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Durable goods and long-run electricity demand: Evidence from air conditioner purchase behavior

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ABSTRACT

I estimate a dynamic structural model of demand for air conditioners, the most energy-intensive home appliance in the US. The model explores the links between demand for durable goods and expected changes in key attributes: energy efficiency and price. I incorporate expectations explicitly as a feature of the choice setting, and use parameter estimates from the model to calculate durable good demand elasticities with respect to energy efficiency, electricity price, and price of the durable itself. These estimates fill a large gap in the literature, and also shed light on consumer behavior in this setting. Results indicate that consumers are forward-looking and value the stream of future savings derived from energy efficiency.

Introduction

Dynamic considerations are important in a variety of decision contexts relating to the environment. Depletion of common-pool resources, extraction of non-renewable resources, and stock externalities are just a few of the most vivid examples where actions taken today alter tomorrow's state variables and choice set, with environmental consequences.[1] An extensive literature explores economic efficiency and optimal policy in these settings, yet in only rare instances are dynamic elements of decisions explicitly built into empirical models of consumer choice. In this paper I estimate a dynamic discrete choice model of the demand for air conditioners, the most energy-intensive home durable good in the United States and a major contributor to residential sector carbon emissions. The model explicitly allows for different behavioral hypotheses with respect to the nature of consumer expectations. The underlying rationale for using such a model is that consumers do not simply choose *whether or not* to purchase an energy-efficient durable, but also *when* to do so.[2] A main result of this study is that, after accounting for this feature of consumer behavior, the data fit more closely with a model of forward-looking rationality than with myopia or naïve expectations.[3]

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[1] For classic references, see Gordon (1954) on common pool resources, Hotelling (1931) on natural resource extraction, and Keeler et al. (1972) on optimal pollution control. Each spawned a long literature, recent contributions to which include Smith et al. (2009) on fisheries, Lin (2013) on dynamics of oil extraction, and Nordhaus (1991) and Falk and Mendelsohn (1993) on optimal abatement paths.

[2] Jaffe and Stavins (1995) emphasize this distinction in a model of energy-efficient technology diffusion, and it is a key feature of a large body of dynamic discrete models used in Industrial Organization, beginning with Rust (1987).

[3] Under "myopia", consumers fully discount future utility, whereas naïve expectations imply that the current value of key attributes is also the expected future value.

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The purpose of this paper is in part to advocate for the inclusion of dynamic discrete choice methods in the empirical toolkit for applied environmental economists. In addition, the application itself is relevant today given the urgent focus on choosing between environmental policy instruments to combat global climate change. With most energy-consuming durables, the full social cost of use is not internalized by the user. External costs of energy use include the harm generated from carbon emissions (climate change) and criteria pollutants (health effects of poor ambient air quality).[4] A common recommendation among economists is to impose a Pigouvian tax that aligns private and public costs. However, for reasons unrelated to economic efficiency, regulators are slow to embrace this solution. Instead, energy efficiency standards have been the most common tool that policy-makers use to reduce the external cost of energy use. It is thus reasonable to seek to quantify the extent to which these standards achieve their intended effect. As a first step to understanding whether efficiency standards reduce energy usage (a necessary but not sufficient condition for economic efficiency), one must understand how consumer demand responds to changes in energy efficiency, the relevant product attribute.

In the model, fully informed and rational consumers form expectations about future changes in key product attributes (e.g. energy efficiency and price), and time their purchases in order to maximize the present value of the associated stream of net benefits. During the period studied here (1987–2005), room air conditioners became 23 percent more efficient and 49 percent less expensive from 1987 to 2005, while central units became 27 percent more efficient and, depending on their size, between 14 and 49 percent less expensive. The dynamic framework encapsulates intensity-of-use (and the future stream of production costs that it implies) that varies with energy efficiency and energy prices. The model builds on dynamic discrete choice literature, drawing primarily on Rust (1987).[5] Rust estimates the optimal replacement timing of bus engines, a decision that has several similarities to the timing of consumer durable good purchases. I use a repeated cross section of appliance purchase decisions which classifies air conditioners into vintages. The model is then extended to incorporate a wide gamut of observed consumer heterogeneity. Individual level data on demand makes the empirical approach similar to Goldberg (1995), extended to include dynamic considerations.

I use structural parameter estimates from the model to calculate a variety of policy-relevant summary statistics, including the long-run elasticities of demand for air conditioners with respect to durable price, energy efficiency, and the price of electricity. In this and other environmental settings, estimates of these statistics help us to alleviate a scarcity in the empirical literature. The structural parameters are also then used to simulate the model forward under different assumptions about state variable transitions. In other words, I simulate policy counterfactuals which allow for predictions of environmental policy effectiveness. The counterfactuals reflect a Pigouvian tax, increases in average energy efficiency, and a durable good subsidy.[6]

I also use the model to generate suggestive evidence about the nature of inter-temporal consumer preferences. The discount rate is non-parametrically unidentified (Magnac and Thesmar, 2002), making it impossible to reliably estimate directly. However, one may compare model fit under various specifications as evidence of forward-looking behavior, which I do by comparing information criteria (AIC and BIC). I estimate the model under three behavioral hypotheses relating to consumer expectations over the paths of dynamic state variables (energy efficiency and AC unit prices). The *rational expectations* hypothesis assumes that consumers generate expectations over these variables that are ex post correct. At the opposite end of the dynamic behavior spectrum is the *myopic* consumer, who exhibits an infinite discount rate. Finally, the intermediate case modeled here is that of *naïve expectations*, under which consumers expect dynamic state variables to follow a random walk. These are admittedly extreme versions of the behavioral possibilities.

This study has five main qualitative findings. First, the model provides evidence that behavior governed by rational expectations fits the data better than behavior under the alternatives (myopic and naïve expectations). The difference in model fit is equivalent to roughly seven additional degrees of freedom. Second, consumers generally exhibit more elastic demand with respect to energy efficiency than with respect to either the durable price or the price of electricity. This is true for central AC units without exception, whereas efficiency-elasticity for room AC units is roughly the same as the electricity price elasticity in the short run. While economic theory dictates that consumers should respond symmetrically to changes in energy efficiency and electricity prices, I allow these effects to differ in the model. This is consistent with other energy demand studies[7] and is motivated by the observation that consumers actually appear to respond differently to economic incentives on these margins. Third, increases in the average energy efficiency of air conditioners raise air conditioner demand and lower overall energy consumption. Fourth, increased electricity prices lower current energy consumption but have a statistically weak negative effect on demand for air conditioner units. Fifth, lower air conditioner prices increase unit demand and slightly lower energy consumption because consumers replace old, inefficient units with newer, more efficient ones. Energy efficiency gains outweigh energy increases from first-time purchases and platform upgrades (from room to more energy-intensive central AC). These results are robust to a wide range of values of key parameter inputs.

Poor model fit under the myopia hypothesis combines with high estimates of the demand elasticity with respect to energy efficiency to suggest that consumers are forward-looking in the timing of their choice of durable. This deviates from

[4] There may also be information asymmetries leading to principal–agent problems, as estimated in Gillingham et al. (2012).

[5] A similar approach has been used in the environmental literature to examine fishing location choice (Provencher and Bishop, 1997; Smith, 2005).

[6] One might consider this study to be a demand-side analog to Jaffe and Stavins (1995), who examine dynamic supply-side response to these same policy alternatives. They make the reasonable assertion that the long-run development and adoption of energy efficient technologies is inextricably linked to the extent of environmental protection induced by policy.

[7] E.g. Hausman (1979) and Bento et al. (2009).