based on the regional net value of construction work per permitted residential housing unit, as shown in Equation 4-2. Regional labor availability was measured for the year directly prior to the year the disaster event occurred. This provided a snapshot in time of the residential construction industry's labor availability during normal operating conditions.

Equation 4-2. Pre-Disaster Regional Labor Availability

$$\text{Pre - Disaster Regional Labor Availability}_{\text{Disaster Year X}} = \frac{\text{Regional Net Value of Construction (\$)}_{\text{Disaster Year X-1}}}{\text{Regional Residential Housing Units Permitted (total)}_{\text{Disaster Year X-1}}}$$

Pre-Disaster Regional Material Availability

The third step was to measure pre-disaster residential construction industry material availability as the annual 'wholesale trade sales' (USD) sold at wholesale establishments (NAICS 4233) per 'cost of materials, components and supplies (USD) purchased by residential contractors (NAICS 23611). In other words, pre-disaster regional material availability indicates if material supply (wholesale trade sales) typically exceeds material demand (cost of materials purchased) within a region. First, regional-level annual 'wholesale trade sales' were calculated for all BEA disaster regions in the years 2002, 2007, and 2012, as shown in Equation 4-3. Second, regional-level annual 'cost of materials, components, and supplies' purchases were calculated for all BEA disaster regions in the years 2002, 2007, and 2012, as shown in Equation 4-4.

Equation 4-3. Regional Wholesale Trade Sales

$$= \sum \left\{ \left[\left(\frac{\text{Sales}_{\text{State}^A}}{W_{\text{State}^A}} \right) \times W_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Sales}_{\text{State}^B}}{W_{\text{State}^B}} \right) \times W_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Sales}_{\text{State}^n}$ = Sales of building materials by wholesalers (Stateⁿ total)

W_{State^n} = Number of Wholesale Trade Establishments (Stateⁿ total)

$W_{\text{State}^n-\text{counties}}$ = Number of Wholesale Trade Establishments (for Stateⁿ counties within economic region)

Equation 4-4. Regional Cost of Materials, Components and Supplies

$$= \sum \left\{ \left[\left(\frac{\text{Cost}_{\text{State}^A}}{E_{\text{State}^A}} \right) \times E_{\text{State}^A-\text{counties}} \right] + \left[\left(\frac{\text{Cost}_{\text{State}^B}}{E_{\text{State}^B}} \right) \times E_{\text{State}^B-\text{counties}} \right] + \dots \right\}$$

Where:

$\text{Cost}_{\text{State}^n}$ = Cost of building materials, components, & supplies purchased by laborers (Stateⁿ total)

E_{State^n} = Annual average employment of laborers (Stateⁿ total)

$E_{\text{State}^n-\text{counties}}$ = Annual average employment of laborers (for Stateⁿ counties within economic region)

Third, the authors estimated regional-level annual wholesale trade sales and cost of materials, components, and supplies for the years 2003-2006 and 2008-2011 based on an assumption that both construction material metrics would follow a consistent annual change pattern. Lastly, the authors calculated the pre-disaster annual regional material availability for all BEA disaster regions, based on the regional wholesale trade sales per cost of materials, components and supplies, as shown in Equation 4-5. Regional material availability was measured for the year directly prior to the year the disaster event occurred. This provided a snapshot in time of the residential construction industry's material availability during normal operating conditions.

Equation 4-5. Pre-Disaster Regional Material Availability

$$\text{Pre - Disaster Regional Material Availability}_{\text{Disaster Year X}} = \frac{\text{Regional Wholesale Trade Sales (\$)}_{\text{Disaster Year X-1}}}{\text{Regional Cost of Materials, Components, and Supplies (\$)}_{\text{Disaster Year X-1}}}$$

Post-Disaster Regional Capital Availability

The fourth step was to calculate the amount of post-disaster regional capital availability based on disaster damage coverage, in the form of federal disaster grant assistance provided by FEMA. Post-disaster capital availability was measured as the ratio of regional FEMA housing reconstruction grants (\$ USD) to regional FEMA assessed damages to residential housing units (\$ USD), shown in Equation 4-6.

Equation 4-6. Post-Disaster Regional Capital Availability

$$\text{Post – Disaster Regional Capital Availability}_{\text{Disaster Year X}} = \frac{\text{Regional FEMA IHP Reconstruction Grants (\$)}_{\text{Disaster Year X}}}{\text{Regional FEMA Assessed Damages (\$)}_{\text{Disaster Year X}}}$$

Post-Disaster Reconstruction Outcomes

The fifth step was to calculate the difference in the annual average percentage change in number of permits issued for residential housing units between the two-year pre-disaster and post-disaster phases. First, the annual percentage difference between the number of permits issued from each year to next was calculated for all BEA disaster regions from 2005-2015. Second, the pre-disaster and post-disaster annual average percentage change in residential permits issued was calculated for all BEA disaster regions, as shown in Equation 4-7.

The authors included the percentage change in permits issued the year of the disaster to adjust for the effects of any post-disaster reconstruction that took place in the same year as the disaster event. Some disasters struck in the first half of the year, allowing for some reconstruction to be completed within the BEA disaster region in the same year the disaster occurred. For example, in a region struck by a disaster in 2007, the pre-disaster annual average percent change in the number of permits issued included permits issued between 2005-2006 and 2006-2007. Post-

disaster annual average percent change in the number of permits issued included permits issued between 2007-2008 and 2008-2009.

Equation 4-7. Post-Disaster Growth Rate of Annual Average Residential Permits Issued

$$\text{Post – Disaster Regional Annual Average Permits Issued } \Delta\% = \frac{(P_{x+1} + P_{x+2})}{2} - \frac{(P_{x-1} + P_{x-2})}{2}$$

Where:

P_x = Annual Percent Change in Permits Issued over Previous Year *Disaster Year X*

RESULTS AND ANALYSIS

The final data analysis step was to run a linear regression analysis, using the statistical software RStudio. First, the explanatory variables were checked for normality both visually (box and whisker plots) and statistically (Shapiro-Wilkes test). Normality of the predictor variables leads to meaningful parameter estimates. Both the labor availability (e.g., net value of construction per permitted residential housing unit) and the material availability (e.g., wholesale trade sales per cost of materials, components and supplies) had left-skewed distributions and were non-normal. These skewed distributions were made more symmetrical by transformation to a logarithmic scale, so both explanatory variables were transformed using the natural log (ln) function (Hua 2012).

Next, the coefficients of the natural log transformed explanatory variables from the linear regression were transformed back to the original units. Interactions were included between pre-disaster labor and material availability because both resources are simultaneously required for reconstruction, and they were the only explanatory variables with statistically significant correlation per Pearson's correlation test. The linear regression formula is shown in Equation 4-8.

