Adoption of High-Performance Housing Technologies Among U.S. Homebuilding Firms, 2000 Through 2010

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Abstract

This article describes foundational processes of a larger project examining U.S. home builders' choices to adopt innovative housing technologies that improve the environmental performance of new single-family homes. Home builders sit at a critical juncture in the housing creation decision chain and can influence how new housing units change related to energy consumption, and the units they produce can also reflect shifting technology, demography, and policy landscapes. With some exceptions, U.S. home builders have been characterized as being slow to adopt or resistant to the adoption of product and process innovations, largely because of path-dependent and risk-averse behavior. This article focuses on home builder choices by analyzing a summary of innovation adoption literature and that literature's relationship to homebuilding. Researchers then describe analytical approaches for studying home builders' choices and markets at a Core Based Statistical Area level, the data and statistical methodologies used in the study, and the policy implications for promoting energy efficiency in housing. Future work will draw on the foundation presented in this article to specify versions of this generic model and report results using improved quantitative analyses.

Introduction

In the National Climate Assessment, researchers report that the warming of the U.S. climate during the past 50 years is significantly related to human (Melillo, Terese, and Yohe, 2014). They argue that a strong need exists for businesses and individuals to adopt innovative products, processes, and thinking that changes how products are produced and energy is consumed. Failure to move toward these innovations, scientists believe, will result in continued growth in the severity and types of risks to the United States.

The U.S. Department of Energy (DOE) reports that the housing stock has been increasing energy efficiency since 1980. Houses built most recently are 14 percent more energy efficient (EE) than homes built 30 years ago and 40 percent more EE than homes built 60 years ago (DOE, 2014). With respect to energy consumption, in 2014, all residential buildings consumed 21.15 quadrillion BTUs (British Thermal Units) of energy, down 1.1 percent from 2010.

From 2005 to 2010, the academic literature focused on climate change doubled in size along with heavy expansion in the range of topics, geographies, and disciplines analyzed (Burkett and Suarez, 2014). One study area has had an expansion of analysis is in regard to innovation applied to issues of environmental change and performance. Innovation can be a powerful lens to process empirical information about changes within markets and can be used as a framework for gaining increased understanding of potential solutions to environmental problems. After more than 100 years of innovation research, scholars can show that adoption and diffusion of innovation are critical forces that build competitive advantage, disrupt existing markets, and create new markets (Christensen, Anthony, and Roth, 2004). Despite innovation being applied to a wide swath of disciplines, until recently, scholars of innovation have not focused a great deal on construction. Few diffusion-of-innovation modeling techniques have been applied in the commercial construction literature (Kale and Arditi, 2009, 2006, 2005; Rose and Manley, 2014, 2012) and scholars have not regularly experimented with advancing variations of innovation diffusion models within residential building construction or new and existing housing. At the same time, U.S. home builders have been characterized as being resistant or slow to adopt innovation.

In light of these industrial concerns, a substantial opportunity for new analysis exists. This work (and article) sits at the convergence of these topics and serves as a foundational step of a larger project examining U.S. home builders' choices to adopt innovative housing technologies that improve the environmental performance of new single-family homes. The article begins by summarizing literature on adoption and diffusion of innovation and defining its relationship to homebuilding. The work then describes a conceptual statistical model and application for analyzing innovation adoption among home builders. Another goal of the work is to distill current and previous research, variables, and methods for future work. Future projects could augment the statistical model to examine extant factors that explain U.S. home builders' choice of EE and high-performance technology over traditional and less EE substitutes.

In the following sections of this article, the authors address these research questions: (1) What external parameters are likely to be associated with builders' decisions to adopt high-performance housing technology alternatives across time and into recent years and (2) do external parameters surrounding this change support a general shift toward environmental performance as a central component of diffusion in the homebuilding industry? In answering, we describe an array of data that will inform diffusion modeling and enable others to refine industry models and draw empirical conclusions about builders' innovation adoption choices. Our description of the data and the generic conceptual model further proposes (1) methods for measuring adoption patterns of high-performance technologies, (2) a comparison of the sample with independent measures of the builder population, (3) regression analysis tools, and (4) the potential significance of the preliminary model for diffusion of technology in general. The article links the diffusion of innovation among home builders to broader concepts of sustainability and highlights several implications for federal policymakers.

Literature Summary

Researchers have argued that the characteristics of the construction industry, particularly the residential construction industry, are important in determining the role of innovation in the industry (Koebel and McCoy, 2006; McCoy et al., 2010a; McCoy, Koebel, and Sanderford, 2011; McCoy, Thabet, and Badinelli, 2008). The construction industry is characterized by low levels of research and development (R&D) expenditures, volume-based modular product offerings that have to be adjusted to site characteristics, asynchronous liability problems, highly cyclical markets, disaggregation (many small firms) and reliance on subcontractors, diverse building codes, and financing and insurance impediments that can (and do) inhibit the adoption of innovation. The construction industry is often seen as laggard because of the numerous impediments to innovation, adopting innovations only after the rewards of the products or techniques are clearly established and the risks minimized (Dibner and Lemer, 1992; Laborde and Sanvido, 1994; Tatum, 1987). Focusing on impediments to innovation could result in underestimates of actual innovation, and evidence suggests that innovation does occur in this industry (Koebel et al., 2004; Laborde and Sanvido, 1994; Toole, 1998).

Unlike most consumer products "facilities are large, very complex, long lasting, and they are created and built by a temporary alliance of disparate organizations within an explicit social and political context" (Slaughter, 2000: 3). Further, the construction industry is unusual because the firm (the builder) acts as an assembler that is reliant on multiple subcontractors for subassembly along the supply chain between the upstream manufacturers and suppliers and the downstream consumer-occupant. Slaughter (1993a) argues that reliance on the tried and true (path dependency) could hinder successful adoption because builders are the agents of technical expertise that operate between the two and shoulder the liability of installing new products. For example, the timing of the commitment to adopt an innovation, the communication within a project team about the requirements of using an innovative product, the degree to which an innovation requires the use of special resources, or outside expertise, and the levels of supervisory competency are drivers and obstacles of innovation in construction (Slaughter, 1993b).

For some time, housing researchers and policymakers have struggled with the lack of technological innovation in the housing industry in the United States and abroad (Gann and Salter, 2000; Koebel, 1999; Woudhuysen and Abley, 2004). Previous interventions to promote innovation adoption and studies of adoption have focused on impediments to innovation and strategies borrowed from other industries. The divergence of green building technologies from previous adoption and diffusion patterns provides a new opportunity to examine innovation in this industry. In place of path dependency and resistance to innovation, numerous industry studies point to a widening awareness and likely use of innovative practices and techniques that support environmental goals (Bodie, Kane, and Marcus, 2008; Turner and Council, 2006).

