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AN ANALYSIS OF DEPARTMENT OF ENERGY RESIDENTIAL APPLIANCE EFFICIENCY STANDARDS

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Residential Appliance Efficiency Standards Versus Appliance Efficiency Taxes - Introduction and Overview

Since 1975, national efforts to improve the efficiency of residential energy-using appliances have gained momentum. Legislation establishing procedures for appliance efficiency improvement has been passed in several stages. In 1975, the Energy Policy and Conservation Act (amended by the Energy Conservation Policy Act of 1976) identified thirteen categories of appliances for the National Bureau of Standards (NBS) to test.[1] The NBS was directed to develop test procedures which would determine annual operating costs and at least one other measure of energy consumption for each appliance. In addition, the NBS was instructed to develop an "energy efficiency improvement target" for each appliance. For 10 appliance categories, the target was designed to raise aggregate energy efficiency at least 20% above 1972 levels. For the remaining three (TVs, clothes washers and dehumidifiers/humidifiers), the target was set at the maximum feasible improvement level as determined by NBS and the Federal Energy Administration (FEA). Labeling procedures were designed for the Federal Trade Commission (FTC) to implement.

The National Energy Conservation Policy Act (NECPA) of 1978 changed these targets to prescribed standards and specified that standards for nine of the thirteen appliances be published in the

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[1] Refrigerators and refrigerator-freezers, freezers, clothes dryers, water heaters, room air-conditioners, home heating equipment (excluding furnaces), kitchen ranges and ovens, central air conditioners, furnaces, dishwashers, televisions, clothes washers and humidifiers/dehumidifiers.

Federal Register by December 1980, and the remaining four (dishwashers, TVs, clothes washers and humidifiers/dehumidifiers) be published by November 1981. The standards are to be designed to achieve the "maximum improvement in energy efficiency" deemed technologically feasible and economically justifiable by the Secretary of the Department of Energy (DOE). This determination is to be based on seven factors including economic impact, cost-benefit ratios, amount of energy saved, impact on competition and the effect on product performance. According to the discretion of DOE, standards may vary across appliances and are to be phased in over a five-year period through the promulgation of interim standards. DOE's present plans (Federal Register, January 2, 1979) are to publish 2 sets of intermediate standards to become effective June 1981 and December 1983. Final standards are to become effective in December 1985.

In the legislative hurry for the implementation of efficiency standards, three important questions have received little attention. They are

- Should energy efficiency standards or energy efficiency taxes be used to attain the "energy efficiency improvement targets"?
- Just what are the economic impacts of appliance efficiency standards, and are the engineering and economic analysis underlying the impact estimates correct?
- What will the effects of proposed appliance efficiency standards be on other DOE policy areas, in particular, on the efforts to commercialize solar photovoltaics?

Let us discuss each question in some greater detail. The first question regarding relative desirability of taxes versus standards has long concerned economic theorists and policy pragmatists (for example, within the Environmental Protection Agency). The theoretical literature addressing the relative appropriateness of efficiency taxes and standards is instructive. In a world of full information and no market failures, the price system will determine the optimal level or distribution of appliance efficiency [12]. However, in a world characterized by asymmetric market information, Leland [9] demonstrates that minimum quality or efficiency standards are welfare increasing. Weitzman [14] examines the use of either standards (quality controls) or taxes/subsidies (price controls) to attain a socially desired production of a given good, say appliance efficiency.

While these latter two analyses justify the use of standards and/or taxes in certain cases, they leave empirical ambiguities. For example, Weitzman [14] derives a measure for the comparative advantage of using price controls rather than quantity controls. His measure depends upon the curvature of the benefit and cost functions (B" and C" - - using his notation) for the provision of the particular good and the variance or uncertainty in the cost function [14, p.485]. In the case of using standards or taxes for appliance efficiency, the costs of providing efficiency seem fairly certain; they depend upon fairly well understood engineering calculations. The benefits to consumers seem subject to greater uncertainty [1]; however, Weitzman's analysis suggests such uncertainty has no effect upon the relative desirability of prices over quantities.

