Adoption Patterns of Energy Efficient Housing Technologies 2000-2010: Builders as Innovators?

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Abstract

The U.S. housing industry is often considered an innovation laggard. Whether because of endogenous or exogenous risks, homebuilding firms have traditionally resisted innovation. However, recent evidence suggests builders' material selections have been growing more innovative—more specifically, these selections have been growing greener. Though little empirical work exists that measures and analyzes such phenomena, the paper will report on a national study[2] of "green building" innovation in residential construction from 2000-2010. This paper asks two research questions: 1) to what extent are builders, if any, adopting higher efficient building products over their traditional economic substitutes? And 2) what are the market, demographic, and regulatory factors associated with homebuilders' green and energy efficient technology selections? The authors analyze data from the National Association of Homebuilders' Builders' Practices Survey (BPS) from 2000 to 2010, estimating a series of logit models focusing on builders' choices to install high performance building technologies including PEX piping, custom sized-HVAC systems, programmable thermostats, and high efficiency insulation. This research builds both methodologically and substantively upon the foundation laid by Koebel et al (2013) and McCoy et al's (2013) work examining builders' choices to adopt high efficient windows and Sanderford et al (2013) paper examining factors associated with the diffusion patterns of Energy Star certification in new homes.

Introduction

Innovation is often noted as a key ingredient in the recipe for creating competitive advantage and distinction among firms as well as for generating new markets for products and processes (Chesbrough et al. 2006; Christensen et al. 2004; Von Hippel 2005). The literature focusing on the diffusion of innovations is rich and covers a diverse range of topics including building science and construction (for a sample of literature see Beal and Bohlen 1957; Beal and Rogers 1957; Bose 1964; Downs and Mohr 1976; Li and Sui 2011; Shields and Manseau 2005; Watts and Dodds 2007).

Over the last twenty years, building science scholars have studied innovation in building construction, predominantly focusing on commercial and large-scale facility creation (Slaughter 1993; Slaughter 1993; Slaughter 1998; Tatum 1987). In fact, a journal (*Construction Innovation)* has been created to continue this scholarship. However, much like previous research, the recent literature in this and other related journals has largely retained a commercial focus (e.g., Habets et al. 2011; Morledge 2011; Wong et al. 2011) or focused on firm size as a predictor of adoption of innovation (Abbot et al. 2006; Hardie and Newell 2011).

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A growing portion of the construction innovation literature has cropped up around residential construction and housing technologies. Supported, in part, by programs such as the Partnership to Advance Technology in Housing (PATH), a joint effort between the Department of Housing and Urban Development and the National Association of Homebuilders, the segment of the literature has helped provide insight into how innovation blooms and can best be supported in housing and homebuilding (Blackley and Shepard III 1996; Bradshaw II 2011; Koebel 1999; Koebel 2008; Koebel and McCoy 2006; Koebel et al. 2004; Manseau and Shields 2005; McCoy et al. 2010; McCoy et al. 2008; Toole 1998).

Historically, in the construction innovation literature, the homebuilding industry (and by extension the builder) has been considered an innovation laggard—or the last of Rogers' classifications of adopters to take up new ideas and products (Gann and Salter 2000; Rogers 1995; Woudhuysen and Abley 2004). Based on the homogeneity of homes, volumetric production, assembly risks, and the fact that most innovations are hidden behind walls, this attribution is not unfounded or regularly inaccurate. The builder essentially plays the role of the assembler, stitching together various housing components. They bear a significant amount of risk, as they are required to assemble these technologies according to building code and manufacturer specifications. They must also intermediate the needs and preferences of the end user—all while earning a return sufficient enough to continue playing their part in this (somewhat) theater of absurd expectations. However, as innovation has been observed to play a role in creating competitive advantage for firms, homebuilders may adopt innovations that allow them to earn a superior return as compared to their less innovative counterparts.[3] At present there is a limited understanding of the market, policy, firm, climate, product, and industry characteristics that are associated with a builder's choice to adopt innovative technologies in housing.

