



Original research article

Economic, sociological, and neighbor dimensions of energy efficiency adoption behaviors: Evidence from the U.S residential heating and air conditioning market



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ABSTRACT

This study identifies factors that affect the adoption behavior for residential Heating, Ventilating, and Air Conditioning (HVAC) systems, including a spatial and temporal contagion effect, house characteristics, and other economic and contextual factors. The study draws on a dataset of house sale records in the greater Chicago area, spanning 1992–2004. First-differenced models and restricting the sample to new construction allow separate identification of adoption determinants for homeowners and for developers, respectively. We show that attributes of the building stock and demographics influence adoption decisions of both homeowners and developers. This includes a strong influence of square footage, a modest spatial clustering effect for existing homes, a consistent deterrent effect of higher property tax rates, and a positive influence of neighborhood education levels. Adoption decisions for existing homeowners appear to be driven by different factors than sellers of newly constructed homes. Adoption coincided with multi-story homes for developers, and neighbor adoption rates predicted adoption by existing homeowners but not developers. The results highlight the need for more research into the social context of energy efficiency investment.

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1. Introduction

Demand for energy and pressures to reduce carbon dioxide emissions continue to grow. Instead of increasing energy supply to meet demand, many recommend improving energy efficiency. [29] review a cost-effective collection of energy efficiency programs that could reduce energy consumption in buildings by 12 percent. In this sense, energy efficiency can be viewed as a source of supply of energy resources [57]. Moreover, Heating, Ventilation, and Air Conditioning (HVAC) consume nearly one-third of building energy end-use, making this the largest end-use among all residential energy consumption activities [42]. Thus, if the goal is to reduce residential energy consumption by improving energy efficiency, HVACs should be a top priority. As residential use accounts for 20–30% of total energy demand globally [25] and rapidly increasing electricity consumption around the world

follows higher economic status [21], better understanding the human and social aspects of residential energy efficiency poses a challenge to energy-intensive economies and those rapidly intensifying.

A growing volume of research demonstrates the benefits of adopting energy-efficient or zoned HVACs, with engineers concluding that substantial energy savings can be achieved through zoned systems [9,47,58,50,4]. Zoned HVAC systems allow the consumer to set different temperatures for different parts of the house and reduce energy consumption when a room is unoccupied, similar to turning off lights when leaving a room. It is generally accepted that zoned HVAC systems can substantially reduce the 39 percent of HVAC energy costs that do not add to increased comfort [50]. [4] report reductions in energy consumption exceeding 50 percent for zoned HVAC systems and simulate a 65 percent energy cost savings for a typical residential building in Des Moines, Iowa. [47] find similar simulated savings. While our data do not measure energy consumption or savings in individual houses, understanding the factors that drive technological adoption and choices about housing characteristics can inform our understanding of the energy efficiency gap and households' indirect effects on energy consumption [25].

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Research focusing on the adoption behavior for these systems, however, is relatively limited. Evidence indicates that adopting energy efficient technologies benefits homeowners, but homeowners frequently forgo the adoption of cost-effective technologies, creating an energy efficiency “paradox” or “gap” [1,34,38]. Factors affecting homeowners’ decision-making—either the possible motivations or barriers to the adoption of energy efficient HVACs—merit additional research [2]. From a policy perspective, an improved understanding of adoption behavior enables better policies to enhance the diffusion of energy-efficient HVACs or lower the barriers to adoption. Higher energy prices, for example, should result in more energy-efficient HVAC adoption. Yet prices are not consumers’ sole consideration, and they cannot explain the variation in adoption behavior among homeowners in the same market, facing identical energy prices and building codes. Identifying the determinants of adoption can guide the design of appropriate policies to stimulate the diffusion of energy-efficient HVACs.

This study offers several contributions to the literature regarding energy efficiency technology adoption behavior. First, we use market data on major investments at the house level. This represents an improvement over many existing studies, which typically rely on potentially biased survey [66] or aggregated data. Second, this study allows for spatio-temporal spillovers in household behavior, which measures the diffusion of technology change. Third, this study adds new empirical tests of the relationships between the factors expected to impact HVAC adoptions and observed adoptions. This study also contributes to Estiri [25] new approach to understanding residential energy use by providing more evidence about housing choice behaviors that impact energy consumption.