While it is difficult to realistically estimate the social benefit and cost functions for appliance efficiency, it is possible to broadly discuss their curvature in an attempt to give empirical content to Weitzman's measure. If we let q* be the socially optimal efficiency for a given appliance, then Weitzman demonstrates that if the benefit function is kinked around q* and the cost function rises fairly constantly and monotonically, then B" will be large and C" will be relatively small. In this case, efficiency standards (quantity restrictions) will have a relative advantage. If, however, benefits are fairly flat (B" is small) and the costs are rising quickly around q*, efficiency taxes (price restrictions) will have a relative advantage. The former case is exhibited in Figure 1a: if the benefits (B) of efficiency (q) rise quickly and level off asymptotically, the benefits curve is kinked at q* and efficiency standards will be the better instrument to ensure the optimal level. Dewees [1] seems to suggest that benefits do rise rapidly with respect to efficiency and then level off. If costs in the relevant range rise more steadily, then Figure 1a obtains and efficiency standards would be desirable.

Figure 1b exhibits the shapes of the benefit and cost functions when costs are kinked and benefits rise smoothly. This case would obtain if the costs of increased efficiency rise slowly for certain levels and then rise abruptly as efficiency becomes more difficult to produce - i.e., near the technologically maximum levels of efficiency. In this case, efficiency taxes would be optimal.

A more realistic case seems to be that found in Figure 1c.

The benefits curve rises quickly to q^b but then levels off fairly rapidly while the cost curve rises fairly steadily to q^c, the approximate level of technically achievable efficiency. Beyond q^c, costs rise very steeply. In this example, the optimum level will be either q^b or q^c. If $q^c < q^b$, then q^c is the optimum and efficiency taxes are optimal. If $q^b < q^c$, then the relative desirability of standards versus taxes depends upon whether q^b or q^c is optimal the level $q*$. That will depend not only upon local curvature, but also upon the entire schedule of B and C. As drawn in 1c, $q^b = q*$ and efficiency standards are optimal.

The second question is more empirical in nature; it concerns the estimated impacts of the appliance efficiency standards. The standards are to be set at the maximum level deemed technologically feasible as long as they are economically justifiable. Some studies have assessed the effects and the cost/benefit characteristics of proposed standards [7]. However, I know of no study that has incorporated DOE estimates of maximum feasible efficiency improvements in order to assess the economic effects and compare them to effects generated by other plausible scenarios. Likewise, I know of no study that has examined the realism of DOE estimates of maximum appliance efficiency gains.

The third question emphasizes the need for DOE to understand the interrelationships between their dispersed energy policies. Appliance efficiency standards will have impacts upon residential demand for appliances using natural gas, oil and electricity; furthermore, such standards will affect appliance utilization. Such effects will directly impact electricity demand within a given household and