This paper is part of a larger research project by a team of researchers at Virginia Tech. The goal of the project is to develop a deeper understanding of the factors that help explain the geographic and temporal variation in adoption and diffusion rates for various green housing technologies. For a description of the larger project and a detailed literature review, see (McCoy et al. 2013). Papers by team members have reported on national studies of the diffusion of innovation among home builders and production home builders respectively (Koebel 2008; Koebel and McCoy 2006); the diffusion of high efficiency insulation products (Sanderford et al. 2013); the commercialization of innovation in residential construction (McCoy et al. 2010); the diffusion of green certification (Energy Star) in new housing (Sanderford et al. 2013); the role and importance of high efficiency performance in green certification standards (Nikhoo et al. 2012); the impact of valuation models on the Moore's Chasm challenge for green building (Sanderford et al. 2013; Sanderford and Pearce 2013) and the application of Agent Based Modeling to develop diffusion scenarios (Rahmandad et al. 2013) based on the empirical results reported herein.

Differentiating itself from previous literature and its broader research project, this paper asks two research questions: 1) to what extent are builders, if any, adopting higher efficient building

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[3] Architectural historian Bar Faree once remarked that, "a *building* must pay, or there will be no *investor* ready with money to meet its cost." While he was talking about the decision to build taller skyscrapers with fewer rentable floors, his logic carries for builders and housing. Builders constantly must assess what types of units they know they can sell. Where an innovation creates a risk relative to the potential sale-ability of a home, it must be scrutinized carefully. In the US, the appraisal process tends to be based on a comparable sales analysis. Where there is sufficient data about a home and others with similar attributes, the appraiser can easily distinguish the contributory value of the attribute to the estimated market value of a home. However, as there often is limited data available in the housing data about the presence of various innovations, appraisals can be confounded—reinforcing innovation weary behavior of builders.

products over their traditional economic substitutes? And 2) what are the market, demographic, and regulatory factors associated with homebuilders' green and energy efficient technology selections? The authors analyze data from the National Association of Homebuilders' Builders' Practices Survey (BPS) from 2000 to 2010, estimating a series of logit models focusing on builders' choices to install high performance building technologies including PEX piping, custom sized-HVAC systems, programmable thermostats, and high efficiency insulation. This research builds both methodologically and substantively upon the foundation laid by Koebel et al's (2013) work examining builders' choices to adopt high efficient windows. Based on Koebel's findings this paper also makes some observations on the long-held view that builders are innovation laggards.

Literature Review

Detailed reviews of the housing innovation and green housing technology diffusion literature can be found in (McCoy et al. 2013; Sanderford et al. 2013). This short review focuses on the literature conducted around three themes in housing innovation: energy efficiency, eco-labels or green building certifications, and high performance housing technologies. We focus on these themes, as they are some of the key building blocks of innovation that drive increased environmental performance and are connected to increases in housing value.[4] The authors noted when diagramming this paper that there were blunt parallels between our work and the stories of first generation Blackberry and iPhone consumers buying the devices with the sole intention of smashing them open to examine its unique arrangement of components. While the metaphor has limited utility, the notion that technologies are the building blocks of increased performance was rather useful in this paper's development.

Germane to the broadest of the three themes, energy efficiency, the literature offers a wide range of highlights. Scholars have shown that there are health benefits that can be generated through the use of various types of building insulation that also increase the operational efficiency of the home (Chapman et al. 2009; Howden-Chapman et al. 2007). Additionally, research indicates that the internal temperature and relative humidity of a home are key metrics that can help frame a builder's or occupant's decision to upgrade housing technologies to their more energy efficient economic substitutes (Milne and Boardman 2000). Further, understanding the needs and preferences of the occupant are central to matching innovative technologies and market opportunities (Crosbie and Baker 2010). In a Swiss study of more than one hundred fifty apartments, owners of these housing units showed a strong and significant preference for upgrading to energy efficient technology options (Banfi et al. 2008). Koebel et al (2013) suggest that builders in larger markets with higher incomes, larger networks of builders, and supportive public policy are more likely to choose energy efficient window options over less efficient options (Koebel et al. 2013). Devine and Bond (2013) confirm Koebel's results showing that with respect to green homes, communities with supportive public policy have stronger associations with new green home construction (Devine and Bond 2013).

The housing markets appear to have recognized the value of innovative energy efficient housing technology choices. In California, homes with solar panels commanded a price premium over similar homes without them (Dastrup et al. 2012). Similarly, based on sample of home sales in Texas, homebuyers paid a premium for homes with more energy efficient windows (Aroul and

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[4] Primarily, the authors assume that green and energy efficient building technologies qualify as innovations as they meet many of the definitions offered across the literature. See Sanderford, Koebel, and McCoy (2013), a working paper, for a more in-depth discussion of the alignment of the definition of innovation and green building technologies.