In addition to identifying the relationships between HVAC adoption and microeconomic determinants that ought to affect HVAC adoption (e.g., tax rates, age of the house, size of the house), suggestive evidence about a “spatial contagion” is offered. That is, our model construction allows us to test for peer effects and the impact that energy efficient technology adoption behavior at the house level has on nearby house adoption behavior. Policymakers and economists appear increasingly interested in the diffusion of energy-efficient technologies among houses. Early adopters can influence later adopters through sharing knowledge, “keeping up with the Joneses” copycatting, “green signaling,” “competitive altruism,” or “conspicuous conservation” [60]. We examine a spatial contagion effect for HVAC technology adoption in a large panel dataset of home sales that reveal housing choices across the Chicago suburbs.

The empirical analysis here directly addresses the shortcomings of the “physical-technical-economic model” (PTEM) of energy efficiency adoption, with its “very little consideration of social systems, consumers as social actors, or other non-engineering/non-economic social considerations” [46], 143. We explicitly introduce neighborhood effects and allowing for more heterogeneity by decision-makers, all while controlling for many PTEM concerns either by explicit controls (e.g., structural characteristics) or by holding those conditions fixed within the data (e.g., climate, regional policies). Broadening the adoption model to include factors beyond financial attributes like technology costs and energy prices lends insight into the contextual factors as well as more rarely analyzed personal influences [66] and peer effects [48].

2. Background

2.1. Related Work

An “energy efficiency gap,” where decision-makers forgo seemingly cost-effective energy efficiency technologies, has recently

attracted renewed interest by economists [30]. Economists have raised concerns that engineering estimates of energy efficiency overstate real-world gains, in part, by overlooking behavioral components (e.g. [1,37,12,49,31,38]). The question of who adopts efficiency technologies remains critical. A handful of recent studies have explored these questions with respect to household technologies, both large [41,49,39] and small [51]. Nevertheless, investigations of single-family household-level adoption behavior for energy efficient large appliances like HVAC systems remain rare.

To date, studies that focus on homeowners’ adoption of zoned HVAC systems are limited. The handful of studies addressing homeowners’ adoption of energy-efficient heating and cooling systems tend to use case studies (e.g., [52] or surveys (e.g., [53,54]. Niemeyer [54] survey of 800 households in Nebraska finds variables that impact adoption choices such as knowledge of existing technologies, budget constraints, obstacles to making changes, demographics, and attitudes. [53] survey 3000 Swedish homeowners to discover that personal attributes, such as income and education, and contextual factors, such as age of the house and perceived energy cost, influence homeowners’ choices regarding energy efficiency improvements (which could include major investments like new heating systems). Of course, increases in resale price [20] might also motivate adoption. Wilson et al. [66] lengthier review of the literature modeling renovation decisions highlights the dominance of choice experiments and surveys. Our analysis of actual market data complements this previous household-level adoption literature.

In a broader context, our work stems from [32] work on technology diffusion theory, which has received recent attention in green building and other energy efficiency technology adoption studies. [36] show considerable evidence of a powerful “keeping up with the Joneses” effect in home maintenance decisions. More recently, [35] finds evidence of neighborhood effects in residential renovations. Kahn and Vaughn [41] discuss the idea of contagion among neighbors’ hybrid vehicle purchases, and work by [15] and others (see, e.g., [2,60] frequently point to social pressure involved in energy consumption decisions. The influence of neighbor characteristics is also evident in Dastrup et al. [17], who identify larger price premiums for homes with solar panels in communities with high education levels. Keeping up with the Joneses may include major decisions like upgrading HVAC systems, although these interior investments are not as visible as the distinctive Prius or exterior solar paneling. Network effects, via personal communication among neighbors or shared real estate agents or contractors, may promote information sharing, increased demand, and diffusion of new technologies [27,5,6].¹ Social interaction can promote energy efficiency improvements as recently shown with survey data [62] and simulations [48].

The emerging literature on green building diffusion demonstrates similar trends. [43] analyze the metropolitan-level diffusion of green building certifications. Professional networks predict more adoptions [43], and local policies that require green building certification promote networks that generate positive spillovers to neighboring cities [61,14]. [11] find significant effects of neighborhood-level characteristics rather than buildings’ thermal characteristics (e.g., insulation) in predicting household participation in an energy efficiency certification program. Dastrup et al. [17]

¹ In addition, economic circumstances of some neighbors that lead to adoption may also attract localized efforts to market the technology to others in the neighborhood. This economic development spillover, in Galster’s terms, functions equivalently to a social network effect although it does not require direct ties between neighbors but rather a more indirect spillover of merely attracting businesses to the area.

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