Whereas homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies exhibit accelerated adoption patterns (Koebel et al., 2004). Little empirical work exists that measures and analyzes such phenomena, which is the subject of this work. Commercial construction scholars have started to apply classic empirical models of the diffusion of innovation to analyze the adoption of various technologies and construction strategies (Kale and Arditi, 2009; Rose and Manley, 2014. This research confirms previous hypotheses that the diffusion of innovation can be mathematically modeled in construction (Larsen, 2005; Hartmann, 2006) and suggests attributes of the adopter, context, and the innovation each influence the adoption decision. A model that includes these three types of factors has not yet been applied to housing, however. Given this opportunity, we focus on the home builder as the central actor and will set the stage for a series of different empirical analyses of builders' adoption of EE green building technology innovations. Previous research has tended to focus on the attributes of the firms that catalyze the adoption of innovation. When capturing attributes of the building firms, we will also move beyond that traditional focus and will analyze a broader array of factors including public policy, climate, and market area characteristics that could help explain builders' high-performance technology adoption patterns. Quite simply, our larger project seeks to offer new insight into the factors, other than time and the attributes of the firm, which explain builders' choices to adopt high-performance housing technologies.

EE construction is gaining acceptance as a sign of excellence in the trade, limiting the options in the market for firms who cannot bring these skills to a building project (McCoy, Pearce, and Ahn, 2012). Others have realized the importance of defining tools of performance at a broad level for their industry. Such metrics have become central to customers' abilities to comfortably make purchasing decisions and trust in these decisions (Adomatis, 2010). An inclusive and comprehensive definition is first needed for high efficiency in housing technology. Literature suggests no one standard definition; however, all definitions emphasize energy-efficiency, sustainability, and environmentally friendly products (Adomatis, 2012, 2010). In general, technologies that can be described as having high performance are (1) safer and healthier, (2) more energy and resource efficient, (3) more durable, and (4) more comfortable. Highly efficient technologies also exist as alternatives to traditional or existing state-of-the-art technologies. By exploring the diffusion of innovation with respect to energy efficiency, we also have the opportunity to develop innovation's linkage with sustainability.

The Adoption Decision

In seminal work, Rogers (1995) distilled evidence across a number of disciplines and suggested that attributes of the product, the adopter, and communication about the innovation each contribute to the decision to adopt an innovation. These product and adopter attributes form the backbone of diffusion modeling, a technique that focuses on why and when different actors choose to adopt various innovations. In the construction industry, and particularly the residential sector, the builder is the key adopter of innovations, much like the farmer in the agricultural industry (Koebel, 2007). Within the construction industry, the builder is the critical link between a host of factors (for example, capital, manufacturing, entrepreneurship, geography, and public policy) and the innovation—yielding significant opportunities for research.

Attributes of the Adopter

A 2004 survey of builders revealed that national and regional home builders, multifamily builders, modular builders, and custom home builders were more likely to adopt innovations than other firms (Koebel et al., 2004). These firms were likely to (1) have a technology advocate in the firm, (2) stress creativity, (3) use a technology transfer program (for example, PATH), and (4) use unionized labor at least some of the time. Innovative firms also recognized the importance of demand for innovative products (from homebuyers) and the ability of a manufacturer to stand behind the quality of their product (Koebel et al., 2004). To be more specific, home builder research has found that—

- Larger builders tend to be early adopters of innovations only when new materials provide potential cost savings, improvements in production processes, reductions in call-backs, and reduced exposure to liability (Koebel et al., 2004).
- Smaller builders tend to adopt new materials when consumer awareness of the product is high, the price of the new material is superior to its replacement, and the home-production process must be substantially altered (Koebel et al., 2004).
- Not all innovation should be assumed "good" for the firm, but some new technology may contain benefit(s) (Koebel and McCoy, 2006; Koebel et al., 2004).

These findings built on earlier evidence suggesting that the primary barriers to the diffusion of innovation in the construction industry were highly cyclical markets, a preponderance of small firms (vertical and horizontal fragmentation), institutional factors such as building and zoning codes, and unionization (Blackley and Shepard III, 1996).

Because the builder is the central focus of this article, it is important to note that they represent, to a large degree, the interests of a homebuyer. Therefore, measurement of the attributes of the potential buyer is also important—though the literature is opaque on precise attributes that play significant roles. An examination of the characteristics of homebuyers who influenced the purchase of a green-certified home showed increased income as a significant factor (Goodwin, 2011). A related study found that the political persuasion of most voters in an area is associated with green-certified industrial building prices (Harrison and Seiler, 2011). In the end, it appears that no evidence suggests individuals with green technology leanings occupy green buildings with more frequency than those individuals without the same disposition (Wilkinson, Van Der Kallen, and Kuan, 2014). Together, these findings suggest that researchers may find more utility in measuring the attributes of the buyers in aggregate—analyzing the extent to which factors such as income, levels of educational attainment, owner-occupancy rates, and the age of the housing stock are associated with the adoption decision of builders.

Attributes of the Product, Supply Chain, and Communication Networks

According to a National Association of Home Builders (NAHB) poll (Hudson, 2011), nearly 80 percent of respondents mentioned actions and products within the 'green' portfolio. Building industry professionals provide ample testimony that green building is an upward trend (McCoy, Pearce, and Ahn, 2012). Instead, energy-efficiency and related building practices are quickly becoming the state of the art in the building industry, and the ability to deliver these services to clients is increasingly important to maintain a successful business. Research on innovation in the construction industry has also focused on the attributes of products in green building (McCoy, Pearce, and Ahn, 2012) and the commercialization of innovative building technologies (Habets, Voordijk, and van der Sijde, 2011, 2006).

Builders' choices to adopt innovative and EE technologies could be linked to variation in the price of the technology and the characteristics of the builders' market and supply chain (Koebel, 2007; Koebel and McCoy, 2006; McCoy et al., 2010b; Rogers, 1995). Local markets can affect the ability to conduct business using variability in material and labor costs or the total cost of construction. Uncertainty along the supply chain also plays a major role in determining the success of a product's adoption and diffusion. The presence of individual stakeholders of the supply chain at a local level can also influence decisions using either veto or endorsement. Within the homebuilding supply chain, home builders are often considered the most influential in determining commercialization success (McCoy et al., 2010a). We also posit that adoption choices are also associated with the presence of, and variation in, public policy and climate (Kontokosta, 2011; Simons, Choi, and Simons, 2009).

Finally, we hypothesize network effects may be based on the density and proximity of builders on a regional basis, reflecting the communication and contagion characteristics of diffusion and have created an explanatory variable (Raub and Weesie, 1990) using a "gravity index."