Hansz 2011). Buyers also appear willing to pay more in some markets for homes with eco-labels such as Energy Star or Green Point (Bloom et al. 2011; Kok and Khan 2012). However, as energy literacy has been observed to be rather low (Brounen et al. 2011), more scholarship focused on the interaction of people, markets, and energy efficiency is needed. Sanderford and Pearce (2013) confirmed this need via a survey of residential real estate appraisers with green home valuation training. Across this elite group, there was not a standard method of valuation for energy efficient homes (Sanderford and Pearce 2013).

Researchers have also turned their focus towards the diffusion of green building certifications into property markets. Simons et al (2009) and Kok et al (2011) both examined the spatial and temporal diffusion patterns of green building certifications in the commercial office market (Kok et al. 2011; Simons et al. 2009). Both papers suggested that, vis-à-vis office buildings, climate, and public policy are critical factors associated with the diffusion of Leadership in Energy and Environmental Design (LEED) and Energy Star certifications. Kok et al. also provided clear evidence that market and industry characteristics also played a significant role in the diffusion of these certifications (Kok et al. 2011). Sanderford et al. (2013) analyzed the same problem in the housing markets by exploring the factors associated with the choice to certify new homes via the Energy Star program (Sanderford et al. 2013). This paper showed that many of the same factors that explain the diffusion of eco-labels in the office market have analogs in the housing market. Kontokosta (2011), Simcoe & Toffel (2011), and Choi (2009) each examined the diffusion of green building public policies into property markets (Choi 2009; Kontokosta 2011; Simcoe and Toffel 2011). Simcoe & Toffel's work suggested a very interesting finding; that when using a coarsened exact pairs matching protocol, communities with green public procurement policies tend to see positive spillover effects (higher concentrations of green office space) than a city with similar demographic characteristics (Simcoe and Toffel 2011).

Recent research indicates that the number of patents for renewable energy technologies has grown substantially (Altwies and Nemet 2012; Johnstone et al. 2010; Johnstone et al. 2012). Similarly, an exploratory paper presented last year at this conference showed that builders' use of green and energy efficient technologies is growing (Nikhoo et al. 2012). Building from that initial work, McCoy et al. (2013) framed a general model to analyze the diffusion of high performance housing technologies in the homebuilding industry (McCoy et al. 2013). This paper specified a binary model based on builders' choices to use or not use a high performance technology as well as the factors potentially associated with that choice. Koebel et al. (2013) operationalized and refined that model specification relative to highly efficient window options (Koebel et al. 2013). The paper showed strong associations between builders' choices to adopt the high efficiency window option and the presence of green focused public policy, climate, market characteristics, and firm characteristics. The paper presented here distinguishes itself from the two streams of research described above in that it extends the investigation started by Koebel et al. (2013) into other high performance housing technologies (e.g., insulation, piping, and climate control).

Data and Methods of Analysis

To answer the proposed research questions, the authors used a very similar dataset based on the same set used by Koebel et al. (2013) in their analysis of windows. Using the majority of the same dataset used by Koebel and his colleagues, we appended a few additional variables (described below). We analyzed a large national data set covering nearly 29,000 builders from the Builders' Practices Survey (BPS), an annual survey conducted by the National Association of Homebuilders Research Center (NAHB RC). The BPS is designed to capture builders' usage patterns of new residential construction projects across nearly 1,100 product types and over 40 clusters of products. McCoy et al. (2013) discuss the development of the dataset for analyzing builders' use of innovative green construction products from 2000 to 2010 incorporating local, state, and regional level data for industry characteristics, local market characteristics, and public policies. The BPS data are collected through an annual mailed survey to builder members of the NAHB. Respondents reporting zero homes built in a year were dropped from the analysis dataset, as were respondents from Alaska, Hawaii, and US territories. The respondents cannot be considered a random sample of the universe of homebuilders. However, the respondents reflect the state-by-state distribution of builders reasonably well. A comparison between BPS respondents and the number of homebuilders reported in County Business Patterns in randomly selected years of the analysis window had an average coefficient of determination of .7 indicating sufficient similarity between the distributions (McCoy 2013, Koebel 2013).

The BPS includes product use within the housing types of Single-Family Detached (SFD), Single-Family Attached (SFA), and Multi-Family (MF) at the unit of analysis of the builder firm (typically an individual survey respondent). The BPS data do not contain any information about the characteristics of the firms beyond the city and county of the respondents' addresses and summary measures of the number, size, building type, and price of the housing units built during the previous year. The data are non-longitudinal since respondents cannot be linked over time. The data set is the largest of its kind and unique in its integration of industry, market, and public policy measures (Koebel et al. 2013).