Equation 4-8. Linear Regression Formula

$$P \Delta\% = \beta_0 + \beta_1 \ln(\text{Labor}) + \beta_2 \ln(\text{Materials}) + \beta_3 \text{Capital} + \beta_4 \ln(\text{Labor}) * \ln(\text{Materials})$$

Where:

P $\Delta\%$ = Annual Average Percent Change in Permits Issued Between Pre-Disaster and Post-Disaster Phases

Linear Regression Results

To summarize, the purpose of this research was to develop a model to predict regional post-disaster levels of reconstruction for residential housing units, based on regional pre-disaster construction industry labor and material resource availability, while controlling for post-disaster capital availability. Examining 204 regions devastated by a federal disaster declaration between 2007 and 2013, the authors calculated post-disaster regional residential housing reconstruction outcomes, measured as the difference in the average annual number of residential housing permits issued in the two years before and two years after a disaster struck a given region.

The linear regression model included labor, materials, the interaction of labor and materials, and capital availability provided via FEMA grants. Regional reconstruction (i.e., the outcome variable) was measured as the percentage difference in regional annual average number of residential permits issued between the two-year pre-disaster and two-year post-disaster phases. Such a model allows one to measure the independent impact of each explanatory variable on reconstruction while controlling for the effects of the others. The results of the multiple linear regression indicate that post-disaster outcomes are statistically and positively linked to pre-disaster construction labor resource availability. Pre-disaster regional material availability and post-disaster regional capital availability also have a positive relationship with the response variable, but do not have statistically significant effect sizes. Results are highlighted in Equation 4-9 and Table 4-2.

Equation 4-9. Linear Regression Equation

$$y = -3.5286 + 0.0029(\text{Labor}) + 0.0056(\text{Materials}) + 0.0581(\text{Capital}) - 0.0004(\text{Labor} * \text{Materials})$$

Where:

$y = P \Delta\%$ = Annual Average Percent Change in Permits Issued Between Pre-Disaster and Post-Disaster Phases

Table 4-1. Linear Regression Results

	Estimate	Std. Error	t-value	P-value
(Intercept)	-3.52867	0.63740	-5.536	9.69e-08***
Labor	0.00291	0.05263	5.553	8.89e-08***
Materials	0.00559	0.80345	0.699	0.486
Capital	0.05809	0.06903	0.842	0.401
Labor*Materials	-0.00040	0.06731	-0.595	0.553

***Correlation is significant at $p < 0.001$; $n = 204$

R-squared = 0.2843

Labor

Pre-disaster regional labor availability is measured as the annual net value of construction per permitted residential housing unit. The data show a very strong, statistically significant, and positive relationship between pre-disaster regional construction labor availability and post-disaster regional reconstruction outcomes ($p\text{-value} = 9.69\text{e-}08$; $\beta_1 = 0.0029$). The percent difference in regional annual average number of residential permits issued between the pre-disaster and post-disaster phases (e.g., regional reconstruction outcome) increases by 0.00291% for every one unit change increase in pre-disaster labor availability within the region. In other words, for every ten-thousand dollar increase in pre-disaster net value of construction per permitted residential house, there is a 29.1% increase in post-disaster permits. To put this in perspective, the median labor availability across all 204 BEA disaster regions is approximately \$185,000 net value of construction per residential housing unit. An increase of 5% in the pre-disaster labor availability should therefore increase the expected annual average number of post-disaster permits issued by about 29%.

Materials

Pre-disaster regional material availability is measured as the ratio annual wholesale trade sales to costs of materials, components, and supplies. The data show a slightly positive, but not statistically significant relationship between pre-disaster regional construction material availability and post-disaster regional reconstruction outcomes ($p\text{-value} = 0.486$; $\beta_2 = 0.0056$). The percentage difference in regional annual average number of residential permits issued between the pre-disaster and post-disaster phases (e.g., regional reconstruction outcome) increases by 0.0056% for every one-unit change increase in pre-disaster material availability within the region. Thus, for every 100% increase in pre-disaster regional material availability, there is a 0.5% increase in post-disaster permits. To increase post-disaster housing permits, a regional construction industry would need to increase material availability to a point that is not realistically feasible.

These results are surprising, given that building materials are a necessary and costly expense for residential housing reconstruction. This may be due to the intrinsic connection between labor and material availability. Without sufficient labor availability, the material resource availability seems to have minimal impact on post-disaster reconstruction. Further detailed case studies of regions might confirm whether regions with material availability that rebuilt slowly also had low labor availability.

Capital

Post-disaster regional capital availability is measured as the ratio of the total value of FEMA IHP disaster reconstruction grants awarded to total FEMA-assessed disaster damages. The data show a slightly positive, but not statistically significant relationship between post-disaster regional capital availability and post-disaster regional reconstruction outcomes ($p\text{-value} = 0.401$; $\beta_3 = 0.0581$). The percentage difference in regional annual average number of residential permits

issued between the pre-disaster and post-disaster phases (e.g., regional reconstruction outcome) increases by 0.0581% for every one percent change increase in post-disaster capital availability within the region. In other words, for every 10% increase in FEMA damages covered by FEMA IHP grants within a region, there is a 0.5% increase in regional post-disaster permits issued.

Additionally, the raw data used in this study provide insight into reconstruction outcomes. For example, there were significant differences in levels of post-disaster reconstruction across the 204 BEA disaster regions. The median post-disaster change in the annual average number of permits issued increased by approximately 6.3% over pre-disaster permit trends. However, the lowest performing region saw a 91.2% drop in annual permits in the post-disaster phase, while the best performing region saw a nearly 73.4% increase in post-disaster average annually issued permits. Although the predictive model proposed in this research highlights the importance of pre-disaster residential construction industry labor availability, other socio-economic factors may also be influencing regional housing reconstruction outcomes and requires further study.

LIMITATIONS AND FUTURE WORK

The authors acknowledge limitations in this research. First, results are based upon a combination of state-level and county-level data that have been aggregated for BEA disaster regions. The construction industry labor and material economic data are only available from the Census Bureau every five years. As a result, construction labor and material availability were estimated for timeframes between Census Bureau data points. Additionally, the quantitative model proposed in this research accounts for approximately 30% of the variability within the entire model. There are definitely many other regional variables that also affect post-disaster reconstruction outcomes because disasters are complex systems that affect physical, social, information, and economic infrastructures.

DISCUSSION

This research highlights the importance of labor, material, and capital resource availability in the ability of regions to repair and replace damaged residential housing after disaster events. Studying post-disaster reconstruction from a market perspective of economic theory allows us to begin to understand the role of regional pre-disaster labor, pre-disaster material, and post-disaster capital resource availability in post-disaster outcomes.

Policy Implications

Responses by regional economies to economic shocks has been a focus of increased attention since the 2008 global recession (Martin and Sunley 2015). Particular focus has been paid to how large-scale economic disruptions, such as disasters, result in uneven recovery and development across regional geographies (Doran and Fingleton 2015). Results indicate that post-disaster regional reconstruction is significantly and positively influenced by pre-disaster construction labor availability, and to a much lesser extent, positively affected by pre-disaster material and post-disaster capital regional resource availability. Thus, the research findings align with other recent economic studies of regions by indicating that regional recovery from economic disruptions depends on the market characteristics where the impact occurs (Martin and Sunley 2015). The collective ability of a regional construction industry to deal with the economic shock of a disaster is based on the pre-disaster state of the labor market and material supply chain. Geographical variations of labor, material, and capital availability will yield uneven regional patterns of reconstruction.