Attributes of the Market

Diffusion research and policy suggests that a number of attributes of the market where the adoption decision occurs are significant predictors. A study of the decision to adopt ecolabels such as the U.S. Green Building Council's Leadership in Energy and Environmental Design, or LEED, or the Environmental Protection Agency's ENERGY STAR, researchers found that a significant percentage of the decision could be predicted using market factors describing income, unemployment rate, climate, energy prices, and public policy (Kok, McGraw, and Quigley, 2011). Devine and Bond showed clearly that different types of public policy encouraged the adoption of ecolabels in multihousing markets (Devine and Bond, 2013). These market attributes are logical predictors that are regularly used in the sustainable real estate literature as predictors in hedonic pricing models. Scholars analyzing commercial and residential property with increased environmental performance have used the presence of public policy, climate, income, employment, energy prices, and relative location (or urban form attributes) as predictors of green home and building price premiums (Eichholtz, Kok, and Quigley, 2011; Pivo and Fisher, 2011; Wiley, Benefield, and Johnson, 2010). We posit that adoption choices are associated with the presence of and variation in public policy and climate given the geographic variation and availability of policy (Kontokosta, 2011; Simons, Choi, and Simons, 2009). In a similar way, many of these same factors are used in models examining the extent to which environmental innovations and features mitigate mortgage default (Kaza, Quercia, and Tian, 2014; Pivo, 2013; Rauterkus, Thrall, and Hangen, 2010). These findings are bolstered by evidence from studies in commercial construction innovation on the role of the government policy in promoting the adoption of innovations (Morledge, 2011; Wandahl et al., 2011; Wong, Wong, and Nadeem, 2011). Further, urban design and compactness have been linked to a range of public health and property related issues (Ewing and Hamidi, 2013; Ewing et al., 2014).

Energy Prices

Referenced in another green product diffusion study, information about energy prices appears to have significant influence on the ecolabel adoption decision (Kok, McGraw, and Quigley, 2011). It is also a fundamental assumption by most real estate researchers relative to green building prices (Costa and Kahn, 2009; Jaffee, Stanton, and Wallace, 2012; Warren-Myers, 2012). Scholars have shown a positive association between ecolabel adoption and green building prices. A cautionary study of Dutch households relatedly demonstrates that residential energy literacy varies substantially and many households are unaware of their energy consumption (Brounen, Kok, and Quigley, 2011). Tangibly reflecting energy prices and their role in housing decisions, previous research suggests that in certain markets, high-efficiency windows (HEWs), such as double-pane windows, solar panels, and energy-efficiency certifications are associated with premium home prices (Aroul and Hansz, 2011; Bloom, Nobe, and Nobe, 2011; Dastrup et al., 2012).

Time

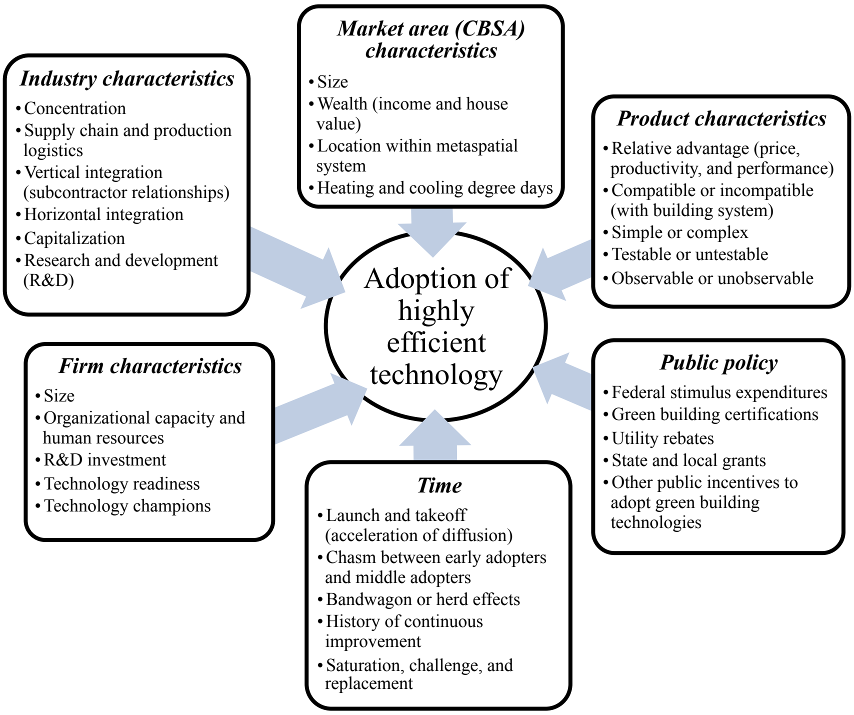
Traditional Bass models stress the role of time as a critical factor in the spread of an innovation into a market (Bass, 2004). Analyzing the effect of time provides researchers with the ability to observe the extent to which bandwagon effects, exogenous shocks such as recessions, and also unobserved variables that may also contribute to the adoption decision. Given the Technology recession of 2001 through 2002 and the Great Recession of 2007 through 2009 it will be of paramount importance to include time in any adoption model covering these periods. Further, because the implied task of the adoption model is to identify additional variables that help explain the adoption decision beyond time, control variables for time should be considered de rigueur for all analyses. Large, unexplained time effects confirm that diffusion is occurring along a mathematically modeled trajectory, but they fail to explain the underlying factors influencing this trajectory.

Conceptual Model

Basing our decision on the literature summarized in the previous sections, we propose the conceptual model in exhibit 1 as a graphic representation of the adoption decision. In the center is a builder with a dichotomous choice to adopt or not adopt a high-performance housing technology. Helping to explain that choice are those attributes and factors identified by literature and team logic. These factors include attributes of the adopter (builder firm), market, product, climate, public policy, industry, and labor supply chain, time, and communication networks.

Exhibit 1

The Conceptual Model and Variables



CBSA = Core Based Statistical Area.