As this paper is part of a larger research effort to investigate the diffusion of innovative technologies into the homebuilding industry, we borrow heavily from previous working papers published by members of the research team. To help select the high performance technologies investigated in the models below, the team leaned on the clusters of high performance housing technologies identified by Nikhoo et al. (2013) and McCoy et al. (2013). Where as Koebel et al. (2013) analyzed the diffusion of high performance windows, this paper investigates the diffusion trajectories and factors associated with those trajectories for high performance water distribution piping, heating systems, cooling systems, insulation, and programmable thermostats.

These previous papers also created six categories of characteristics influencing high performance product adoption by builders: Market Area (categorized at the Core Based Statistical Area or CBSA level), Product, Industry, Firm, Public Policy, and Time. Firm characteristics reported in the literature include size; organizational capacity and human resources; R&D investment; and presence of technology champions.

In place of the traditional S-Curve models used to estimate the parameters for the diffusion trajectory, the authors opted for a dichotomous choice model where time is modeled as a potential factor influencing adoption. The dependent variable for each of the products evaluated in this paper is specified in binary form—reflecting whether or not a builder respondent in the BPS indicated use of a high performance product.

To analyze how external parameters surrounding this change support a general shift towards environmental performance as a central component of diffusion in the homebuilding industry, we fit a logistic regression model for the dependent variable representing the choice by a builder to use or not use a high efficient window option. The dependent variable is specified so that 0 describes use of the alternative cluster of products and 1 describes the use of a product in the high-efficiency product cluster (e.g., PEX piping). The generic logistic regression used for the base of this analysis is:

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

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 $= 1, \dots, k$. Logistic regression is a popular technique to predict binary outcomes (such as use/non-use) as a function of multiple variables, because the resulting usage percentages are correctly constrained between 0 and 100%. For more details, see Agresti (2002).

The modeling approach taken in this paper is similar to Koebel et al. (2013) where both the dependent variables and independent variables are similarly functionally specified and analyzed.

Based on the generic logistic regression function above, the functionally reduced form of the general model presented here is:[5]

$$Use\ of\ High\ Perf\ Product_n \left(\frac{P_n}{1-P_n}\right) = \mu + \beta_1 + \beta_2 + \cdots + \beta_7$$

where n = one of the five high performance products, µ is the y-intercept, and β_x are:

1. Time
2. Firm Characteristics
3. Market Area Characteristics
4. Product Characteristics
5. Industry & Labor Supply Chain Characteristics
6. Public Policy
7. Climate

The dependent variable for each of the five models included in this paper represents choices by respondent builders in the BPS indicating use of a particular high performance technology in a particular year. Where the models are all dichotomous choice analyses, when a respondent indicated use of a high performance technology, their response was coded as a one. All responses that indicated use of other technologies in the same year were coded as a zero. Framing the dependent variable in this manner allows for comparison of economic substitutes. For example, we intend to analyze a builder's choice to use high efficient HVAC components and in one model use the decision rule that the efficient product is a 13 SEER or higher cooling unit versus the other choices of 12.9 and lower SEER units. Similar distinctions were made amongst economic substitute products in the BPS for each of the other dependent variables.

The authors gathered the independent variables at the geography of the CBSA or State and merged to the BPS data based on a cross walk file based on the U.S. County identified by the BPS respondent. For example, if the respondent indicated their primary area of business as Albemarle County, Virginia, independent variable data not drawn directly from the BPS was assigned based on the Charlottesville CBSA that includes the independent City of Charlottesville along with Albemarle, Fluvanna, Greene, and Nelson counties. Where CBSA boundaries crossed state lines, any state level was merged based on the state of the primary city/county of the CBSA. The models tested a similar set of independent variables used in Koebel et al. (2013) and Sanderford (2013), two papers where high performance windows and housing certifications were analyzed.

