DO APPLIANCE EFFICIENCY STANDARDS REALLY SAVE ENERGY?

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INTRODUCTION

When Congress passed the National Energy Conservation Act of 1978 requiring the Department of Energy to promulgate energy-efficiency standards for household appliances, several authors (Khazzoom, 1980, RARG 1980) pointed out that standards on some products could actually increase energy consumption. They argued that raising the efficiency of appliances was equivalent to lowering the price of the energy they use, and lower prices result in higher consumption. Under some conditions this rebound effect could result in increased energy consumption after mandated standards. Their conclusion is based on a simple model of the demand for service provided by the appliance and on the price elasticity of energy demand being large. Unfortunately, DOE found that standards were not justified, and the point remained moot.

Last year Congress passed the National Appliance Energy Conservation Act (NAECA) which mandated standards on 11 types of consumer products. The Act also required DOE to consider new or amended standards for these and other products over the next twenty years. The question of increased energy use under the NAECA standards was raised once again. In this report, we examine the question from both a theoretical and an empirical point of view. First, we show that the simple service demand model is inadequate to accurately determine the rebound effect. Second, the measured energy demand elasticities are biased in such a way as to increase the predicted rebound. Finally, studies in which household insulation or comfort system efficiency is increased show that energy consumption does decrease and the rebound is small. We conclude that appliance efficiency standards *do* save energy.

It is important to point out that the rebound effect is in fact a measure of the benefit of appliance standards to the consumer. If consumers increase their energy use after installing a more efficient appliance, it means they are willing to trade-off the additional energy cost against the increased service provided by the appliance. The value of the additional service to the consumer is at least as great as the additional energy cost. The rebound effect thus is not an argument against mandated efficiency standards on economic grounds.

THEORETICAL CONSIDERATIONS

The underlying basis for the rebound effect is the relationship between e, the elasticity of demand for energy with respect to appliance efficiency, and η, the absolute value of the long-run price elasticity of demand. Khazzoom expresses this as

$$e = \eta - 1 .$$

In Equation (1), the "-1" term is the mechanical or engineering effect of an efficiency change. Thus η which is the magnitude of the rebound is equal to the long-run price elasticity of demand according to this theory. Note that if the price elasticity is greater than one, the efficiency elasticity e will be positive and energy consumption would increase after standards are imposed. Equation (1) can be derived from the assumption that service demand ($s = E/\epsilon$ = energy use divided by appliance efficiency) depends on energy price p and appliance efficiency ϵ only through their ratio p/ϵ. This ratio is the effective price of the service provided by the appliance, so the assumption is equivalent to assuming that service demand depends on the price of service and not on p and ϵ separately. The question of the validity of Equation (1) can be addressed by examining this assumption. The remainder of this section will point out several reasons for believing that the demand for services is a more complicated function of energy price and efficiency. A more detailed theoretical treatment can be found in Henly, *et al.* (1987).

In the long run, both the reduced operating cost and the increase in appliance price due to mandated efficiency standards affect service demand. Higher efficiency appliances cost more which may result in the purchase of fewer or smaller appliances, thus reducing service demand. The magnitude of this effect depends on the elasticity of service demand with respect to appliance price and the dependence of appliance price on efficiency. This results in an additional term in Equation (1). Furthermore, Equation (1) does not correctly embody the long-run dependence of efficiency choice on energy price. When this is taken into account, the proper price elasticity to use is the conditional one with efficiency held constant, i.e., the short-run price elasticity rather than the long-run price elasticity. The conditional elasticity should be used because once a more efficient appliance is installed, its efficiency is constant and consumers react as in the short run.

Equation (1) also ignores any inability of a household to distinguish the energy consumption of the appliance responsible for electricity savings from that of other appliances; it ignores the existence of declining and increasing block rates for residential electricity; and it ignores the effects of compliments and substitutes for the appliance in question. For example, the replacement of a refrigerator by a more efficient one will show up as a reduction in the monthly electricity bill. Any increased consumption due to the rebound effect will be distributed across all electricity-using appliances, not just refrigerators. Henly, *et al.* show that these and other factors will change the formulation of Equation (1), although the magnitude and direction of the effect of these terms on the estimated rebound varies.

Since standards force an increase in efficiency, their effect on the utilization of appliances is similar to a reduction in the price of energy. Yet price elasticities currently available have been estimated from data obtained during periods of increasing prices. To the extent that consumer behavior has been altered by the period of increasing prices, the response to increasing or decreasing prices will differ. For example, many consumers now set back thermostats at night, and once this habit has been formed, it may be maintained even if operating costs fall. Furthermore, additional insulation or high efficient appliances will not be removed when energy prices fall. If behavior is only partially reversible, then price elasticity measured with increasing price over-estimates the elasticity in response to decreasing price.