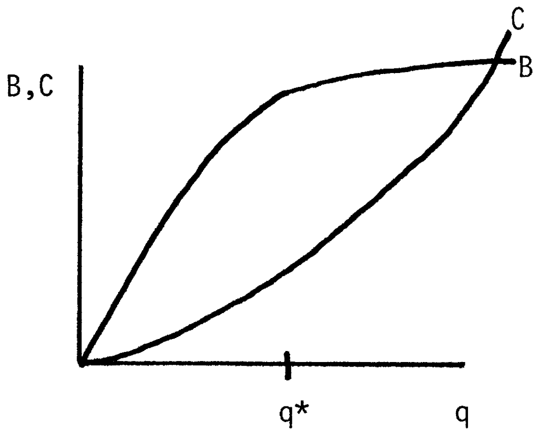

Figure 1a: Comparative Advantage of Standards

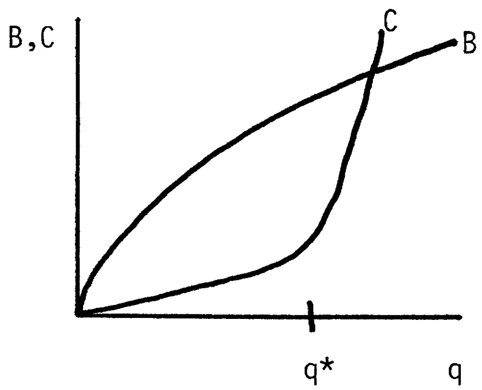

Figure 1b: Comparative Advantage of Taxes

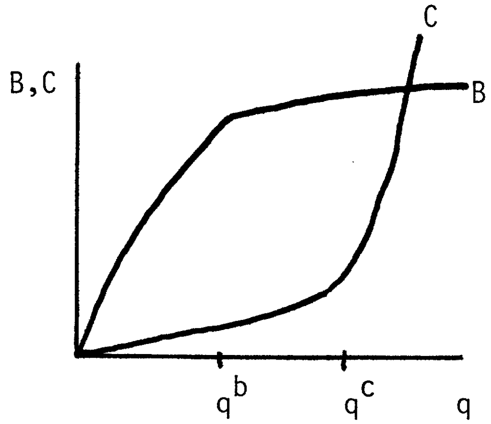

Figure 1c: Potential Realistic Case

consequentially, indirectly impact the potential for solar photovoltaic devices. Since DOE has committed itself to rapid commercialization of residential solar photovoltaics, it should be aware of the effects upon commercialization of its appliance efficiency standards.

This paper does not pretend to answer all of these questions. The first question requires greater theoretical effort. This paper attempts to help answer the second and third questions and to provide a modest empirical word of caution before we rush headlong to efficiency standards. To that end, it first introduces and examines the behavioral characteristics of residential energy demand and residential demand models to indicate how proposed efficiency standards and taxes will affect energy demand. Using an existing demand model (the Oak Ridge National Laboratory Model - ORNL), Section 2 estimates the effects of potential appliance efficiency standards (maximum technologically feasible) and compares them to several other policy scenarios including a series of appliance efficiency taxes. The effects estimated and compared are levels of appliance efficiency and energy demand; a full cost-benefit comparison of the increased capital costs and decreased operating costs for each scenario is not performed. Furthermore, the ORNL model is used to examine whether the DOE assessments of maximum technological feasibility are reasonable and to estimate the level of appliance efficiency taxes required to achieve those proposed levels. Section 3 speculates on the effects of the efficiency standards on solar photovoltaics commercialization. Finally, Section 4 summarizes the relevant conclusions.

1) Residential Energy Demand and Models of It

In order to analyze and predict the effects of appliance efficiency standards in the residential sector, it is necessary to understand the nature and determinants of residential energy demand, to understand how standards will alter that demand behavior, and to incorporate that understanding into models for policy prediction.

Residential energy demand is derived from the demand for the services provided by an energy source in conjunction with the appliances used with that energy source. Any analysis of energy demand must, therefore, deal with the fact that fuels *and* fuel using appliances are combined in varying ways to produce a particular residential service. This appliance demand behavior is composed of three decisions:

1) The decision to buy an energy-using appliance, capable of providing a particular comfort service (e.g., cooking, heating, lighting, air conditioning, etc.)
2) The decision concerning the technical characteristics of the appliance, the fuel to be used by the appliance and whether the appliance embodies a new technology.
3) Given the purchase of an appliance, the decision about the frequency and intensity of use.

These decisions span the short run (when the appliance stock is fixed) and the long run (when the size and characteristics of the appliance stock are variable).

A model of these three decisions will predict appliance purchase and use and can assess new technology potential when the new technologies are embodied into end-use appliances, such as heat pumps, solar thermal water heaters and solar thermal space heaters. For some new technologies, such as solar photovoltaics, a fourth decision (long-run) must be modeled:

4) The decision concerning how to provide a particular energy source. For electricity, the decision concerns the extent to which solar photovoltaics (PV) should be used to supply electricity.

The second decision focuses upon appliance purchase; conditional on the initial cost of an appliance, the cost of operating it, and the discount rate of the household, residential consumers will decide how efficient the appliance should be [3]. This decision can be left to the household, or the government can impose efficiency standards on the types of appliances purchased.

The third decision focuses on appliance use; utilization can be left to market conditions or the government can impose utilization decisions such as thermostat controls.

The fourth decision is determined by the household trade-off between the increased capital costs of PV installations and the consequential decreased operating costs. This decision depends upon the level of electricity use, the cost of grid electricity, and the discount rate of the household.