In contrast with donor-driven resource economies found in most developing nations after a disaster, developed countries with mature construction sectors rely on the market economy to successfully meet post-disaster demand for construction services (Chang-Richards et al. 2013).

However, reliance on market resources and private industry coordination mechanisms leaves the entire reconstruction process vulnerable to the market. National and regional markets experience both short term shocks and long-term stressors (including but not limited to disasters) that can restrict resource availability. For instance, the U.S. construction industry was hard hit by the 2008 global economic crisis. The economic downturn had a major impact on the number of residential contractors and building material wholesale establishments operating in the US. According to BLS, residential construction employment peaked in 2007 and then experienced a significant decrease in annual average employment (U.S. Bureau of Labor Statistics 2007a). For example, the annual average employment of residential contractors (NAICS 23611) fell over 39% between 2007 and 2012, while the annual number of residential construction firms (NAICS 23611) dropped nearly 24% in that same timeframe (U.S. Bureau of Labor Statistics 2002, 2007a). Even as of 2012, the annual number of residential contractors and firms both remain approximately 17% below peak 2007 numbers (U.S. Bureau of Labor Statistics 2012a). This ongoing shortage of construction laborers in the U.S. will have long-term consequences for the construction industry and the post-disaster reconstruction process.

Therefore, the role of the construction industry in future disaster events needs to be reevaluated. Although the value of direct damages to residential housing is trending upwards over time (FEMA 2014), there are large regional fluctuations in construction industry labor and material availability. Regional construction industry resources may not be able to keep pace with demand spikes for post-disaster residential housing reconstruction services. Currently, the federal government does not play a direct role in residential housing reconstruction (Zhang and Peacock 2009). Rather the government indirectly facilitates reconstruction by providing financial capital in the form of FEMA IHP grants. However, this study finds that FEMA IHP grants have much less

impact on post-disaster reconstruction outcomes in comparison to construction industry labor availability. Since regions with higher levels of market resources lead to improved post-disaster regional economic recovery and reconstruction (Doran and Fingleton 2015), more coordination between the government and regional construction industries is needed to improve post-disaster reconstruction outcomes.

CONCLUSIONS

Recent disaster events in the U.S. and globally have underscored the importance of post-disaster reconstruction. Although the construction industry's critical role in repairing and replacing residential homes destroyed by disasters is well acknowledged, the industry is hampered by regional availability of labor, material, and capital resources. This is troubling since, according to the U.S. Department of Housing and Urban Development, residential housing is the key component to the long-term growth and survival of American communities (Cantrell et al. 2012).

This research provides a quantitative model for predicting regional post-disaster levels of reconstruction for residential housing. This model is based on regional pre-disaster construction industry labor and material resource availability, and controls for post-disaster capital availability. An analysis of 204 U.S. regions affected by disasters between 2007 and 2013 indicates that labor, material, and capital resource availability all have a positive effect on post-disaster reconstruction outcomes. Importantly, the pre-disaster residential construction labor availability had a strong statistical link to improved post-disaster reconstruction, based on change in residential permits issued post-disaster. Although not statistically significant, pre-disaster construction material availability and the availability of post-disaster capital from FEMA appear to have positive but minimal effects on post-disaster reconstruction. These results align with recommendations set forth in the U.S. National Disaster Housing Strategy, which stresses the need for timely permanent

residential housing reconstruction and the importance of regional resource availability. To summarize, increases in pre-disaster residential construction labor availability within a region lead to increases in residential housing permits being issued. Higher permit numbers are associated with reconstruction work starting in the first two years after a disaster strikes a region, aligning with the U.S. government's housing strategy.

This research also adds to the literature regarding the economic theory of regional market economies, especially in the context of post-disaster reconstruction in nations with mature construction sectors. Findings indicate that market economies, typically found in more capitalistic countries, tend to minimize the role of the federal government in post-disaster residential housing reconstruction activities. This reliance on the private market to effectively manage post-disaster resource supply and demand mechanisms leaves regions vulnerable. To address the challenges regions face in the reconstruction of residential housing in a post-disaster setting, the federal government and the U.S. construction industry must prioritize the need for regional labor availability. This research can serve as a tool to begin a dialogue between local and federal governments, and the regional construction industries that provide post-disaster reconstruction services.

ACKNOWLEDGMENTS

This research is supported by the Department of Education's Graduate Assistantships in Areas of National Need (GAANN) funding. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agency.

DATA AVAILABILITY STATEMENT

Data generated or analyzed during the study are available in a repository or at a provided location online (<http://www.colorado.edu/lab/gpo/erin-arneson>). Data were collected from publicly available datasets published by the Bureau of Labor Statistics, Census Bureau, and FEMA. (FEMA 2014; U.S. Bureau of Labor Statistics 2002, 2007b; a, 2012b; a, 2017; U.S. Census Bureau 2002a; b; c, 2007a; b, 2012a).

Table 4-2. Regional Labor, Materials, and Capital Metrics

	Reconstruction	Labor	Material	Capital
Definition	Amount of residential housing repairs and replacement that occurs within two years after a disaster event	Annual net value of construction work installed by residential contractors (NAICS 23611) per permitted residential housing unit.	Annual value of building material wholesale trade sales (NAICS 4233) per the cost of materials, components, and supplies purchased by residential contractors (NAICS 23611) to complete residential housing projects	Total value of FEMA IHP disaster grants awarded for reconstruction work per the total value of FEMA assessed damages to residential housing units due to a disaster.
Measurement	growth rate $\Delta\%$ pre-disaster and post-disaster annual average % change permits issued	<i>Regional Net Value of Construction (\$)</i> <i>Regional Residential Housing Units Permitted (total)</i>	<i>Regional Wholesale Trade Sales (\$)</i> <i>Regional Cost of Materials, Components, and Supplies (\$)</i>	<i>Regional FEMA IHP Reconstruction Grants (\$)</i> <i>Regional FEMA Assessed Damages (\$)</i>
Minimum	-91.2%	\$54,072	54.4%	3.4%
Mean	6.3%	\$185,230	216.3%	50.1%
Maximum	73.4%	\$843,594	743.0%	99.4%
Note: $n = 204$				

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CHAPTER 5 - SUMMARY AND CONCLUSIONS

Disruptions to the U.S. construction industry, especially within regional construction supply chains, can lead to delays in material and labor availability and slow down construction work. Within the three chapters of this dissertation: I developed the concept of regional construction capacity; examined why capacity varies by region and changes over time; and explored how pre-disruption levels of capacity hinder or facilitate post-disruption regional construction supply and demand mechanisms. This dissertation aims to improve regional responses to disruptive events addressing the following overarching question: *How does regional construction capacity affect the construction industry's ability to respond to unanticipated disruptions of supply and demand?*

Chapter 2 defines regional construction capacity as *'the maximum building volume a construction industry can supply due to regional supply chain availability of labor and materials.'* The research identified and quantitatively measured two regional metrics to define construction capacity: unit labor costs and capacity utilization. Regional construction capacity was measured using multi-level data analysis and case studies. Chapter 3 explores what residential housing market and socio-economic conditions that exist within any given region may correlate with high or low levels of regional construction capacity for the residential construction industry. Results are based on multi-level data analysis, Pearson's r correlation, and Wilcoxon signed-ranks of medians tests. Chapter 4 uses multi-level data analysis and linear regression to investigate how the availability of regional capacity metrics such as labor, material, and capital, effect post-disaster reconstruction of residential housing. A summary of the research questions, literature gaps, theoretical contributions, and practical contributions can be found in Table 5-1 below.

