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Incorporating experience curves in appliance standards analysis

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HIGHLIGHTS

- Past appliance standards analyses have assumed constant equipment prices.
- There is considerable evidence of consistent real price declines.
- We incorporate experience curves for several large appliances into the analysis.
- The revised analyses demonstrate larger net present values of potential standards.
- The results imply that past standards analyses may have undervalued benefits.

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ABSTRACT

There exists considerable evidence that manufacturing costs and consumer prices of residential appliances have decreased in real terms over the last several decades. This phenomenon is generally attributable to manufacturing efficiency gained with cumulative experience producing a certain good, and is modeled by an empirical experience curve. The technical analyses conducted in support of U.S. energy conservation standards for residential appliances and commercial equipment have, until recently, assumed that manufacturing costs and retail prices remain constant during the projected 30-year analysis period. This assumption does not reflect real market price dynamics. Using price data from the Bureau of Labor Statistics, we present U.S. experience curves for room air conditioners, clothes dryers, central air conditioners, furnaces, and refrigerators and freezers. These experience curves were incorporated into recent energy conservation standards analyses for these products. Including experience curves increases the national consumer net present value of potential standard levels. In some cases a potential standard level exhibits a net benefit when considering experience, whereas without experience it exhibits a net cost. These results highlight the importance of modeling more representative market prices.

1. Introduction

The U.S. Department of Energy (DOE) develops energy conservation standards for residential appliances and commercial equipment.[1] Improved energy efficiency is generally assumed to increase initial purchase costs, but decrease operating costs. In support of any new proposed standard, DOE conducts an analysis of the consumer life-cycle costs (LCCs) and savings of a given product meeting the new standard, in addition to a national impact analysis (NIA) that calculates the economic and energy-savings impact on the nation over a 30-year time period. An important input to these calculations is the engineering analysis, which determines the incremental appliance purchase cost as a function of incremental energy efficiency improvement. As codified in the statute, standards may be promulgated if and only if they are shown to be technically feasible and economically justified. To date, these analyses have assumed that the manufacturing costs and retail prices of appliances and commercial equipment (hereafter referred to generally as "appliances") are fixed during the typical 30-year analysis period.

There is, however, considerable historical evidence of consistent declines in appliance prices. Dale et al. (2009) have noted that U.S. appliance efficiency regulation does not address trends in real market prices and energy efficiency improvements. They studied historical price trends of room air conditioners (ACs), central AC, refrigerators, and clothes washers, and had four major findings: (1) for the past several decades, the retail price of appliances has been steadily falling while efficiency has been increasing; (2) past retail price predictions made in the analyses of efficiency standards, assuming constant prices over time, have tended to overestimate retail prices; (3) the average incremental

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[1] http://www1.eere.energy.gov/buildings/appliance_standards/

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price to increase appliance efficiency has declined over time, and the analyses of efficiency standards have typically overestimated this incremental price and retail prices; and (4) changes in retail markups and economies of scale in production of more efficient appliances may have contributed to declines in prices of efficient appliances. This problem of not addressing real market prices is not limited to the U.S. Appliance standards and labeling programs in Australia, Japan, and Europe suffer from similar overestimations of the cost of increased efficiency (Ellis et al., 2007).

There is an extensive literature, applicable to a broad range of applications and industries, documenting how real production costs and prices of goods tend to fall in a relatively predictable way as cumulative production increases. This phenomenon is generally referred to as learning or experience. Wright (1936) pioneered the concept when studying the falling unit cost of aircraft production (a topic revisited by Alchian, 1963). Early applications continued to focus on manufacturing (Hirsh, 1952; Arrow, 1962), but since then the concept has been widely applied to such diverse products and services as semiconductors (Gruber, 1992), building envelopes (Jakob and Madlener, 2004), nuclear reactors (Joskow and Rozanski, 1979; Zimmerman, 1982), liquefied natural gas (Greaker and Sagen, 2008), solar photovoltaics (Masini and Frankl, 2002; van der Zwaan and Rabl, 2003; Nemet, 2006; van Benthem et al., 2008), wind power (Ibenholt, 2002; Junginger et al., 2005; Klaassen et al., 2005), renewable energy technologies (Neij, 1997; Papineau, 2006), energy generation technologies (Jamasb, 2007), and electric utility investments (Laitner and Sanstad, 2004). Management consulting firms have studied experience for a diverse set of clients and products (e.g., BCG, 1972, 1980). To date, however, the study of experience for appliances and commercial equipment has been limited (Bass, 1980; Newell, 2000; Laitner and Sanstad, 2004; Jardot et al., 2009; Weiss et al., 2010a,b). A thorough review of the extensive historical work on learning and experience, across many disciplines, is provided by Fusfeld (1973), Yelle (1979), Day and Montgomery (1983), Dutton and Thomas (1984), Argote and Epple (1990), Newell (2000), IEA (2000), McDonald and Schrattenholzer (2001), and Weiss et al. (2010a) (and references therein). In addition, Baumol (1967) and Baumol et al. (1985) established the framework of unbalanced growth in the economy, explaining why certain sectors of the economy may have distinct real price trends from other sectors.

