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Forecasting the adoption of residential ductless heat pumps

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ABSTRACT

Energy-efficient technologies have the potential to provide savings to households and utilities, but consumers do not always adopt these innovations over traditional technologies. The ductless heat pump (DHP) is one such technology designed to increase energy efficiency and comfort in space conditioning. DHP adoption by single-family residences in the Pacific Northwest of the United States is investigated by quantifying the effects of utility-provided rebates and expenditures on activities such as advertising and installer training on the number of installations and forecasting installations through 2018. The number of installations is elastic with respect to net installation costs and inelastic with respect to expenditures. Given the proposed rebate budgets, doubling the current rebate is necessary to maximize installations through 2018.

1. Introduction

Some of today's energy-efficient appliances consume less than half the energy consumed by their predecessors (National Resources Defense Council, 2010). Ductless heat pumps (DHPs), developed in the 1970s in Japan, offer increased efficiency in heating and cooling homes (Swift and Meyer, 2010). A ductless system is comprised of an outdoor and an indoor unit to distribute air for both cooling and heating. A line running between the two units requires only a three-inch hole and eliminates the need for expansive ductwork (Northwest Ductless Heat Pump Project., 2014). Unlike other types of heat pumps, DHPs are relatively easy and inexpensive to install (Sutherland, 2012). Benefits of DHPs to homeowners include increased comfort, a reduction in electricity consumption, the ability to heat and cool with a single appliance, relatively low-cost installation, and potential financial incentives for installation, including federal and state income tax credits and utility-provided rebates (Northwest Ductless Heat Pump Project., 2014). Swift and Meyer (2010) and Bugbee and Swift (2013) note almost all residential heating, ventilation, and air conditioning (HVAC) systems in Asia and the majority of those in Europe are ductless, but DHPs represent less than 1% of HVAC systems in the United States. Awareness of DHP technology in the United States has increased since 2006 when redesigned, more efficient, and advanced-controlled ductless technologies were made available (Storm et al., 2012).

The Northwest Ductless Heat Pump Project (NWDHPP), a collaboration between the Northwest Energy Efficiency Alliance (NEEA) and its utility and energy partners, was established in 2008 to accelerate DHP installations in electricity-heated homes in the Pacific Northwest of the United States (NEEA, 2013; NWDHPP, 2012). NEEA (2013) estimates the 13,000 DHPs installed in the Northwest through 2011 saved 40.5 million kilowatt hours of electricity per year. These savings represent 9% of the potential regional savings estimated by Cooney et al. (2008). This research aims to increase the understanding of DHP adoption in the Pacific Northwest of the United States by quantifying the effect of utility-provided rebates and NEEA expenditures on the number of installations and providing forecasts of DHP installations through 2018 given various rebate and NEEA expenditure levels. Because DHPs were introduced relatively recently into the regional market for residential HVAC systems, the adoption of innovation theory is applied.

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2. Literature review

2.1. Energy-efficient technologies and consumers

Vast amounts of public and private capital have been used to advocate energy efficiency. Despite the many energy-efficient appliances available to today's consumers, studies show that consumers do not always adopt the economically feasible set of durables (Gates, 1983; Howarth and Andersson, 1993; Howarth and Sanstad, 1995). Energy-efficient innovations' up-front costs, including the costs of information and of the good itself, are relatively high compared to those of conventional technologies (Howarth and Sanstad, 1995). Gates (1983) argues that even though the returns for conservation investments such as setting back the thermostat, weather stripping, caulking, and adding insulation may exceed the returns of financial instruments, consumers still do not invest in energy-efficiency. Howarth and Sanstad (1995) and Gates (1983) both believe that energy-efficient technologies' low rates of adoption are the result of consumers' relatively high discount rates. A high discount rate may be evidence of the high cost of information or perceived risk of investment in these technologies.

Income and lack of knowledge of household energy consumption are barriers to compact fluorescent light (CFL) adoption (Mills and Schleich, 2010). Panzone (2013) estimates the demand for refrigerators, washing machines, televisions and light bulbs using Deaton and Muellbauer's (1980) Almost Ideal Demand System (AIDS) and draws four major conclusions. First, the influence of own-price on purchases of energy-efficient appliances depends of the possibility of behavioral adjustments associated with the good. In addition, current energy prices may not be driving adoption as much as theory suggests. Next, energy-efficient appliances are perceived as necessities. Finally, consumers may value the good's efficiency less than they value other attributes. His final conclusion supports Mills and Rosenfeld's (1996) findings non-energy benefits often motivate consumers to adopt an energy-efficient technology. Two non-energy benefits of CFLs and light-emitting diodes, for example, are their reduced heat generation and longer lives. As another example, insulated windowpanes offer more comfort than non-insulated windows. Further, consumers may adopt energy-saving technologies for a “warm-glow” feeling of promoting energy and environmental conservation. Examining the effect of residential HVAC systems characteristics on the homeowner's adoption decision, Michelsen and Madlener (2012) find the system's attributes are more relevant to owners of newly-built homes than to owners of existing homes.