Different types of residential energy demand models have been utilized to capture the first three decisions. The last decision has only been incorporated recently [5]. The history of these models has evidenced an evolution from aggregate, static, equilibrium specifications to dynamic, multi-equation specifications disaggregated by the end-use of appliance, such as space heating, water heating, dishwashing, etc. (see [4]). The aggregate static models have generally related energy demand to trends in energy prices and to changes in income levels. While these aggregate, static models proved to be historically useful tools for energy demand analysis, they have become less useful for several reasons. The most important reasons are that these models ignore the specific technological characteristics (including efficiency) of the fuel-burning appliance stock and that they do not explicitly treat the differences between long-run and short-run energy demand indicated in the three residential demand decisions. The aggregate models fail to analyze the relationship of energy demand to the demand for the appliance stock required to burn that energy. They cannot be used to explicitly assess the potential penetration of new energy technologies, the consumer response to mandated conservation and appliance efficiency regulations, changes in patterns of appliance utilization, and/or changes in patterns of appliance purchase and retirement.

To remedy these observed deficiencies, dynamic partial-adjustment models were developed. These models make more explicit the interactive nature of the demand for energy and its requisite energy-burning capital. As energy demand (Decision 3) responds to changing economic conditions, the fixed capital stock cannot adjust as rapidly (Decisions 1 and 2) due to time lags for adding new appliances or for retiring undesired appliances. Disequilibrium in the form of increased or decreased appliance utilization results and energy demand can only partially adjust to desired levels in the short run until the capital stock adjusts. In this case, short-run price and income demand responses are less than long-run responses when the appliance stock fully adjusts to changed conditions.

While partial adjustment models admit to the differences between short-run and long-run demand, they do not treat, formally, Decisions 1-3; nor do they treat the characteristics of the appliance stock (e.g., efficiency), the presence of new technologies and the potential for standards affecting appliance efficiency or use.

To overcome these remaining deficiencies, multi-equation, dynamic end-use models have been developed which characterize the frontier of energy demand models (see [4]). These models explicitly recognize the different behavioral characteristics of short-and long-run energy demand and they incorporate, to varying degrees, the technological characteristics of the energy-burning appliance stock. To accomplish this, the models use separate equations for the short run and long run. In the short run, the energy-using appliance stock is fixed in size and technological characteristics (e.g., efficiency); therefore, the short-run equations analyze demand as the utilization of the fixed appliance stock. In the long run, the size and technological characteristics of the appliance stock can change as a result of behavioral decisions and/or mandated appliance standards; the long-run equations of the multi-equation end-use models treat this explicitly.

Using the notation of the multi-equation end-use models for decisions 1-3 (see [4]); we have

$$q_t = q_t^* = U_t(p_t, y_t, w_t, se_t)K_t \tag{1a}$$

$$K_t = K_{t-1}(1-\delta) + \Delta K_{t-1} \tag{1b}$$

$$\Delta K_{t-1} = F(p_{t-1}, cc_{t-1}, y_{t-1}, w_{t-1}, se_{t-1}). \tag{1c}$$

In words, equation (1a) indicates actual short-run fuel demand (q_t) is equal to desired short-run fuel demand (q_t*), which are both expressed as the utilization (U_t) of a given appliance stock (K_t). The appliance stock is considered fixed in size and characteristics during the period t. The rate of utilization of the fuel-specific (e.g., gas, oil, or electricity) capital stock (K_t) is a function of energy prices, household income, weather/climate and other socioeconomic factors (p_t, y_t, w_t, se_t). Equations (1b) and (1c) treat long-run issues. K_t in any period is given by K_{t-1} minus retired appliances δK_{t-1} (δ is the retirement rate) plus additions during t-1 (ΔK_{t-1}) to the stock of appliances that utilize the particular fuel being analyzed. The size of ΔK_{t-1} measures consumers' choices or preferences for a particular fuel and its requisite appliance; if consumers find a given fuel desirable, based on the cost and characteristics of its appliances, ΔK_{t-1} will be large. ΔK_{t-1} is shown in equation (1c) to be determined functionally by the relative operating costs of all possible fuels (p_{t-1}), the comparative characteristics of the appliances required for the alternative fuels (cc_{t-1}) and y_{t-1}, w_{t-1}, and se_{t-1}. cc_{t-1} includes the capital costs and efficiencies of the appliances of the alternative fuels.