Table 5-1. Summary of Research Contributions

Chapter	Gaps in Literature	Contributions
<i>How can construction capacity be measured within the U.S., based on regional availability of construction industry labor and materials?</i>		
2	Limited understanding of how to identify, measure, and compare construction industry outputs or supply chain capacity at a regional scale.	• Develops a novel method for measuring regional construction capacity. • Adds to supply chain management theory by conducting quantitative, industry-level and regional-level analysis of supply chain performance.
<i>Why does the regional construction capacity of the residential construction industry vary over time and across regions?</i>		
3	Limited understanding of what conditions within a region lead to uneven levels of regional construction capacity, and why capacity changes over time.	• Identifies how regional residential housing market and socio-economic conditions correlate with regional construction capacity. • Adds to economic geography theory by identifying regional wage and location quotients as moderately correlated with regional construction capacity, and as representative of regional buyer or supplier power.
<i>Does pre-disaster regional construction industry labor and material resource availability, when controlling for federal disaster capital availability, predict post-disaster regional reconstruction of residential housing units?</i>		
4	Limited understanding of how regional construction industries repair/replace damaged houses after disaster events.	• Develops a novel model for predicting regional post-disaster housing reconstruction, based on regional labor, material, and capital supply. • Add to economic theory of market-driven resource supply by quantitatively assessing driving factors that prevent or enable residential housing reconstruction following a disaster.

THEORETICAL CONTRIBUTIONS

In this dissertation, I have built upon research and practical knowledge from both the construction management and disaster management fields. I also utilized theory and literature from a number of diverse fields dealing with overarching themes of regional performance, competitiveness, and resource availability.

In Chapter 2 I build upon concepts from the broader supply chain management theory to explore how material and labor resources are coordinated and allocated at the regional level.

Regional construction supply chains have not been adequately studied due to a lack of available construction industry-level data and the difficulty of modeling supply chains above the project-level (London and Kenley 2001).

Chapter 3 adds to the limited literature in economic geography theory that incorporates large-scale, quantitative, regional assessment of economic performance and competitiveness. This research highlights the usefulness of analyzing industry regional performance (e.g., the construction capacity) using unit labor costs and capacity utilization metrics. I also discuss the limitations of general economic theories of regional competitiveness. Much of the existing literature focuses on reducing unit labor costs and capacity utilization rates as a way to improve regional economic growth. The implications of low unit labor costs for the construction industry are explored since they appear to coincide with low wages and decreased contractor negotiating power.

Chapter 4 add the existing literature regarding theories of market-driven economies. Market economies are found in more capitalistic and developed nations (Simmie and Martin 2010), and push the responsibility of post-disaster residential housing reconstruction onto the private market. Therefore, the availability of labor, material, and capital resources the market can supply are the ultimate determinants of post-disaster reconstruction success.

PRACTICAL RELEVANCE

Chapter 2 incorporated the concepts of unit labor costs and capacity utilization into the framework for identifying regional construction capacity metrics. Unit labor costs have been used extensively in the manufacturing sector (Pancotto and Pericoli 2014), but not for the construction industry. Traditional measurements of unit labor costs used in the manufacturing industry track the labor wage costs required to create a single unit of a product (Mulligan 2016). This

measurement does not directly translate to the construction industry, which doesn't create products in an assembly line, but rather transforms raw materials into buildings. Thus, the unit labor costs measurement method has been modified to reflect construction industry specific measurement of production output (e.g., net value of construction installed). Similarly, the measurement method for capacity utilization was transformed to reflect construction industry realities. Capacity utilization in the manufacturing and industrial sectors is often a reflection of how much plant capacity is being utilized at any given time (Corrado and Matthey 1997). Construction industry capacity utilization was updated to be a measure of how much of the available material capacity in the supply chain is being used.

Chapter 3 identifies residential housing market and socio-economic conditions that may correlate with regional construction capacity. It also introduces a new way for contractors to quickly assess regional competitiveness. Wage and employment location quotients can be used to identify regions with high buyer power or high supplier power, since location quotients are correlated with regional construction capacity performance.

Chapter 4 introduces a novel quantitative model for predicting regional post-disaster levels of reconstruction for residential housing units, based on regional pre-disaster construction industry labor and material resource availability, while controlling for post-disaster capital availability. This model could be used in the future to quickly assess the likelihood that damaged residential housing will be repaired or replaced within two years of the disaster event.

LIMITATIONS

The research presented in this dissertation introduces the concept of construction capacity, including the quantitative measurement methods used for calculating regional construction capacity indicators and outcomes. However, there are several limitations of this doctoral research

that merit discussion. A key limitation for Chapters 2, 3, and 4 of this research is the accessibility of publicly available datasets related to the U.S. construction industry, especially at the county or regional scale.

The U.S. Census Bureau's Economic Census series is the only publicly available dataset published by the U.S. federal government that includes detailed economic performance metrics about the construction and manufacturing industries for more than just the national level. However, this dataset has two major limitations: (1) economic performance indicators are only provided at the national and state levels, and (2) much of the county-level data that is collected as part of the Economic Census is purposefully obscured due to privacy concerns.

To address the first major limitation, this dissertation research used state-level averages of construction and manufacturing industry economic performance indicators to make assumptions about county-level metrics. For example, when calculating capacity utilization rates in Chapters 2, 3, and 4, I made the assumption that all wholesaler establishments within a given state would sell the same volume of wholesale trade sales. I used state averages for wholesales (\$ USD) per wholesale establishment (state total number) to estimate county-level wholesales. While this assumption is logical, there were no other publicly available datasets to confirm if this assumption is factual.

FUTURE WORK

The U.S. economy is increasingly tasked with preparing for and rebuilding after large-scale and catastrophic disasters. Since 1980, the U.S. has experienced over two-hundred disaster events that caused damages of at least one-billion dollars (when adjusted for inflation to 2017 dollar values) (NOAA 2018). Recently, 2017 became the costliest year on record for U.S. disasters with 16 disasters producing damages exceeding three-hundred billion dollars (NOAA 2018). As a result,

there is considerable need to explore and understand how regions can better prepare for and respond to disasters.

This dissertation built upon traditional supply chain theory to begin to explore the role of the U.S. construction industry in post-disaster reconstruction of residential housing. As part of my long-term research goals, I seek to produce innovative theoretical and practical contributions related to the intersection of construction capacity, built infrastructure, and long-term disaster recovery. Specifically, I plan to expand my future research in three key ways: (1) gain access to more robust Census Bureau and Bureau of Labor Statistics data programs; (2) examine the role of regional construction capacity with other sub-sectors of the construction industry; (3) incorporate geospatial information systems (GIS) analysis tools into construction capacity research; and (4) explore how the combination of construction industry and disaster related risks can be better conveyed to the public and the construction industry.