Lund (2006), employing a methodology related to our own, estimates the diffusion of new energy technologies. Using international data on twenty technologies, he finds the time required for new energy technologies to reach at least 50% of their market potential ranges between 10 and 70 years. End-use and energy-saving consumer goods, on average, take less than 25 years to reach this level. Shorter times are indicative of a good's relatively high impact on energy production or consumption. Traditional, non-ductless heat pumps, for example, are estimated to take between 35 and 65 years to attain 50% of their market potential in three European countries. Lund (2006) also finds countries with subsidized energy-efficiency programs, other things equal, had higher penetration rates for the technologies relative to other countries.

The importance of financial incentives to potential adopters of energy-efficient goods has been the subject of several other studies. Using a choice experiment, Aalbers et al. (2009) find that a subsidy may entice firm managers to adopt a technology even if the subsidy is too small to make the technology profitable. It may be that “… the presence of a subsidy invokes a positive connotation… [that] may carry enough weight in an agent's decision making to tip the balance in favor of the subsidized technology” (Aalbers et al., 2009, p. 439). Wasi and Carson (2013) examine the role of rebates in shifting the percentage of electric water heaters to climate-friendly units in New South Wales, Australia. The rebate program increases the number of climate-friendly heaters in homes without access to natural gas. Murray and Mills (2011) conclude that the effect of rebates offered for certain Energy Star technologies as part of the American Recovery and Reinvestment Act of 2009 is indeterminate and the widely-available rebates were quickly exhausted. Instead, rebates that target the marginal consumer would have had more of an impact on purchases of energy-efficient goods. Rebate policies, however, “… may also encourage large-scale purchasing of energy-efficient appliances, which may finally result in an increase in electricity consumption (rebound effect)” (Galarraga, Abadie, and Ansuategi, 2013, p. S98).

Many studies have examined consumers' investments in energy-efficient technologies, but few have studied the market-level adoption of these goods. Several studies have examined DHPs, but the majority of studies has been engineering-oriented; see, for example, Francisco et al. (2004), Şahin et al. (2011), and Stecher and Allison (2012). Cooney et al. (2008) note that regional electricity providers are seeking to meet a greater portion of load growth through energy efficiency. They suggest DHPs have achievable savings of upwards of 438 million kilowatt hours per year for the Pacific Northwest of the United States, but at the time of their publication, there were few installers with knowledge of the product. Based on 144 installed DHPs in a pilot study in Connecticut and Massachusetts, annual household energy savings of approximately $400 are reported (Cooney et al., 2008). Storm et al. (2012) discuss a pilot program developed by NEEA which was the precursor to the NWDHPP. This pilot program successfully increased consumers' awareness and interest in DHPs. Through supplier training and distribution networks, NEEA also improved the supply-side of the market. Overall, Storm et al., (2012, p. 2–304) conclude DHPs are “… an important and transformational technology.”

2.2. Literature on adoption models

Because DHPs were introduced relatively recently into the Northwest regional market for residential heating, the adoption of innovation theory is applied. Models of innovation adoption have a common root in the sociological work of Rogers (1962), who identifies four elements of the diffusion process: innovation, communication channels, time, and the social system. Theory and empirical work show the adoption profile, a plot of cumulative adopters over time, is sigmoid-shaped. Diffusion depends on social and economic factors that vary over time and among different groups of potential adopters. Rogers' (1962) original model imposes a normal distribution upon the time of adoption across consumers described as either innovators, early adopters, early majority, late majority, or laggards.

Models of innovation adoption have extended Rogers' (1962) pioneering work. One of the first mathematical extensions of the adoption model is Bass (1969). In this model, the instantaneous rate of adoption f at time t is given by the differential equation

$$f(t) = [\alpha + \beta F(t)][1 - F(t)], \tag{1}$$

where α is the coefficient of innovation, β is the coefficient of imitation, and F is the proportion of all adopters who have adopted by time t. The coefficient of innovation gives the probability of purchase when t is zero and captures the innovativeness of potential adopters. The coefficient of imitation “…reflects the pressure operating on imitators as the number of previous buyers increases” (Bass, 1969, p. 216).

Empirical work using the Bass (1969) model finds that adoption is explained well without any other variables. The model has been used effectively in the retail, industrial, and agricultural sectors (Bass et al., 1994). Extensions of Bass' basic model allow for the inclusion of explanatory variables intended to improve managers' marketing decisions related to influencing either the rate of adoption or market potential. Jain and Rao (1990) and Fernandez (1999) allow the adoption curve to be shifted by a vector of exogenous variables and also estimate demand elasticities.