Equations (1a) - (1c) permit explicit analysis of efficiency standards. Appliance use standards will affect utilization U_t, in equation (1a); policy simulations can fix U_t directly or estimate consumers' response to standards (e.g., thermostat controls for the space heating end use). In equation (1c), appliance efficiency standards and taxes/subsidies will affect the cost and characteristics

(cc_{t-1}) of appliances available for purchase. Households will face an array of more efficient appliances and will determine the extent of appliance purchase (ΔK_{t-1} in (1c)) based upon costs of appliance, cost of operation, other characteristics of the appliance and their discount rate. If the government decides to mandate all appliances to be a particular efficiency, consumers will have no choice with respect to that characteristic; appliance purchases (ΔK_{t-1}) will all be at a prescribed efficiency level.

Both efficiency taxes and standards will generate differential impacts on the demand for appliances and fuels. As a result, they will affect decision 4, which is given functional specification in equation (1d). In (1d), the decision concerning the extent to which photovoltaics will be used by a household (S_t^{PV} - share of electricity provided by photovoltaics) depends upon the level of electricity

$$S_t^{PV} = S^{PV}\ (q_t^e,\ p_t^e,\ d_t,\ y_t,\ w_t,\ se_t) \tag{1d}$$

demanded (q_t^e), the price of grid electricity (p_t^e), the discount rate of the household d_t, and y_t, w_t, se_t.

To adequately assess the full effects of efficiency standards, it is important to have a model that fully disaggregates household energy decisions ((1a) - (1d)) and that appropriately captures both household behavior and the technological characteristics of the available appliances. Two efforts currently exist at the level of behavioral disaggregation in (1a) - (1c) - the model developed at the Oak Ridge National Laboratories [8] and the model currently being developed at the Massachusetts Institute of Technology Energy Laboratory [2]. Only the M.I.T. effort is explicitly modeling decision (4). The models are reviewed in greater detail elsewhere [4]. While it would be desirable to use a model that treats all four decisions (equations 1a) - 1d)) for analyzing the full effects of appliance efficiency standards, the M.I.T. effort is still in the development stage. On the other hand, the Oak Ridge Model (ORNL) is a mature policy model; as a result, I use the ORNL model to tentatively measure the effects of efficiency standards in spite of the fact that decision 4 is not included in that model. Section 3 will attempt to speculate on the extent of effects generated in equation 3d).

2) Assessment of Proposed Appliance Efficiency Standards

This Section uses the Oak Ridge Model to simulate the effects of potential Department of Energy (DOE) appliance efficiency standards. In light of the mandate given the Secretary, I examine the effects of the "maximum improvement" currently deemed technologically feasible. While simulating these effects, this section compares them to appliance efficiencies chosen by the residential sector under several alternative scenarios: a baseline scenario which assumes fuel price increases predicted by DOE and the Brookhaven National Laboratory (BNL) for 1976-2000 [7]; a fuel tax scenario, which differs from the baseline by the imposition of a 100% fuel tax on electricity, gas, and oil; and a "rational household choice" scenario which differs from the baseline in that households are assumed to use the true cost of capital when deciding on appliance efficiencies. The energy demand implied by each of these scenarios is estimated. Finally, the appliance efficiency tax required to achieve DOE standards is estimated. For a full discussion of the price assumptions underlying the baseline scenario, the reader should consult [7].

Table 1 presents energy efficiency levels for new appliances considered by DOE to be the maximum technologically feasible efficiency levels as of 1978. Table II presents the weighted (by shipments) average efficiency of all appliances purchased in 1975 for selected end-uses.