Federal Statistical Research Data Centers

To improve regional construction capacity metrics and measurement methods in the future, I will need to gain access to the full program data collected by agencies such as the U.S. Census Bureau and the U.S. Bureau of Labor Statistics (BLS). Fortunately, the federal government just opened the Rocky Mountain Research Data Center (RMRDC) on the campus of the University of Colorado Boulder. As a future professor at Colorado State University, I plan to avail myself of this resource. There are currently only 29 such research centers in the U.S. (U.S. Census Bureau 2017c). The RMRDC houses full datasets, without excluding any county-level data for privacy concerns as seen in the publicly available data. Researchers must apply for federal approval to work at the RMRDC, a process that typically takes about three years.

Critical Infrastructure

I propose studying regional construction capacity and supply chain capabilities for critical infrastructure sectors as defined by the U.S. Department of Homeland Security. Critical infrastructure includes systems and infrastructure deemed necessary for the safety and functioning of both society and the economy. The U.S. Department of Homeland Security designates sixteen critical infrastructure sectors, including: manufacturing, dams, electrical power grids, and healthcare facilities (U.S. Department of Homeland Security 2018). This topic is of interest to local, state, and federal agencies as they try and prepare for future man-made disruptions (e.g., terrorism, hacking of information technology systems, and changing labor demographics).

Geographic Information Systems (GIS)

Additionally, future research will incorporate GIS data and analysis methods to explore regional construction capacity. GIS is perhaps best known for use in the production of maps and data visualizations. However, GIS software also provides opportunities for advanced statistical analysis of regional data. For example, geospatial regression analysis (GRA) can be run using GIS software. GRA expands upon traditional linear regression results by incorporating an additional independent variable, namely location (Zerger 2002). At the regional-level, GRA analysis will allow for the construction capacity metrics of adjacent regions to be included in the regression formula. Any interactions occurring between regional supply chains will therefore be quantitatively included in future construction capacity assessments.

Disaster Risk Communication

Lastly, the field of disaster risk communication is becoming an important field of research within the broader disaster management literature (Doerfel et al. 2013). Federal agencies, municipal governments, and researchers often have important disaster risk information to share in

the wake of disasters, but it must be communicated to effectively meet the intended audience. Past research has shown that a lack of effective post-disaster communication can decrease community perceptions of resilience and increase confusion about the reconstruction process (Arneson et al. 2017). Therefore, more research is needed to improve how disaster risk information is communicated to both the general public and regional industries involved in repairing and replacing disaster damaged infrastructure.

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APPENDIX A: DOCTORAL PUBLICATIONS

Peer-Reviewed Journal Publications

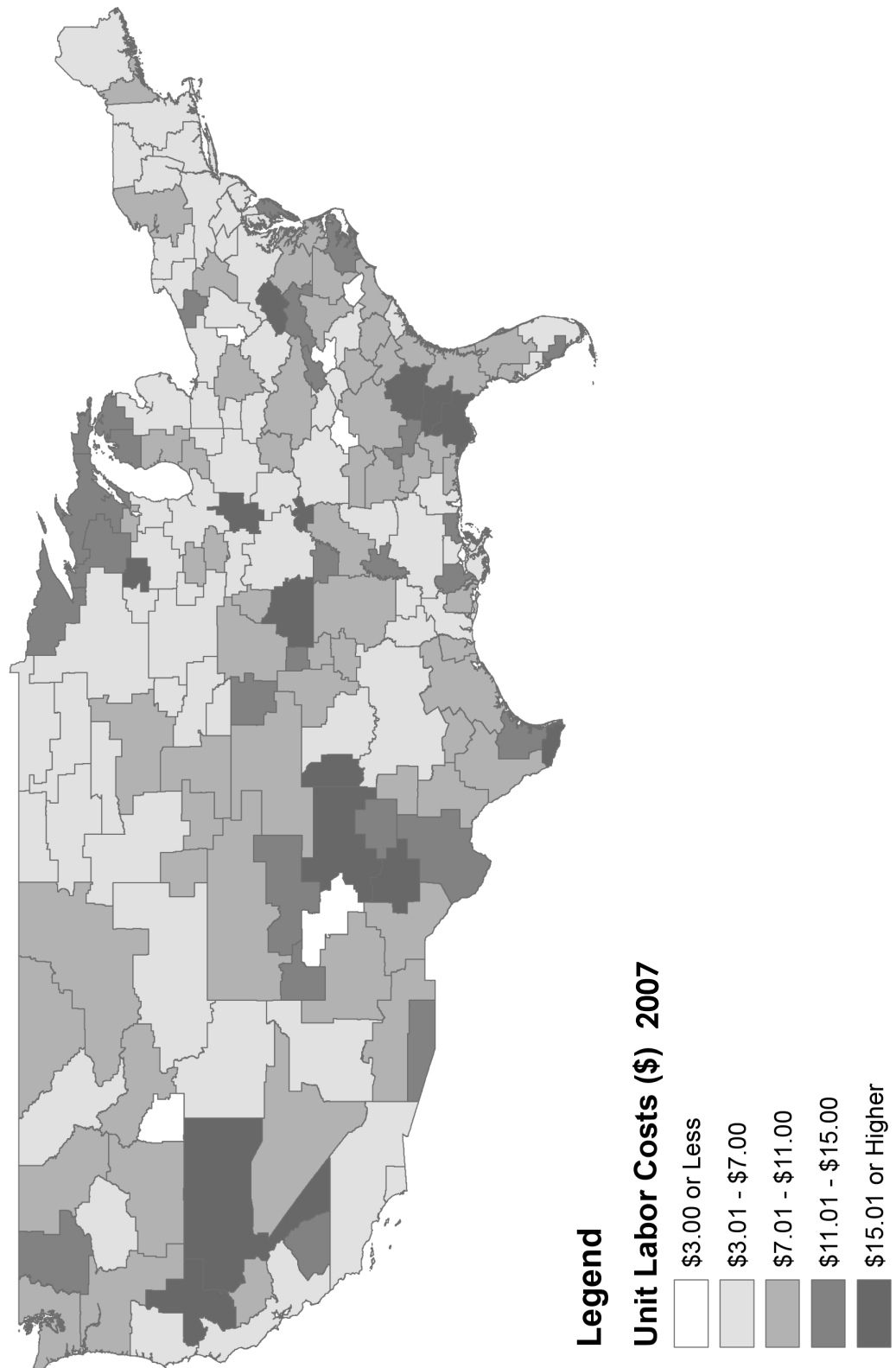
- [1] **Arneson, E.**, Javernick-Will, A., Hallowell, M., and Corotis, R. (2018). “Predicting Post-Disaster Residential Housing Reconstruction Based on Market Resources.” *Natural Hazards Review* (ASCE). (*In Progress*).
- [2] **Arneson, E.**, Hallowell, M., and Javernick-Will, A. (2018). “Regional Responses to Construction Supply Chain Disruptions: Defining and Measuring Construction Capacity.” *Journal of Construction Engineering and Management* (ASCE). (*In Progress*).
- [3] **Arneson, E.**, Deniz, D., Javernick-Will, A., Liel, A., and Dashti, S. (2017). “Information Deficits and Community Disaster Resilience.” *Natural Hazards Review*, (ASCE).
- [4] Deniz, D., **Arneson, E.**, Liel, A., Dashti, S., and Javernick-Will, A. (2016). “Flood Loss Models for Residential Buildings Based on the 2013 Colorado Floods.” *Natural Hazards*.