Data and Proposed Analytical Techniques

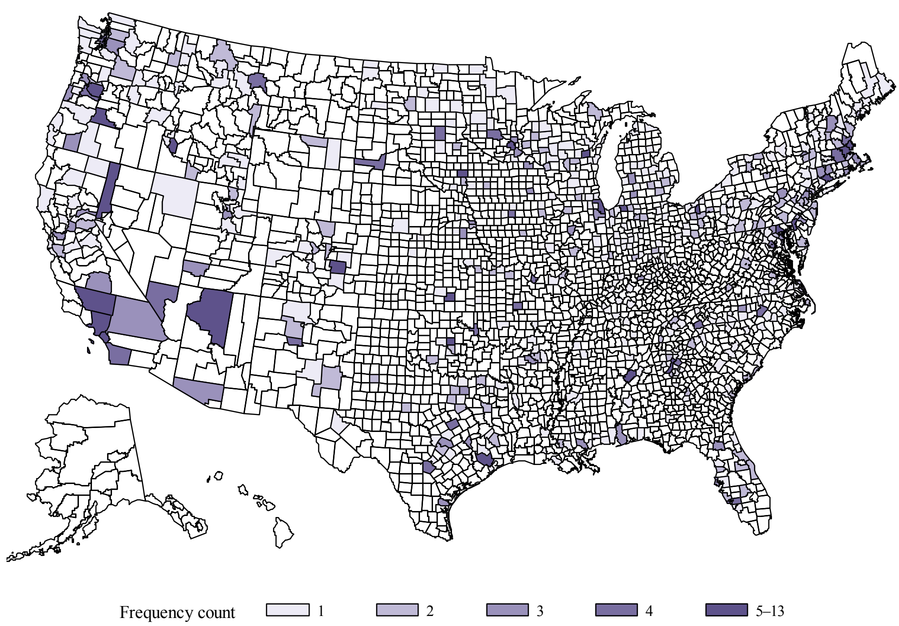
In the context of the literature summarized and conceptual model described previously, the research team assembled a large dataset describing U.S. homebuilding product use from 1996 to 2010. The measures of product use in the dataset come from the Builder Practices Survey (BPS), an annual survey conducted by the NAHB Innovation Research Labs. The BPS is designed to capture builders' product use patterns of new residential construction projects annually across nearly 1,100 product types and more than 40 clusters of products. The coming sections discuss the development of the dataset for analyzing builders' use of innovative high-performance construction products from 2000 to 2010 incorporating local, state, and regional level data for market characteristics proposed in exhibit 1. The BPS includes product use within the housing types of Single-Family Detached, Single-Family Attached, and Multi-Family as the unit of analysis of the builder firm, typically an individual survey respondent (see exhibit 1), because the survey process does not specifically control for multiple respondents from the same firm in the instructions. The BPS data do not contain any information about the characteristics of the firm beyond the city and county of the respondent's address and summary measures of the number, size, building type, and price of the housing units built during the previous year. The data are nonlongitudinal because respondents cannot be linked over time. After being merged with exogenous market characteristic variables sourced by the research team, the dataset is the largest of its kind and unique in its integration of industry, market, and public policy measures.

Most statistical methods assume that the data at hand are representative of the larger population from which inferences are to be made. Representativeness ideally is achieved by drawing respondents (that is, survey participants) randomly from the list of all possible participants in the population such that any set of builders is equally likely to appear in the sample. For data such as these, the responses instead constitute a convenience sample where builders were contacted without use of a probability-based sampling scheme, and they responded on a voluntary basis. Nevertheless, the assembled data constitute the most up-to-date and comprehensive database of this sort, to our knowledge, in residential construction (see exhibit 2).

Because representativeness could be called into question in a strict sense, the research team further compared the amount of respondents in the BPS with public data on the presence of home builders. The team assembled County Business Pattern (CBP) data from 2003 to 2010 by year and compared those data with BPS respondent data, based on single-family and multifamily builders by state (a combination of establishments in North American Industry Classification System (NAICS) codes 236115+236116). Further, the team analyzed total establishments and the number of establishments with fewer than ten employees, based on first quarter payroll. It is not surprising that many builder respondents contain fewer than 10 employees. It is important to note that NAICS codes for the builder categories were changed in 2003 and no data codes for 236115+236116 were available for 2000, 2001 and 2002.

Exhibit 2

Respondent Geographic Coverage—Number of High-Efficiency Window Users, 2010



Based on the team's analysis, the *R*-squared (RSQ) value between 2003 through 2010 CBP and 2003 through 2010 BPS was approximately 0.71; the less-than-10 employee CBP had a slightly higher RSQ value. These RSQ values are interpreted as the proportion of variation in one measure (for example, 2003 through 2010 CBP) associated with the other (for example, 2003 through 2010 BPS). Although not ensuring true representatives at the population level, these values indicate a strong linear association between BPS and CBP overall, meaning that points that are high in BPS tend to be high in CPS and similar for low values.

Although nonrepresentativeness could be seen as an issue to some degree in these data, we proceed with statistical analysis in an attempt to glean insights about builder behavior on the basis of the available data. The granularity of the BPS data allows for deep analysis of individual products, such as windows, which are within the high-performance building envelope and are central to achieving energy efficiency for the home. Although performance of windows varies, saturation of EE, high-performance technology options offers an excellent example of diffusion over time (2000 through 2010) in the marketplace.

Clusters of Dependent Variables

The original goal of the research was to discover patterns of use in EE technologies among builder firms, which was later expanded to high-performance products as explained previously. The research team initially needed to organize BPS variables into clusters of products that affect performance in a home, focusing on energy-efficiency as part of performance. Also in 2007, the Better Housing Coalition (BHC) of Richmond worked with local, regional, and national resources to select a core group of products and technologies that impact performance in new construction (http://www.virginialisc.org/pdf/rpts/Sustainabilitymap.pdf). BHC sorted high-performance technologies in new construction homes into the following clusters: engineered wood systems (including open web joists), EE lighting, air sealing, EE water fixtures, heating and cooling within conditioned space, sealed duct system, advanced framing, house wrap, proper heating and cooling unit sizing, cement board siding, cellulose or spray foam insulation, and HEWs.

As an example of one cluster of technology critical to performance, the HEWs cluster includes insulated glass (IG) in three product types, all of which can be used by builders as choices not mutually exclusive between homes: double-pane, Argon; double-pane, Argon low-E; and triple-pane windows. Single-pane (non-IG) windows have become virtually obsolete and double-pane, no-Argon (no filling) windows had become the lower efficiency and lower cost alternative, although the cost and performance of windows of all types vary considerably between manufacturers based on designs and materials used, including trim. An annual time series plot of use for variable names Double-Pane no Argon (DP-no Argon); Double-Pane with Argon (DP-Argon); Double-Pane Argon-Filled Low-E (DP-Argon Low-E); and Triple-Pane from 2000 to 2010 shows that DP-no Argon was used by 40 percent of builders in 2000 (see exhibit 2). DP-Argon was already used by 50 percent of builders by 2000 and quickly became the dominant[1] window type reaching a near saturation level of 80 percent by 2010.

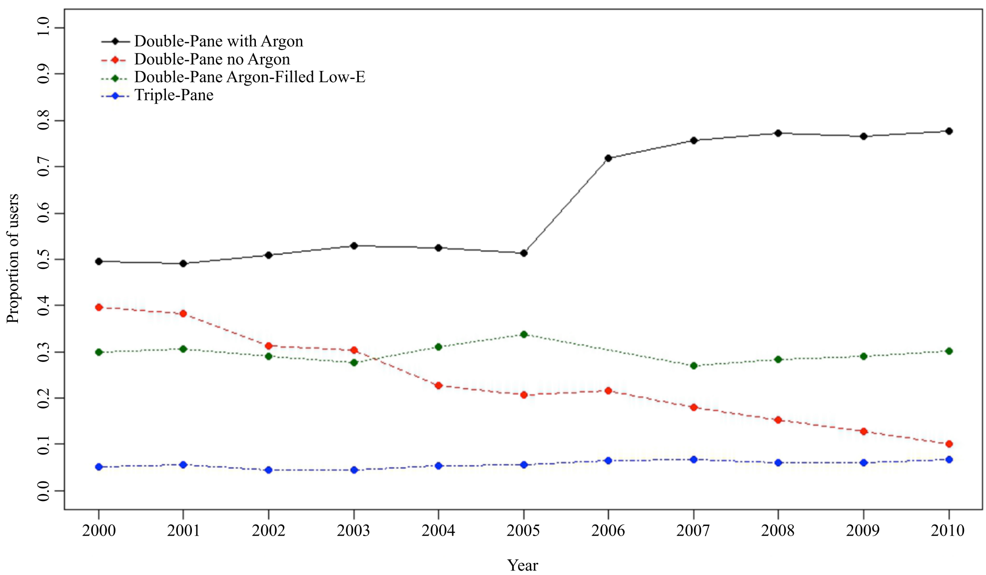
[1] We model whether builders use the products as a binary variable (1 = use, 0 = no use) but not the extent of use across all the units a company builds because of uncertainties about the consistency of responses around percent use. Nor do we weight use by the number of homes the respondent builds in a year (which is used as a proxy for firm size as an independent variable). Because the latter is positively associated with use, the binary use variable could understate market share for DP-Argon.