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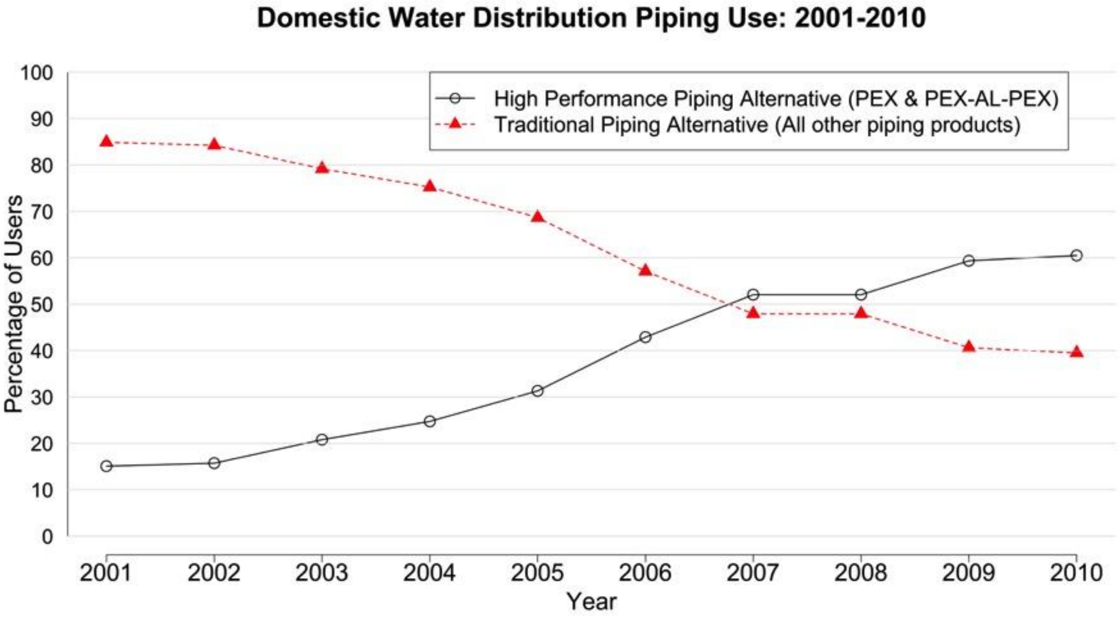
[5] This general model is deployed for each of the high performance technologies to be analyzed. Each technology is analyzed in the context of its economic substitutes and not among its economic complements as part of a cumulative choice to use model.

Reflecting the precedent set in Koebel et al. (2013) and Sanderford et al. (2013) and the broader econometrics literature, this paper analyzed time as both a continuous variable and as a dummy variable. Both specifications of time are examined to make certain that any effects are adequately described. This approach is substantively different from the most recent similar paper (Kok et al. (2011)) where time was modeled as part of the dependent variable—the change in the ratio of eco-labeled buildings from year to year.

From within the BPS, the team gathered the Firm characteristics. These characteristics included firm size (using number of houses built annually as a proxy), and organizational capacity based on diversity of operations spanning residential building types that include multi-family housing. Product characteristics include the per unit price of the high performance technology, a ratio of the cost of the high performance technology to the cost of the less efficient substitute.[6] Additionally, Firm characteristics include measures of the firm's average housing unit size and average sales price.



Based on the Census' County Business Patterns data for 2002, 2006, and 2010, the team included Industry characteristics noted in the residential construction literature such as concentration, supply chain, subcontractor networks, and efficiency. Based on the dependent variable, the authors substitute different sub-contractor specialties. For example, Siding and Framing Contractors were used in Koebel's windows model. Relative to the Piping model here, the authors will replace the Siding Contractors with Plumbing Contractors (and use the appropriate sub-contractor for each of the remaining technologies). To ensure appropriate alignment of the sub-contractor specialty with the dependent variable, we crosschecked the North American Industry Classification System (NAICS) codes with the tasks performed under each code.