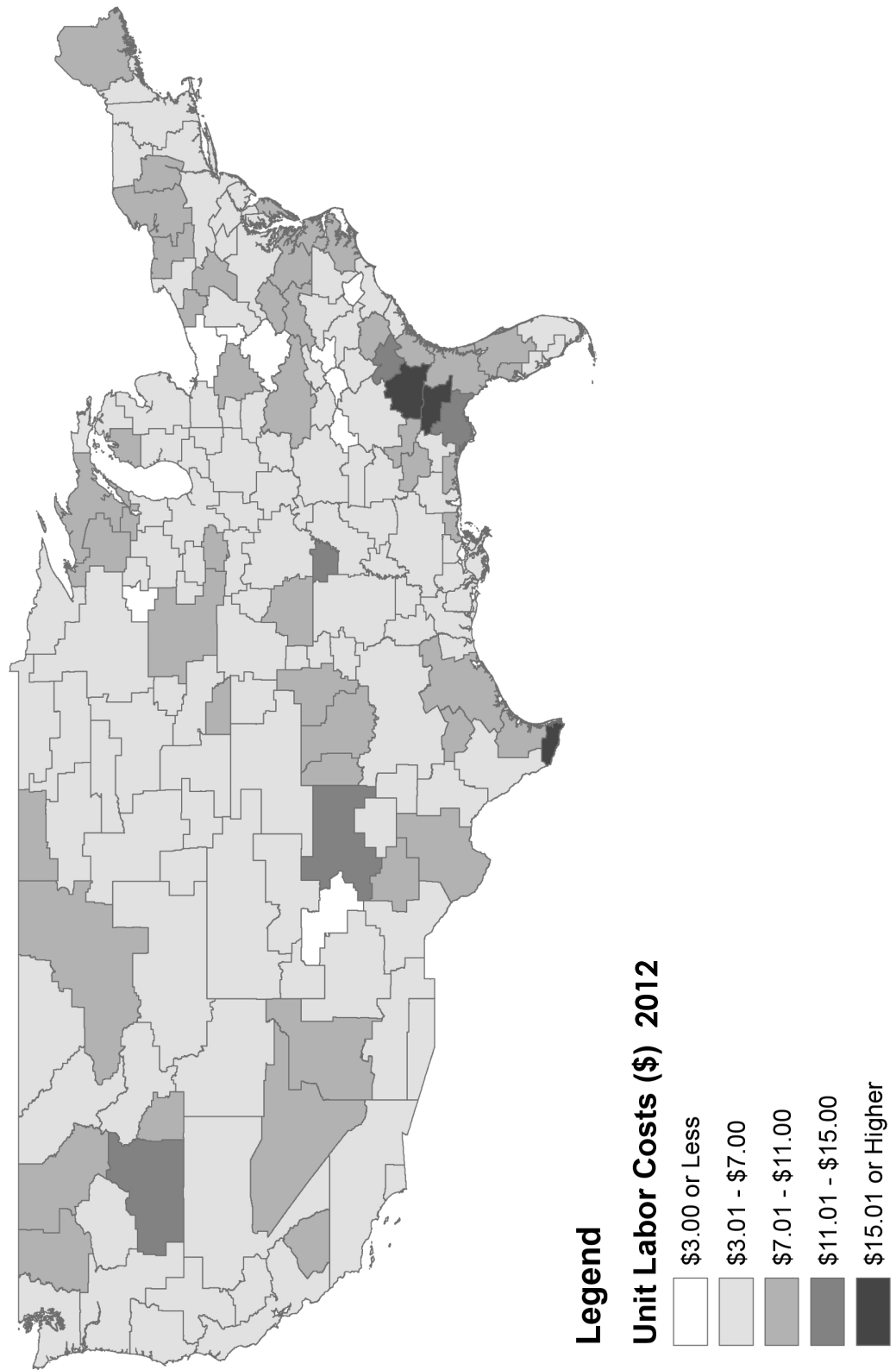
Peer-Reviewed Conference Proceedings

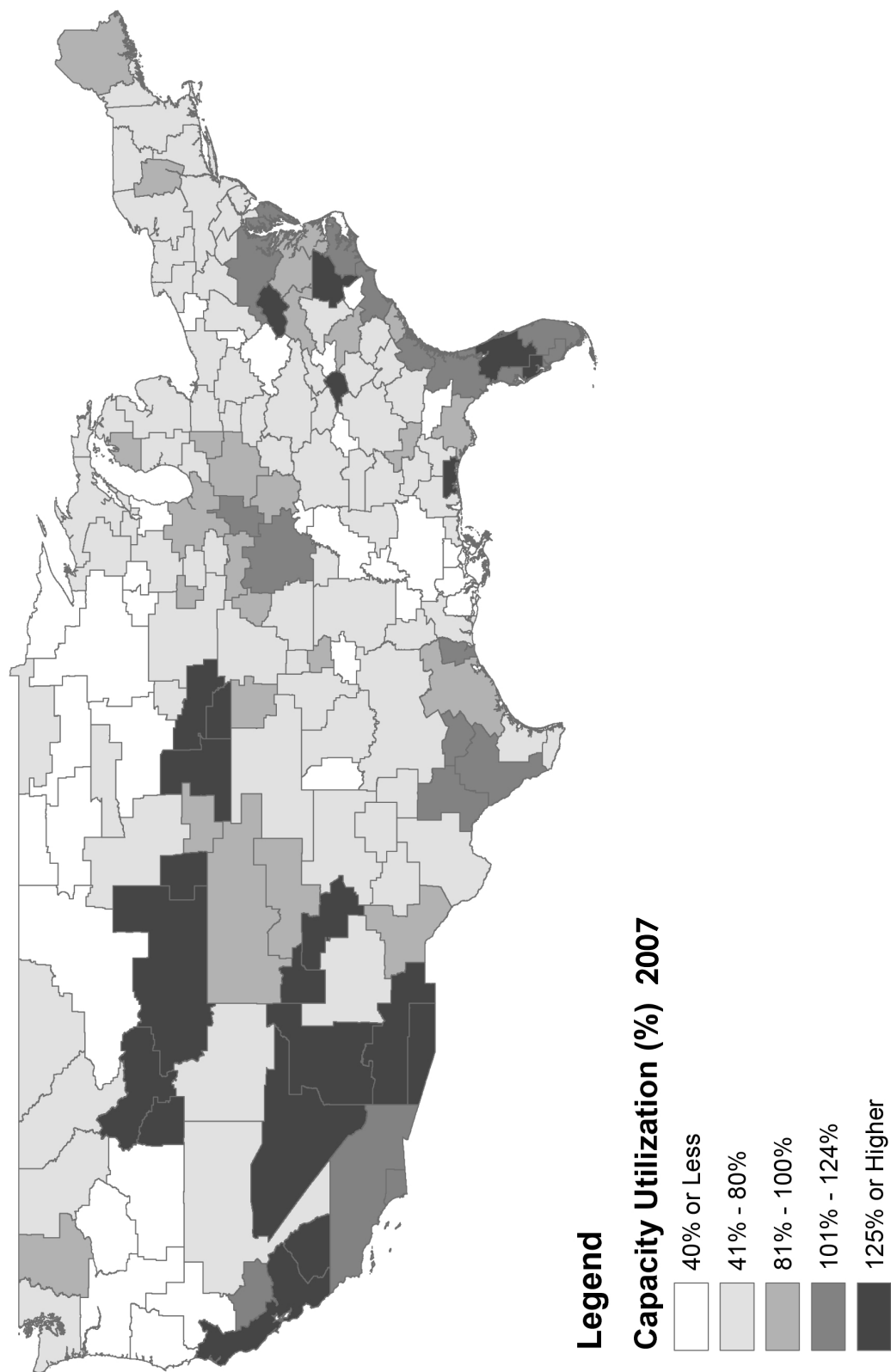
- [1] **Arneson, E.**, Hallowell, M., and Javernick-Will, A. (2018). “How Construction Capacity Affects Housing Reconstruction in Tornado Alley” *Proceedings of the Construction Research Congress 2018*. New Orleans, LA, April 2-5, 2018.
- [2] **Arneson, E.**, Javernick-Will, A., and Hallowell, M. (2017). “Construction Capacity: How Construction Resource Availability Affects Post-Tornado Rebuilding of Residential Housing.” *Proceedings of the Engineering Project Organization Conference*. Stanford Sierra Camp, Lake Tahoe, CA, June 5-7, 2017.