Since 2010 the high-efficiency cluster (Double-Pane with Argon, Double-Pane Argon-Filled Low-E, and Triple-Pane) has rapidly displaced the lower efficiency alternative (DP-no Argon), when the latter dropped from 40 to 10 percent of the market share. Our focus in this article is the general model for the choice between the high-efficiency cluster and Double Pane No Argon; in the aggregate we are modeling the rapid replacement of the low-efficiency alternative by HEWs option (see exhibit 3).

Double-pane (no filling) windows were introduced in 1962 and were commonly available by the late 1970s. Low-emissivity (Low-E) coatings were introduced in the late 1980s and were widely available by the mid-90s; the introduction date for Argon-filled is not clear, but Argon filled low-E windows were widely available in the early 2000s (Fisette, 1998).

Exhibit 3

Use of High-Efficiency Windows, 2000–2010



Potential Statistical Modeling Techniques

The logistic regression model described in the following section for analyzing use of HEW reflects our dichotomous choice framework. Given the structure of the BPS dataset and its nonlongitudinal nature, we consider the adoption decision to be a dichotomous choice to adopt or not adopt the high-performance technology over its traditional economic substitutes. The use of a logistic regression framework to capture builders' year-to-year adoption decisions aligns with and reflects adoption and diffusion theory, research on impediments to innovation in construction, and research on adoption of building construction innovations.

Among the potential contributions of this research will be the ability to analyze data on product use in residential construction for a large national sample of individual firm-respondents geocoded by location and integrated with aggregated measures for industry and market characteristics, climate, public policy, and time. Critical to the generation of these observations is the merging of the BPS data with the assortment of additional independent variables that operationalize the types of factors identified in the literature review. To merge these data, a crosswalk directory was developed linking every county (or county equivalent) to Core Based Statistical Area (CBSA) definitions for 1999, 2003 and 2009, enabling data aggregated to a variety of geographic scales to be added to the microdata (firm respondent level) file.

Independent Variables

For analysis, the research team includes product attributes noted previously in the literature review. Among attributes, cost advantage refers mainly to price and is measured using RS Means 2010 national cost data, which are adjusted by year and available at the three-digit ZIP Code level. Using common software for geocoding, these data were merged with county- and state-level data of the BPS. Although broad performance measures are also available using RS Means data, they are not available for separate technologies and thus cannot be included in a model of technology choice. As a consequence, detailed product characteristics remain exogenous to the model tested to date. Cost factors that affect the local cost of doing business (based on RS Means 2010 national cost data) per year is available, however, and was included in the model. Further, the team surveyed a builder panel to rate attributes of all technologies deemed appropriate for modeling toward environmental goals. Survey results will be used to develop measures of performance for products in the BPS data.

Attributes of the adopter are measured by firm characteristics and market area characteristics. Relative to the firm, the literature reports that size; organizational capacity and human resources; R&D investment; and presence of technology champions are associated with adoption decisions. Mixed results have reported the impact of firm size in the residential construction industry with evidence indicating that small companies led by a technology champion and large companies with technology capacity can each promote innovation. The conceptual model includes measures for company size (using number of houses built annually as a proxy), and organizational capacity based on diversity of operations spanning residential building types that include multifamily housing. In addition, we include measures of the firm's average housing unit size and average sales price. R&D investment in the housing industry is notoriously low and not included. Data on technology champions within each respondent firm were not available.

Industry characteristics noted in the residential construction literature include concentration, supply chain, subcontractor networks, and efficiency. The construction literature discusses the importance of measuring construction efficiency, which includes the productivity values for technologies and the cost of insurance. Productivity values are the expected amount of time to install a product at a national level (available from RS Means by year and location by three-digit ZIP Code). Change in the productivity value could affect the use of product technologies, because it is an indicator of the labor required at a local level. Within productivity, we also consider the subcontractor fragmentation of the industry and separated work division values that independently affect product use. We include a measure for worker compensation insurance fees, also separated by the work division associated with installation of the building product, which could affect the use of technologies, because some divisions of work are considered more risky. In general, the residential construction industry lacks concentration with small firms producing the bulk of housing in some areas, but higher levels of industry concentration in markets dominated by large production firms. As a result, the research team includes the following variables to account for these effects. For the model, we include a proxy measure of firm size and are developing a measure of industry concentration within market areas. To measure supply chain effects, we use proxy measures on the number of firms at the CBSA level for industry data for construction materials suppliers from the CBP series. In a similar way, we test subcontractor network effects using a proxy measure for the number of product related subcontractors at the CBSA level, also from the CBP series. For the HEWs model, we use the number of framing subcontractors in the CBSA. Alternative specifications, of the supply chain and subcontractor network measures, include the number of larger firms in the CBSA (based on those with 50 or more employees).

Market area characteristics include CBSA level measures for population size, income, and wealth (median income and median house value) and location within a network of market areas as an indicator of the potential for contagion effects. For the latter we developed a gravity index based on the product of the CBSA's population size and the population sizes of all other CBSAs divided by the square of the distance between the CBSAs (Raub and Weesie, 1990). This index measures the potential for contagion effects (for example, learning about new technologies) positively associated with size and inversely associated with distance squared (an accelerating distance decay effect). Contagion effects associated with market area sizes and distances have never been tested, but are expected based on the opportunities for learning from builders in other nearby markets.

Public policy impacts on innovation and on green building have been documented in previous research, but the focus has been on buildings and certifications and not on specific product use by residential builders. We incorporate measures for federal stimulus funds (state-level American Recovery and Reinvestment Act Funds Per Capita), green building certifications, utility rebates, state grants, and a variety of other state and local incentives for increasing energy efficiency. We also include the state's sales tax as a potential negative impact because of higher costs. In addition, urban development compactness is measured via Ewing's composite index (Ewing and Hamidi, 2013).