The empirical phenomenon of falling prices is typically modeled by a learning curve or an experience curve, depending on the scope of the analysis and the nature and breadth of causal factors. Learning and experience curves are functions relating the cost of production to quantity produced (typically cumulative production). Learning curve analysis tends to focus more narrowly on relatively well-characterized and localized factors of production that result in price reductions of a single standardized product (e.g., learning by workers and management that reduces labor hours needed for production), while experience curve analysis focuses on entire industries (often operating globally) and aggregates over many causal factors that may not be well characterized. The two main causal factors typically associated with learning curves are labor-based learning and investment in new capital equipment (Dutton and Thomas, 1984). In its broadest sense, however, experience curve analysis implicitly includes factors such as efficiencies in labor, capital investment, automation, materials prices, and distribution at an industry-wide level (Newell, 2000). Since market competition is very effective, learning in one plant or firm rapidly diffuses to other firms as well, leading to industry-wide effects. Learning and experience curves have been empirically demonstrated at both the microeconomic and macroeconomic levels. It should be noted, however, that the literature seldom distinguishes between the use of these two terms, and they are often used interchangeably.

Various studies have examined the conditions under which experience (and learning) curve analysis could be used in support of policy to escalate commercialization of emerging technologies, and as a mechanism of assessment (IEA, 2000; Neij et al., 2003; van Benthem et al., 2008; Jamasb and Köhler, 2008; Ferioli et al., 2009). Experience is already incorporated into the Energy Information Administration's (EIA) National Energy Modeling System (NEMS; Newell, 2000), a model that is utilized for energy policy analysis. Some previous studies of energy-saving potentials achievable through standards have included modest experience parameters (e.g., Rosenquist et al., 2006).

There is therefore a potential bias in past estimates of the cost of efficiency for appliances. However, experience curves have recently been incorporated into the analysis of energy conservation standards for residential clothes dryers, room air conditioners, central air conditioners and heat pumps, furnaces, refrigerators and freezers (US Department of Energy, 2001a,b,c). In this paper, we describe how those experience curves were determined and how the standards analysis was modified to include them (Section 2), calculate the appropriate experience rates and the effects on the national net present value for these appliances (Section 3), and provide some discussion on the methodology and considerations for future analyses (Section 4). Finally, we summarize our results (Section 5).

2. Methodology and data sources

This section describes the methodology and data sources used to determine the experience curve and experience rates for recent DOE energy conservation standards. In addition, we describe how experience rates were incorporated into the existing analysis framework. For more details on data sources and methods used to determine experience, as well as a full description of the appliance standards analysis process, see the energy conservation standards Technical Support Documents (TSDs; US Department of Energy, 2001a–c).

2.1. Experience curves

The conventional functional relationship for both learning and experience is given by

$$P(X) = P_0\left(\frac{X}{X_0}\right)^{-b}, \tag{1}$$

where P_o is an initial price (or cost), b is a constant known as the experience rate parameter, X_o is the initial cumulative production, X is cumulative production, and P is the price as a function of cumulative production. The experience rate is defined as the fractional reduction in price/cost that results from each doubling in cumulative production,

$$ER = 1-2^{-b}. \tag{2}$$

For example, an experience rate of 0.25 implies a 25% cost reduction for each doubling of cumulative production.

Cumulative production is generally considered to be an appropriate proxy for knowledge accumulated. Production-driven models are generally better predictors of learning and experience effects than time-driven models (Newell, 2000; Bailey et al., 2012), since production-driven models implicitly account for variations in production resulting from macroeconomic conditions such as recessions. Despite these advantages, however, it is important to remember that cumulative production is a proxy measure for the underlying (and related) causal factors.