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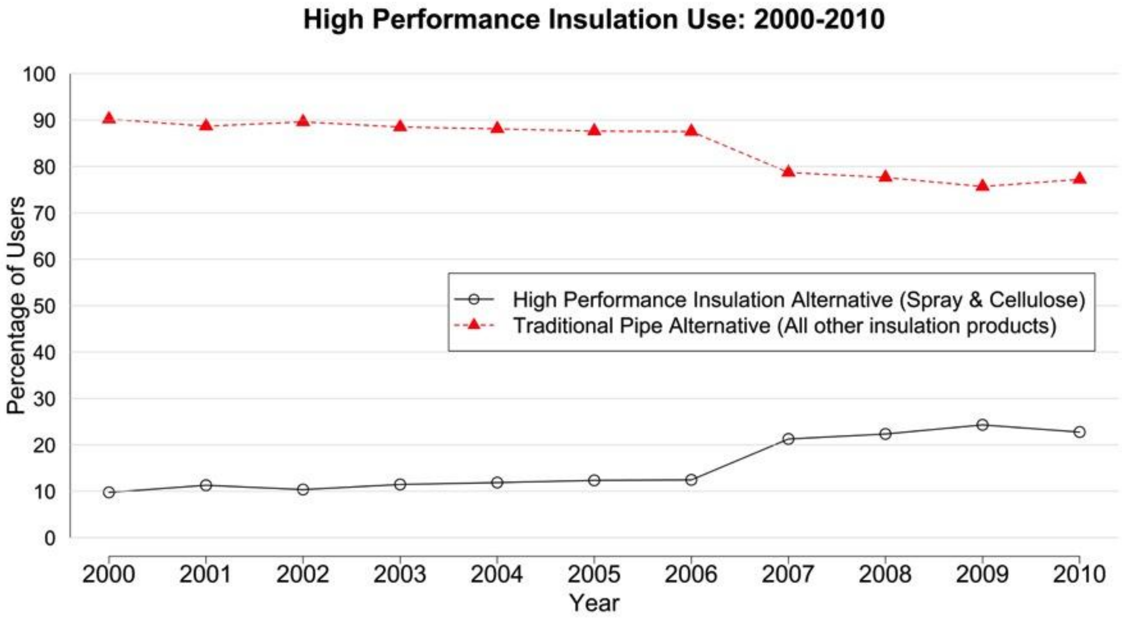
[6] This ratio variable should be considered a relative advantage of cost indicator. A value of 1 would indicate price parity between the high performance and less efficient options. A value greater than 1 would indicate that the high performance product is more expensive than its substitute.

Drawn from the US Census' Summary Files, market area characteristics include CBSA level measures for population size, income and wealth (median income and median house value), density of housing units per square mile, and location within a network of market areas as an indicator of the potential for contagion effects—a distance decay function described in McCoy et al. (2013). Public policy measures captured the funds expended through the American Reinvestment and Recovery Act (state level), green building certifications, utility rebates, state grants, and a variety of other state and local incentives for energy efficiency. Based on the broader housing and taxation literature, the models in this paper also include state sales tax and other related business costs (e.g., workman's compensation premium rates). Additionally, the models contain a variable that measures the average cost of construction by CBSA.

Climate is modeled in this paper as the thirty-year average of the respondents' state heating and cooling degree-days both independently and also as an interaction. Across most of the energy efficiency and building performance literature (e.g., Kok et al. 2011), climate is a substantial factor that helps explain the geographic variation in the diffusion of green building rating systems and building technologies.



Anticipated Results

Based on the findings from the papers used to guide the formation of these models, the team anticipates the following associations between predictor and response variables. The expectation is that each of the models will present coefficients with similar signs to those found in Koebel et al. (2013). Where noted in a separate color, we expect the coefficient signs to align more closely with Sanderford et al. (2013). With respect to the GDP variable, we expect that the adoption patterns of these technologies will more closely track the broader green real estate and construction literature that tends to show positive associations between economic output factors and green durable goods.