Time effects are well documented in diffusion research, but typically in aggregated models of diffusion (for example, Bass models). We include year as either a continuous measure or a discrete dummy variable measure to capture exogenous shocks and bandwagon effects reflected in changes of the impact of time on use, innovation chasm reflected in no impact of time beyond the stage of early adopters, and maturation or peak saturation effects reflected in negative impacts of time. As noted previously, our objective is to build a model that reduces the unexplained variation that might otherwise be absorbed in the time measure.

Regression Modeling

To analyze how external parameters support a general shift toward environmental performance as a central component of diffusion in the homebuilding industry, we will fit logistic regression models to the builders' choice questions. The dependent variable will be specified so that 0 describes use of the traditional technology option(s) (for example, double-pane windows without argon gas filling) and 1 describes the use of at least one of the high-performance economic substitutes (for example, DP-Argon, DP-Argon Low-E, and Triple-Pane). The generic logistic regression used for this analysis is—

$$ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k, \quad (1)$$

where p indicates probability of technology usage, β_0 denotes the y intercept, and x_i and β_i represent ith predictor variable and regression coefficient respectively for $=1,\ldots,k$. Logistic regression is a popular technique to predict binary outcomes (such as use and nonuse) as a function of multiple variables, because the resulting usage percentages are correctly constrained between 0 and 100 percent. For more details, see Agresti (2002).

Variable selection is a statistical approach that attempts to identify a parsimonious model, which is a model that is as simple as possible (that is, fewest predictor variables) while maintaining good predictive ability for the response variable. Parsimony is a fundamental concept for the statistical modeling of outcomes in a wide variety of fields. To obtain preliminary insight into a potentially parsimonious model, we will use stepwise variable selection in the logistic regression framework. Stepwise selection operates by iteratively adding variables that increase model performance and removing variables that become obsolete in the presence of new additions. The process begins by considering the single most predictive variable available (as measured by significance levels) and then iterating between adding and removing variables until no additional variables are added or removed in a given step. We used a criteria of alpha = 0.05 as the criteria for adding and removing variables in this study. The chosen model will be the subject of future work based on the variables and methods described previously.

In addition, we intend to use the Least Absolute Shrinkage and Selection Operator (LASSO) as a penalized regression and variable selection technique. LASSO is a form of continuous variable selection that operates by imposing a constraint on the sum of the magnitude of regression coefficients (Tibshirani, 1996). The LASSO is able to partially include regression coefficients corresponding to variables that have limited predictive ability over the outcome in question, while the stepwise approach either fully includes or excludes each variable. The constraint on the coefficients is frequently chosen based on a k-cross validation approach that chooses the threshold one standard error above the value that minimizes cross-validation mean square error. The LASSO paths are computed using the coordinate descent algorithm (Friedman, Hastie, and Tibshirani, 2010).

By applying statistical modeling approaches to our national database of builder decisions we will able to quantify the adoption rates of the high-performance technology alternatives as a function of time, policy, firm, market, and industry characteristics simultaneously. Characterizing usage rates in this way enables assessment of the impact of disparate predictors on the adoption rates of green technology. Cross-validation was used to assess predictive accuracy of the statistical models. Cross-validation, briefly defined, is a process by which a subset of the available data are withheld from model fitting and retained as a test set. If a model is able to predict the out-of-sample test set well, this provides evidence that the model has good predictive accuracy. Poor performance on the test set indicates potential model over-fitting or other problems with the generalizability of model.

Furthermore, statistical comparisons among the many candidate predictors are possible within the framework of a single model, which can be used to specifically compare usage rates at individual time points for any combination of predictor inputs.

Discussion

This article describes foundational processes of a larger project examining U.S. home builders' choices to adopt innovative housing technologies that improve the environmental performance of new single-family homes. This population is important to study because builders sit at a critical juncture in the housing creation decision chain and can influence how new housing units address change related to energy consumption while also reflecting shifting technology, demography, and policy landscapes. Home builders have been known, in many cases, for resisting adoption of new technology, creating a need for methods that target a divergence from previous firm adoption patterns by—(1) promoting recent trends in environmental goals and (2) providing a view into market agility and competitive advantage for technologies in U.S. housing.

Until now, scholars have engaged in the process of identifying the role of innovation on economic growth and argued that firms are engines of growth through innovation. Studies of innovation have been limited to industries with adequate data, which until now has not been the case for the residential construction industry. Although U.S. housing has historically been marked by its lack of change, innovative building technologies have recently diverged from previous adoption and diffusion patterns. In place of previous path dependency, the construction industry is demonstrating a widening awareness and likely use of innovative practices and technologies. Little empirical evidence measures and analyzes the choice of building products, which is a shortcoming addressed in this project. After reviewing the adoption, diffusion, technology, construction, real estate, and statistics literature, we identified an array of factors that are likely to be associated with builders' adoption decisions around high-performance technologies. In addition, basing our analysis on initial plots of the data, we estimate that the construction industry is moving increasingly toward the adoption of high-performance technologies within new homes.

Moving forward, analysis and measurement of green building diffusion can be defined and modeled using the foundation presented in this article. Analysis is now possible for dichotomous use through product characteristics, firm characteristics, industry characteristics, market area characteristics, climate, public policy, and time. The logistic regression model described in this work enables measurement of the use of green building technologies based on adoption and diffusion theory, research on impediments to innovation in construction, valuation research (hedonic models for price of residential and commercial buildings), and research on adoption of building construction innovations. Among our major contributions in this research will be the ability to analyze data on product use in residential construction for a large national sample of individual firm-respondents geocoded by location and integrated with aggregated measures for industry and market characteristics, climate, public policy, and time. Based on the work presented in this article, innovation in residential firms may be quantified as a method of creating market agility, competitive advantage, disrupting markets, or creating entirely new markets.

Another aim of this work is linking the diffusion of innovation among home builders to broader concepts of sustainability and highlight implications for federal policymakers. Beyond providing initial diffusion of innovation empirical techniques for residential construction, this article provides a roadmap for ensuing work to test and refine an empirical model. As a result, future work can complement innovation's connection to the broader topic of sustainability and interpret housing's significant economic and ecological dimensions.

The innovation-decision process surrounding the use of technologies in housing (and why) clearly influences energy consumption, a rippling effect toward future resource consumption. It is also clear that energy efficiency in housing can influence financial sustainability for multiple stakeholders along the supply chain—residents, developers, owners, and operators, to name a few.

Government plays a strong role in supporting green building causes—incentives, cost relief, regulations, and promotion. From a policy perspective, energy efficiency in housing could benefit residents through reduced overall housing costs and monthly savings that provide a cushion against unforeseen economic shocks. Green building using a third-party, verified process could also serve housing stakeholders as a risk mitigation tool into the future (healthy homes, durability, and long-term value).

Although the trend is toward green design and construction standards, Yudelson (2008) argues "the differentiating point clearly is now on results." Policy should reinforce the need for data that generate results of energy-efficiency standards in housing and measure possible savings to residents.