EMPIRICAL STUDIES OF THE REBOUND EFFECT

One difficulty with the use of Equation (1) to determine the magnitude of the rebound effect is that the estimates of the price elasticity of energy demand cover a wide range. For some appliances and during some seasons the price elasticities may be greater than one, implying increased energy consumption under standards if Equation (1) were valid. Moreover, as pointed out above, the proper elasticity to use is the conditional one with efficiency held constant. Very few if any of the studies have efficiency data, so they are incapable of estimating the conditional price elasticity.

There is, however, a more serious problem with using the results of most of the studies of household energy demand to estimate efficiency elasticities. Because of data limitations, most studies have omitted or included a very rough approximation for appliance efficiency in their specification of the demand equation. The omission of efficiency in the demand equation introduces a bias in the econometric estimate of the price elasticity of energy demand. In the short run, consumers may use appliances less in response to an increase in energy price; in the long run, they may purchase more efficient appliances. The short-run elasticity of energy demand is thus the conditional elasticity with efficiency held constant. The long-run elasticity is larger because it includes the purchase of more efficient appliances. The bias caused by not using the conditional elasticity results in an overestimate of the absolute value of the price elasticity and hence the magnitude of the rebound effect.

We now turn to studies that attempted to examine the rebound effect directly from data sets in which the appliance efficiency is known, not using Equation (1). The one most relevant to appliance standards is the work of Dubin, *et al.* (1986). They examined changes in electricity use in houses whose heat pumps or central air conditioners were replaced with high efficiency units by Florida Power and Light. The rebound effect was as much as 13% for nonsummer months, but only 1-2% for peak summer months. We also looked at Hausman's classic study of room air conditioner electricity demand (Hausman, 1979). His results give an efficiency elasticity of −0.95 or a rebound of 5%.

In addition, there have been several studies of rebound in houses in which the thermal integrity has been increased by adding insulation, reducing infiltration or increasing the amount of glazing. Hirst and White (1985), in a study of 242 homes in the BPA service area, found a reduction in energy savings of 5% during the first year after retrofit and 20% in the second year. They point out that these rebounds are not statistically different from zero. Studies in the change in indoor temperature after retrofit by Goldberg and Fels (1986) and by Dinan (1987) show that little of the savings is taken back by increased indoor temperature. In so far as these studies are applicable to the case of mandated appliance efficiency changes, they also show the rebound is small and real energy savings are achieved.

It is important to point out just how difficult these empirical studies of the rebound effect are. First, the rebound is a second-order effect: the primary effect is the direct energy savings resulting from appliance efficiency improvements in the absence of behavioral changes, and the rebound is the difference between these savings and the actual savings observed. The primary effect is unobservable, so it must be estimated using some sort of model. Second, energy consumption depends on many factors such as energy price, household income and weather in addition to appliance efficiency, which have to be controlled for in any statistical analysis. This requires a large sample of houses studied before and after the efficiency change plus a similar control sample in which no equipment change is made. Given the theoretical and practical difficulties of these studies, it is not surprising that statistically significant estimates of the rebound have not been obtained.

CONCLUSIONS

In trying to answer our original question, we have examined the theoretical basis for the rebound effect and empirical attempts to estimate its magnitude. We found that the equation relating the effect of efficiency improvements on appliance energy demand to the price elasticity of energy demand is based on a simple model of consumer behavior. It does not embody the long-run choices available to the consumer for improving the efficiency of energy use. There are several other factors, discussed in more detail in Henly, *et al.* (1987), that modify Equation (1). Hence we believe the equations used by Khazzoom and others to estimate the size of the rebound effect are not adequately based in economic theory. Furthermore, the price elasticities they used to calculate the rebound are biased because the appliance efficiency was omitted in the estimation procedure. The bias is in the direction to produce high values for the rebound.

The empirical studies described above do not support the notion that the rebound is large enough to wipe out energy savings under mandated appliance efficiency standards. The two studies using disaggregate appliance efficiency data indicate the rebound is small. Studies of thermal integrity improvements to residential buildings support these conclusions. These studies are technically very difficult and their results may not yield statistically significant values for the rebound, but they all show significant energy savings after improvements to appliances or thermal integrity.

Ruderman, *et al.* (1987) demonstrated that consumers have not been making cost-effective decisions on appliance efficiency choice because of market imperfections. Appliance standards mandated under NAECA will remove some of these imperfections and will result in substantial economic benefit to consumers. These benefits will still be enjoyed even if the rebound reduced the expected energy savings, because consumers would willingly trade-off the additional energy costs for the added amenities provided by the more efficient appliances. This paper demonstrates that the rebound is small, hence we conclude NAECA will result in both economic benefits to consumers and energy savings to the nation.

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