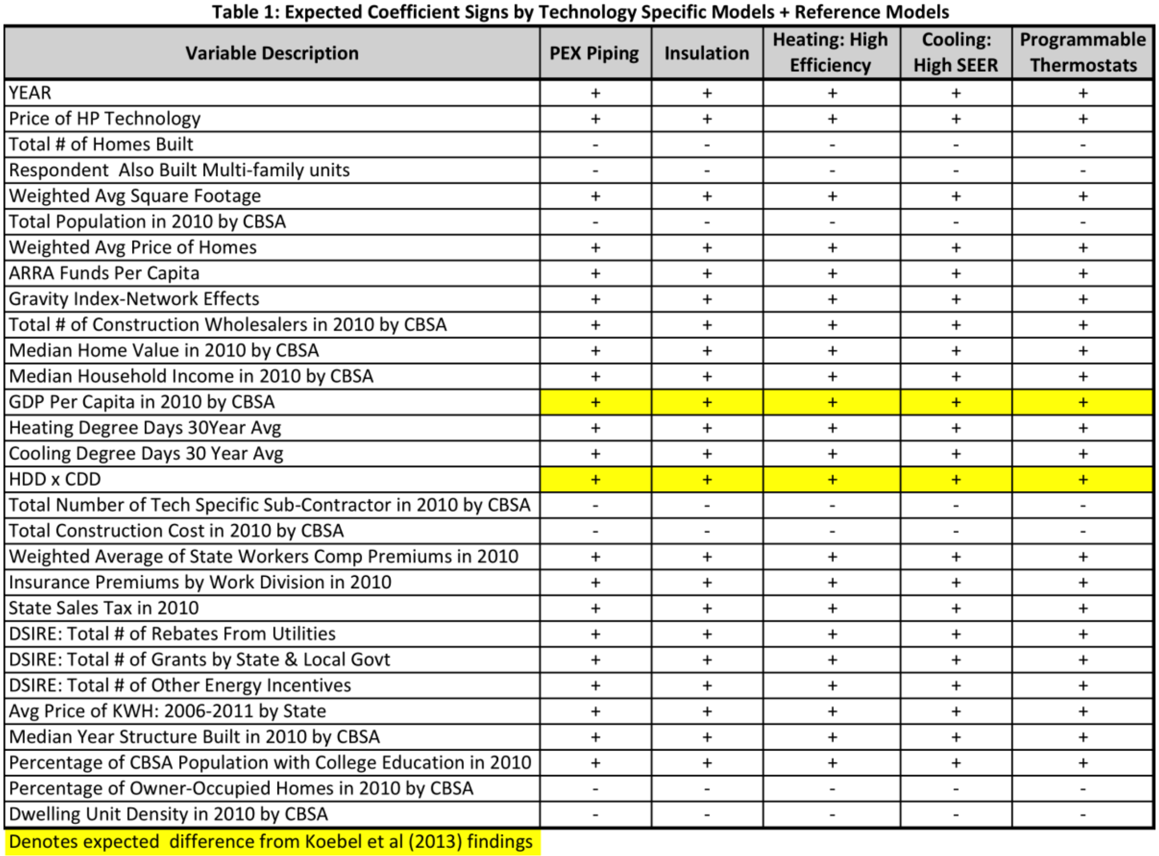


Table 1: Expected Coefficient Signs by Technology Specific Models + Reference Models

Variable Description	PEX Piping	Insulation	Heating: High Efficiency	Cooling: High SEER	Programmable Thermostats
YEAR	+	+	+	+	+
Price of HP Technology	+	+	+	+	+
Total # of Homes Built	-	-	-	-	-
Respondent Also Built Multi-family units	-	-	-	-	-
Weighted Avg Square Footage	+	+	+	+	+
Total Population in 2010 by CBSA	-	-	-	-	-
Weighted Avg Price of Homes	+	+	+	+	+
ARRA Funds Per Capita	+	+	+	+	+
Gravity Index-Network Effects	+	+	+	+	+
Total # of Construction Wholesalers in 2010 by CBSA	+	+	+	+	+
Median Home Value in 2010 by CBSA	+	+	+	+	+
Median Household Income in 2010 by CBSA	+	+	+	+	+
GDP Per Capita in 2010 by CBSA	+	+	+	+	+
Heating Degree Days 30Year Avg	+	+	+	+	+
Cooling Degree Days 30 Year Avg	+	+	+	+	+
HDD x CDD	+	+	+	+	+
Total Number of Tech Specific Sub-Contractor in 2010 by CBSA	-	-	-	-	-
Total Construction Cost in 2010 by CBSA	-	-	-	-	-
Weighted Average of State Workers Comp Premiums in 2010	+	+	+	+	+
Insurance Premiums by Work Division in 2010	+	+	+	+	+
State Sales Tax in 2010	+	+	+	+	+
DSIRE: Total # of Rebates From Utilities	+	+	+	+	+
DSIRE: Total # of Grants by State & Local Govt	+	+	+	+	+
DSIRE: Total # of Other Energy Incentives	+	+	+	+	+
Avg Price of KWH: 2006-2011 by State	+	+	+	+	+
Median Year Structure Built in 2010 by CBSA	+	+	+	+	+
Percentage of CBSA Population with College Education in 2010	+	+	+	+	+
Percentage of Owner-Occupied Homes in 2010 by CBSA	-	-	-	-	-
Dwelling Unit Density in 2010 by CBSA	-	-	-	-	-

Denotes expected difference from Koebel et al (2013) findings

With respect to the climate interaction variable, the expectation is that as the climate in a State is more diverse and variable, the more likely a builder is to adopt any of these technologies. There is the complicating factor of whether or not the interaction will be significant or not. Where it was in Sanderford et al. (2013), it required the authors to discard the main effects of the individual variables.