Low-income housing tax credit programs in Virginia are already using energy-efficiency housing requirements for developments and resulting data may guide policy for its programs and elsewhere. Data would guide developers and property owners in benefits from implementing a green building protocol in the broader housing stock. At a minimum, the collection of accurate data on energy use could catalyze our understanding of energy, its use, and our modeling of its effect on home builder decisions in the larger built environment.

Further, American Housing Survey and American Community Survey data could provide opportunities to define current levels of local need in housing using longitudinal data. Modeling real depreciation (age of unit, actual versus expected upkeep, improvement expenditures, and location) and worst case housing needs at state and local levels could provide an empirical basis.

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References

Adomatis, Sandra K. 2012. "Residential Appraising: Describing the Green House Made Easy," *Appraisal Journal* 80 (1): 21–29.

———. 2010. "Valuing High Performance Houses," *The Appraisal Journal* 78: 195–201.

Aroul, Ramya R., and J. Andrew Hansz. 2011. "The Role of Dual-Pane Windows and Improvement Age in Explaining Residential Property Values," *The Journal of Sustainable Real Estate* 3 (1): 142–161.

Bass, Frank M. 2004. "Comments on 'A New Product Growth for Model Consumer Durables: The Bass Model'," *Management Science* 50 (12): 1833–1840.

Blackley, Dixie M., and Edward M. Shepard III. 1996. "The Diffusion of Innovation in Home Building," *Journal of Housing Economics* 5 (4): 303–322.

Bloom, Bryan, MaryEllen C. Nobe, and Michael D. Nobe. 2011. "Valuing Green Home Designs: A Study of ENERGY STAR Homes," *The Journal of Sustainable Real Estate* 3 (1): 109–126.

Bodie, Zvi, Alex Kane, and Alan Marcus. 2008. *Investments*. New York: McGraw-Hill Higher Education.

Brounen, Dirk, Nils Kok, and John Quigley. 2011. "Residential Energy Literacy and Conservation," *47th Annual AREUEA*. Chicago: American Real Estate and Urban Economics Association.

Burkett, Virginia R., and Avelino G. Suarez. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, 5th ed. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Christensen, Clayton M., Scott D. Anthony, and Erik A. Roth. 2004. *Seeing What's Next: Using the Theories of Innovation to Predict Industry Change*. Cambridge, MA: Harvard Business Press.

Costa, Dora L., and Matthew E. Kahn. 2009. "Toward a Greener California: Why Has California's Residential Electricity Consumption Been So Flat Since the 1980s?: A Microeconometric Approach. In *Proceedings, Conference on Green Building, The Economy and Public Policy*. Berkeley, CA: D&R International.

Dastrup, Samuel, Joshua S. Graff Zivin, Dora L. Costa, and Matthew E. Kahn. 2012. "Understanding the Solar Home Price Premium: Electricity Generation and 'Green' Social Status," *European Economic Review* 56 (5): 961–973.

Devine, Avis, and Shaun A. Bond. 2013. Do Policy Incentives Promote Green Building? Working paper. Cincinnati: University of Cincinnati.

Dibner, David R., and Adrew C. Lemer. 1992. *The Role of Public Agencies in Fostering New Technology and Innovation in Building*. Washington, DC: National Academies Press.

Eicholtz, Piet, Nils Kok, and John M. Quigley. 2013. "The Economics of Green Building," *Review of Economics and Statistics* 95 (1): 50–63.

Ewing, Reid, and Shima Hamidi. 2013. *Measuring Urban Sprawl and Validating Sprawl Measures*. Washington, DC: National Institutes of Health, National Cancer Institute; Smart Growth America.

Ewing, Reid, Gail Meakins, Shima Hamidi, and Arthur C. Nelson. 2014. "Relationship Between Urban Sprawl and Physical Activity, Obesity, and Morbidity—Update and Refinement," *Health & Place* 26: 118–126.

Fisette, Paul. 1998. "Choosing Energy-Efficient Windows," *Fine Homebuilding* February: 68–72.

Friedman, Jerome, Trevor Hastie, and Rob Tibshirani. 2010. "Regularization Paths for Generalized Linear Models Via Coordinate Descent," *Journal of Statistical Software* 33 (1): 1–22.

Gann, David M., and Ammon J. Salter. 2000. "Innovation in Project-Based, Service-Enhanced Firms: The Construction of Complex Products and Systems," *Research Policy* 29 (7): 955–972.

Goodwin, Kimberly R. 2011. "The Demand for Green Housing Amenities," *The Journal of Sustainable Real Estate* 3 (1): 127–141.

Habets, Thijs, Hans Voordijk, and Peter van der Sijde. 2011. "The Adoption of Innovative Asphalt Equipment in Road Construction," *Construction Innovation: Information, Process, Management* 11 (2): 229–245.

———. 2006. Adoption of Alternative Transport Technologies in the Construction Industry. Working paper. Enschede, the Netherlands: Twente University.

Harrison, David, and Michael Seiler. 2011. "The Political Economy of Green Office Buildings," *Journal of Property Investment & Finance* 29 (4/5): 551–565.

Hartmann, Andreas. 2006. "The Context of Innovation Management in Construction Firms," *Construction Management and Economics* 24 (6): 567–578.

Hudson, E. 2011. "Using the National Green Building Standard To Improve Marketing Results." Published in *Proceedings of the International Builders Show*, Orlando, FL. Washington, DC: National Association of Home Builders.

Jaffee, Dwight, Richard Stanton, and Nancy Wallace. 2012. *Energy Factors, Leasing Structure and the Market Price of Office Buildings in the U.S.* Berkeley, CA: University of California, Berkeley, Fisher Center for Real Estate and Urban Economics. http://escholarship.org/uc/item/03d6w2m1.

Kale, Serdar, and David Arditi. 2009. "Innovation Diffusion Modeling in the Construction Industry," *Journal of Construction Engineering and Management* 136 (3): 329–340.

———. 2006. "Diffusion of ISO 9000 Certification in the Precast Concrete Industry," *Construction Management and Economics* 24 (5): 485–495.

———. 2005. "Diffusion of Computer Aided Design Technology in Architectural Design Practice," *Journal of Construction Engineering and Management* 131 (10): 1135–1141.

Kaza, Nikhil, Roberto G. Quercia, and Chao Yue Tian. 2014. "Home Energy Efficiency and Mortgage Risks," *Cityscape* 16 (1): 279–298.

Koebel, C. Theodore. 2007. "Innovation in Homebuilding and the Future of Housing," *Journal of the American Planning Association* 74 (1): 45–58.

———. 1999. "Sustaining Sustainability: Innovation in Housing and the Built Environment," *Journal of Urban Technology* 6 (3): 75–94.

Koebel, C. Theodore, and Andrew P. McCoy. 2006. "Beyond First Mover Advantage: The Characteristics, Risks, and Advantages of Second Mover Adoption in the Home Building Industry." In *Proceedings, American Real Estate and Urban Economics Association Meeting*, Washington, D.C.