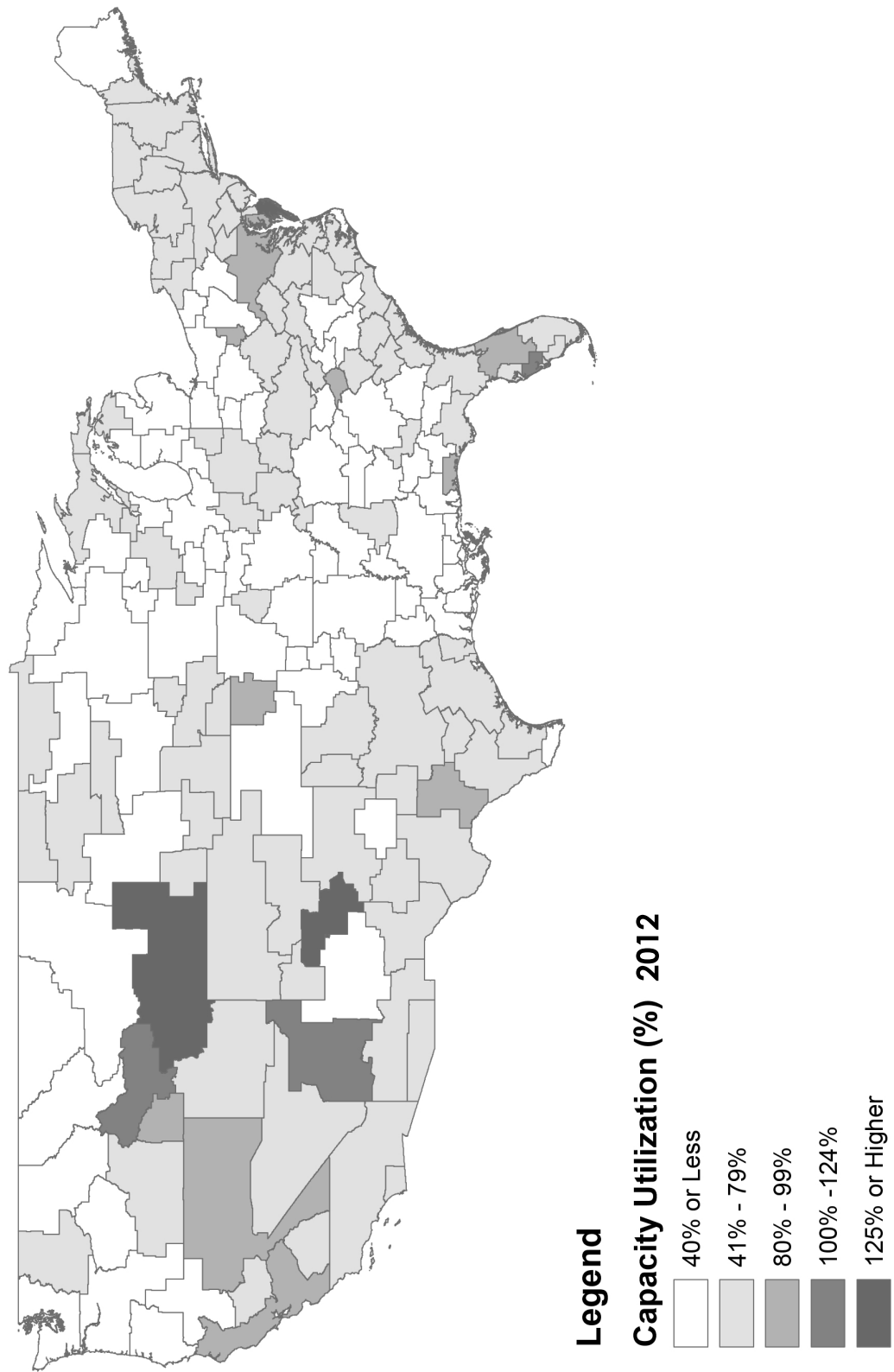
- [3] **Arneson, E.**, Hallowell, M., and Javernick-Will, A. (2017). "How Construction Capacity Affects Post-Disaster Rebuilding of Residential Housing." *Proceedings of the 6th Construction Specialty Conference*. Vancouver, British Columbia, May 31-June 3, 2017.
- [4] **Arneson, E.**, Javernick-Will, A., Hallowell, M., and Thomas, W. (2016). "Construction Capacity: The Role of Regional Construction Supply Chain Resources in Post-Disaster Rebuilding." *Proceedings of the Engineering Project Organization Conference*. Cle Elum, Washington, June 28-30, 2016.
- [5] **Arneson, E.**, Deniz, D., Javernick-Will, A., Liel, A., and Dashti, S. (2016). "Information Deficits and Post-Disaster Recovery." *Proceedings of the ASCE Construction Research Congress 2016: pp. 1546-1555*. San Juan, Puerto Rico, May 31-June 2, 2016. <http://dx.doi.org/10.1061/9780784479827.155>
- [6] Soden, R., Palen, L., Chase, C., Deniz, D., **Arneson, E.**, Sprain, L., Goldstein, B., Liel, A., Javernick-Will, A., and Dashti, S. (2015). "The Polyvocality of Resilience: Discovering a Research Agenda through Interdisciplinary Investigation and Community Engagement." *Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2015)*. Kristiansand, Norway, May 24-27, 2015. [Best Paper Nominee].