Builders As Innovators

Based on research produced over the last ten years, it appears that the idea of the builder lagging behind others in the housing creation chain is losing its luster. Instead of considering builders as innovation laggards, researchers are able to 1) use increasingly more robust data to analyze around the decisions builders make about the choice to adopt innovative technologies, 2) deploy best data management practices and analytical methods in processing this data, and 3) see more clearly the continuous innovations that have been made in individual products assembled by the builder. So, where scholars can ask new questions of new data, it appears that they are finding that builders are not necessarily innovation laggards—especially with respect to green and energy efficient technologies. Instead, one theme that appears to have emerged from building construction innovation is the builder as a selective risk taker. As the builder is an assembler of various components, they are a rather different agent than typically analyzed in information technology or other areas of innovation research. The builder as the assembler is not responsible for creating the innovations but rather identifying and safely combining innovations that work together in systems to meet the needs of the occupant/buyer. These are influenced by market conditions, the availability of credit, qualified appraisers, climate, and a number of other complicating risk factors. Where innovations such as green certifications have been shown to reduce some of the market and performance risks in housing, we see builders moving towards these innovations. So, the builder as an innovation laggard may, at one time, have been a useful paradigm for the construction industry. However, where this paradigm often paints all builders with a broad brush, we find evidence that in some cases, builders are using more innovative products than traditional products (Koebel et al. 2013). In fact, as building science scholars adapt best research practices from their counterparts in information technology (e.g., patent analysis—see (Altwies and Nemet 2012; Johnstone et al. 2010; Johnstone et al. 2012), the prevailing notion of the builder as laggard may begin to crumble.

Next Steps and Limitations of Approach

The next steps for this project are to conduct the logistic regressions described above and to interpret the results. Differences between the model findings will be of significant interest as will differences between the model findings and those from Koebel et al. (2013). These differences will be of significant interest as the general model used here was adopted based on the model selection outcome from Koebel et al. (2013) where seven candidate models were pitted against one another using a 'least absolute shrinkage and selection operator' (LASSO) protocol. LASSO is an analytical technique that shrinks some coefficients in a regression model and sets others to zero in an attempt to retain the good features of both subset selection and ridge regression (Tibshirani 1996). Koebel et al. used the LASSO technique as part of their cross validation strategy and to select the most competitive diffusion model. In lieu of replicating the cross validation and LASSO processes, we have adopted Koebel's model specification here as it represents the most advanced model within the extant literature. While we have no reason to suspect that this model specification is incomplete as it has been rigorously tested and aligns with Rogers' classic diffusion indicators, we remain cognizant that the Koebel's model was specified on high performance window data. To the extent that the products analyzed in this paper are different with respect to adoption and diffusion, these differences could create the possibility for mis- or under-specification.

Two additional limitations of the approach taken here are 1) the embedded researcher bias in selecting the green and energy efficient technologies and 2) the degree of subjectivity about which products do and do not meet a definition of high performance. With respect to the first limitation, we selected the technologies analyzed here based on a review of the frequency and reliability of their response patterns. Further, each of these technologies was selected because of its growth in adoption over time. For example, we did not include a model analyzing the factors associated with Structural Insulated Panels (SIPS) on account of that product's flat adoption trajectory (growth from 0-3% and sustained use at the upper end of that range over the study period). Each of the technologies analyzed here exhibited an adoption trajectory that moved from a small initial value to a significantly larger value by the end of the study period. Further research will examine innovative products that have market trajectories akin to SIPS. However, for the sake of brevity we will address that analysis in a separate paper. With respect to the second limitation, we relied on previous methodologies and subject area expertise from the building scientist on our research team to help attenuate risk. The most recent methodology for selecting technologies based on the traditional-high performance distinction, we adapted Koebel et al.'s model focused on windows where the window's ability to moderate the tightness of the building envelope and reduce heat transfer were the characteristics of most importance. Where we could select technologies based on their ability to reduce air infiltration or reduce heat transfer we chose products with the most advanced scores, ratings, and characteristics. Where we couldn't, the decision focused on the upper end of a performance range. For example, airconditioning units with a 13 or higher Seasonal Energy Efficiency Ratio (SEER) rating as high performance while all SEER ratings 12.9 and below were considered to be traditional alternative.

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