Koebel, C. Theodore, Maria Papadakis, Ed Hudson, and Marilyn Cavell. 2004. *Diffusion of Innovation in the Residential Building Industry*. Report prepared for the U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Washington, DC: Government Printing Office.

Kok, Nils, Marquise McGraw, and John M. Quigley. 2011. "The Diffusion of Energy Efficiency in Building," *The American Economic Review* 101 (3): 77–82.

Kontokosta, Constantine E. 2011. "Greening the Regulatory Landscape: The Spatial and Temporal Diffusion of Green Building Policies in U.S. Cities," *The Journal of Sustainable Real Estate* 3 (1): 68–90.

Laborde, Maria, and Victor Sanvido. 1994. "Introducing New Process Technologies Into Construction Companies," *Journal of Construction Engineering and Management* 120: 488–508.

McCoy, A.P., A.R. Pearce, and Y. Ahn. 2012. "Toward Establishing Attributes for Innovative Green Building Products: A Survey of SIPS Builders," *Journal of Green Building* 7 (3): 53–176.

McCoy, Andrew P., Ralph Badinelli, C. Theodore Koebel, and Walid Thabet. 2010a. "Concurrent Commercialization and New-Product Adoption for Construction Products," *European Journal of Innovation Management* 13 (2): 222–243.

McCoy, Andrew P., C. Theodore Koebel, Hazhir Rahmandad, and Christoper T. Franck. 2010b. *Impact of Market Behavior on the Adoption and Diffusion of Innovative Green Building Technologies*. Washington, DC: U.S. Department of Housing and Urban Development; Blacksburg, VA: Virginia Polytechnic Institute and State University.

McCoy, Andrew P., C. Theodore Koebel, and Andrew R. Sanderford. 2011. "Establishing A Long-Term Research Agenda on Design, Construction and Technology: A Framing Paper for PD&R Research Conference." Washington, DC: U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

McCoy, Andrew P., Patrick O'Brien, Vera Novak, and Mason Cavell. 2012. "Toward Understanding Roles for Education and Training in Improving Green Jobs Skills Development," *International Journal of Construction Education and Research* 8 (3): 186–203.

McCoy, Andrew P., Walid Thabet, and Ralph Badinelli. 2008. "Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction," *Construction Innovation: Information, Process, Management* 8 (2): 137–155.

Melillo, Jerry M., Terese Richmond, and Gary W. Yohe, eds.. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Research Change Research Program. Washington, DC: U.S. Government Printing Office.

Morledge, Roy. 2011. "Colleges As Agents for Construction Innovation—A Case Study," *Construction Innovation: Information, Process, Management* 11 (4): 441–451.

Pivo, Gary. 2013. "The Effect of Transportation, Location, and Affordability Related Sustainability Features on Mortgage Default Prediction and Risk in Multifamily Rental Housing," *Journal of Sustainable Real Estate* 5 (1): 50–67.

Pivo, Gary, and Jeffrey D. Fisher. 2011. "The Walkability Premium in Commercial Real Estate Investments," *Real Estate Economics* 39 (2): 185–219.

Raub, Werner, and Jeroen Weesie. 1990. "Reputation and Efficiency in Social Interactions: An Example of Network Effects," *American Journal of Sociology* 96 (3): 626–654.

Rauterkus, Stephanie Y., Grant I. Thrall, and Eric Hangen. 2010. "Location Efficiency and Mortgage Default," *The Journal of Sustainable Real Estate* 2 (1): 117–141.

Rogers, Everett M. 1995. *Diffusion of Innovations*. New York: Free Press.

Rose, Timothy M., and Karen Manley. 2014. "Revisiting the Adoption of Innovative Products on Australian Road Infrastructure Projects," *Construction Management and Economics* 32 (9): 904–917.

———. 2012. "Adoption of Innovative Products on Australian Road Infrastructure Projects," *Construction Management and Economics* 30 (4): 277–298.

Simons, Robert A., Eugene Choi, and Donna M. Simons. 2009. "The Effect of State and City Green Policies on the Market Penetration of Green Commercial Buildings," *The Journal of Sustainable Real Estate* 1 (1): 139–166.

Slaughter, E. Sarah. 2000. “Implementation of Construction Innovations,” *Building Research and Information* 28 (1): 2–17.

———. 1998. “Models of Construction Innovation,” *Journal of Construction Engineering and Management* 124 (3): 226–231.

———. 1993a. “Builders As Sources of Construction Innovation,” *Journal of Construction Engineering and Management* 119 (3): 532–549.

———. 1993b. “Innovation and Learning During Implementation: A Comparison of User and Manufacturer Innovations,” *Research Policy* 22 (1): 81–95.

Tatum, C.B. 1987. “Process of Innovation in Construction Firms,” *Journal of Construction Engineering and Management* 113 (4): 648–663.

Tibshirani, Robert. 1996. “Regression Shrinkage and Selection Via the Lasso,” *Journal of the Royal Statistical Society*, Series B (Methodological) 58 (1): 267–288.

Toole, T. Michael. 1998. “Uncertainty and Home Builders’ Adoption of Technological Innovations,” *Journal of Construction Engineering and Management* 124: 323–332.

Turner, Cathy. 2006. *LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report*. Prepared for the Cascadia Region Green Building Council. Seattle: Cascadia Region Green Building Council.

U.S. Department of Energy (DOE). 2014. *Buildings Energy Data Book: Energy Efficiency and Renewable Energy*. Washington, DC: U.S. Department of Energy.

Wandahl, Soren, Alexia Jacobsen, Astrid Heidemann Lassen, Soren Bolvig Poulsen, and Henrik Sorensen. 2011. “User-Driven Innovation in a Construction Material Supply Network,” *Construction Innovation: Information, Process, Management* 11 (4): 399–415.

Warren-Myers, Georgia. 2012. “The Value of Sustainability in Real Estate: A Review From a Valuation Perspective,” *Journal of Property Investment & Finance* 30 (2): 115–144.

Wiley, Jonathan A., Justin D. Benefield, and Ken H. Johnson. 2010. “Green Design and the Market for Commercial Office Space,” *The Journal of Real Estate Finance and Economics* 41 (2): 228–243.

Wilkinson, Sara J., Paul Van Der Kallen, and Leong Phui Kuan. 2014. “The Relationship Between the Occupation of Residential Green Buildings and Pro-Environmental Behavior and Beliefs,” *Journal of Sustainable Real Estate* 5 (1): 1–22

Wong, Andy K.D., Francis K.W. Wong, and Abid Nadeem. 2011. “Government Roles in Implementing Building Information Modelling Systems: Comparison Between Hong Kong and the United States,” *Construction Innovation: Information, Process, Management* 11 (1): 61–76.

Woudhuysen, James, and Ian Abley. 2004. *Why Is Construction So Backward?* Hoboken, NJ: Wiley.

Yudelson, Jerry. 2008. *Marketing Green Building Services*. Oxford, United Kingdom: Architectural Press, an Imprint of Elsevier.