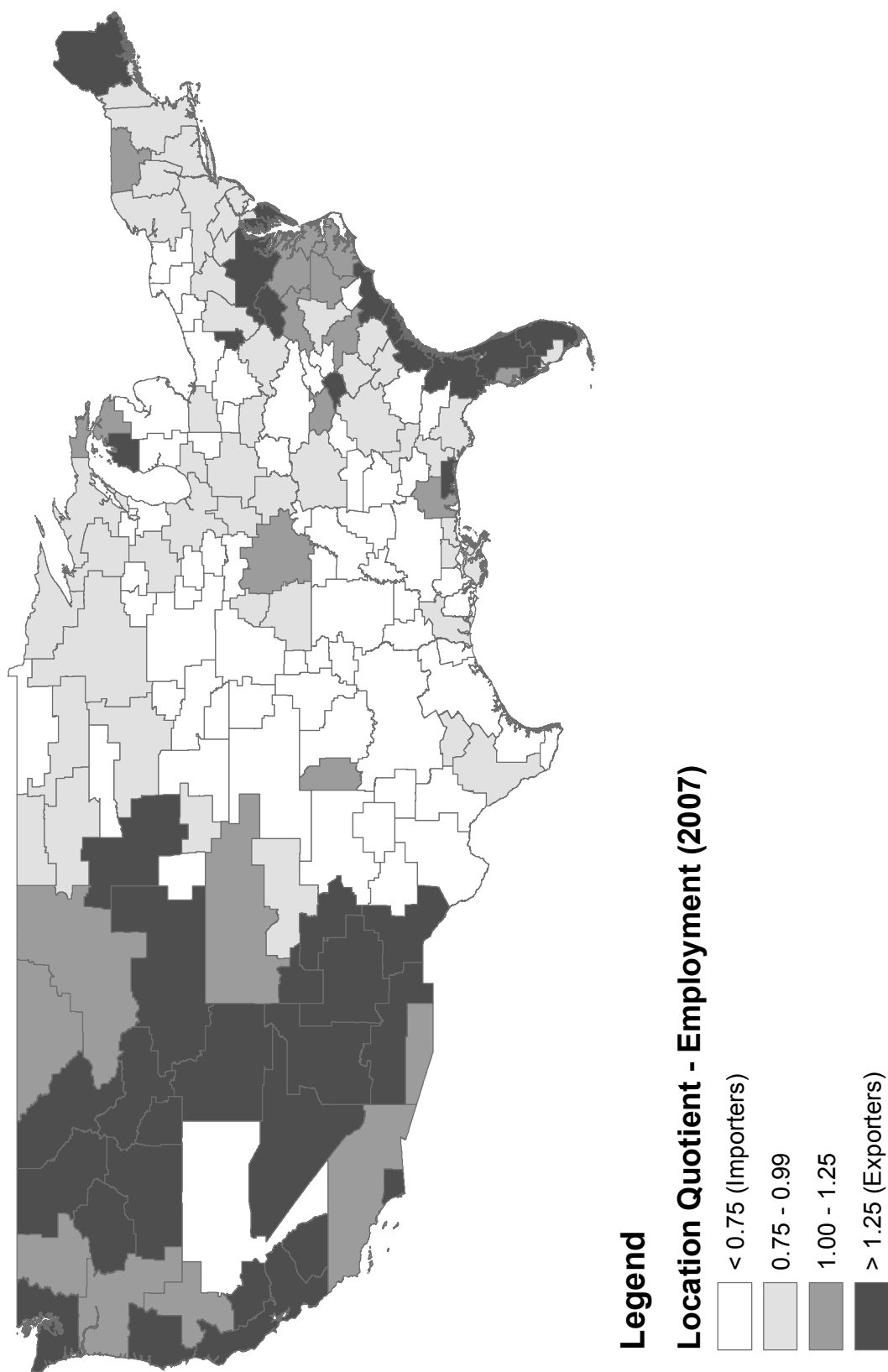
APPENDIX B: CONSTRUCTION CAPACITY MAPPING

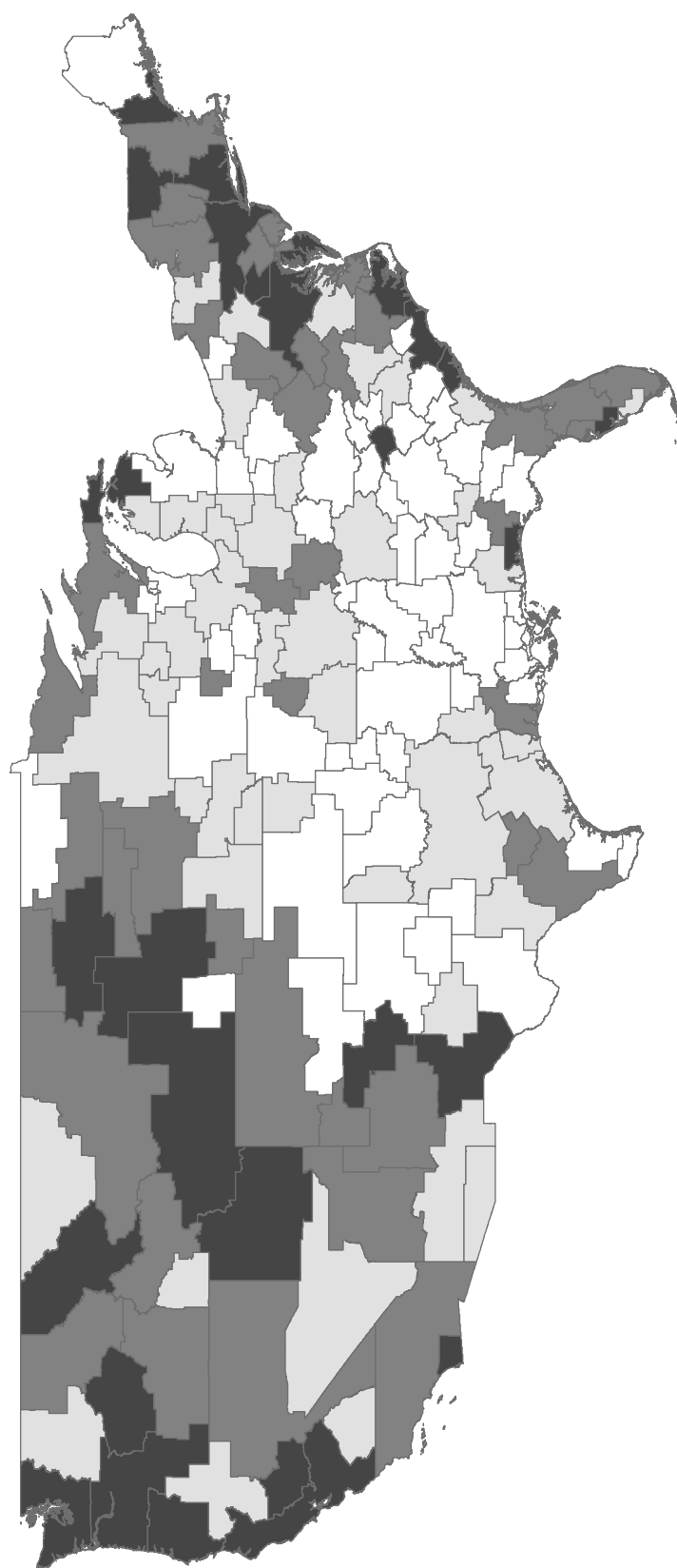












Legend

Location Quotient - Employment (2012)