The estimates of Table II must be interpreted with some care, For several end-uses, such as room air conditioners, water heaters, refrigerators and freezers, the efficiency of various models differ considerably and the mean is a rough central tendency of appliance efficiency. For other end-uses, such as furnace and boiler space heating, actual efficiencies are all fairly close to the mean. Using 1975 shipment levels[1], the efficiencies in Table 1 are aggregated to the end-use categories in Table II. It is these estimates of maximum technologically feasible efficiency levels that I shall examine as potential standards.

Before assessing the impacts of these standards on residential energy demand, it is useful to comment upon the patterns found in Table II. The potential for efficiency increases seem to be much smaller for space conditioning appliances than for ranges, water heaters, clothes dryers, refrigerators and freezers. The potential space heating efficiency increases are on the order[2] of 2%; furthermore, the single large increase for oil furnaces may be due to the use of two different efficiency measures. There is room for large efficiency increases in gas ranges and water heaters, due to changes in the pilot light system. The large increases in efficiency in refrigerators, freezers and ranges are possible as consumers move to better insulated

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[1] Over time, the relative appliance shipments will presumably change toward more efficient appliances (within an end use) thereby rendering the estimated average standards in Table II conservative. I do not attempt to approximate such compositional shifts here; the percentage efficiency increase in Table II measures the increase in mean efficiency with compositional effects assumed constant.

[2] While the potential efficiency increases in the actual space conditioning appliances appears small, it should be clear that we are not analyzing changes in the residential housing shell, such as storm windows and doors and insulation. Such increases in the thermal integrity of the structure will contribute more significantly to efficiency gains.

Table I - Likely Classes and Tentative Determinations of Maximum Technologically Feasible Energy Efficiency Levels

Covered product type	Class	Preliminary maximum technologically feasible energy efficiency level**
Refrigerators and refrigerator freezers	Electric, manually defrosted 15' freezer	10.4 ft^3/kWh-day (EF)
	Electric manually defrosted 5' freezer	10.1 ft^3/kWh-day (EF)
	Electric automatic de-	6.6 ft^3/kWh-day (EF)
Freezers	Manual defrost, chest	16.9 ft^3/kWh-day (EF)
	Manual defrost, upright	13.9 ft^3/kWh-day (EF)
	Automatic defrost	9.1 ft^3/kWh-day (EF)
Clothes dryers	Electric, standard	2.77 lb/dWh (EF)
	Electric, compact	2.61 lb/dWh (EF)
	Gas	2.46 lb/dWh (EF)
Water heaters	Electric	0.89 (EF)***
	Gas	0.59 (EF)***
	Oil	0.50 (EF)***
Room air conditioners	Window and through the wall (with outdoor side louvers)	11.6 Btu/watt-hour (EER)
	Through the wall (no outdoor side louvers)	7.5 Btu/watt-hour (EER)
	Packaged terminal	8.7 Btu/watt-hour (EER)
	Reverse cycle	8.8 Btu/watt-hour (EER)
Home heating equipment, not including furnaces	Electric, primary and sup-	100% efficiency
	Gas, gravity, vented room heater	58% (AFUE)***
	Gas, forced air, vented room heater	74% (AFUE)***
	Gas, gravity, vented wall furnace	60% (AFUE)***
	Gas forced air, vented wall furnace	70% (AFUE)***
	Gas, gravity, vented floor furnace	70% (AFUE)***
	Oil, gravity, vented room heater	(AFUE)*
	Oil, forced air, vented floor furnace	(AFUE)*
	Oil, gravity, vented wall furnace	(AFUE)*
	Oil, forced air, vented floor furnace	(AFUE)*
	Oil, forced air, vented floor furnace	(AFUE)*
Kitchen ranges and ovens	Microwave oven	44% (EF)**
	Electric cooking top	79% (EF)
	Electric oven	16% (EF)***
	Electric oven, self-cleaning	14% (EF)***
	Gas cooking top	46% (EF)
	Gas oven	8.5% (EF)
	Gas oven, self cleaning	7.8% (EF)

Table I (cont'd.)

Covered product type	Class	Preliminary maximum technologically feasible energy efficiency level**
Central air conditioners	Split system	10.3 (SEER)***
	Single package	8.9 (SEER)***
Furnaces	Gas, gravity	70% (AFUE)
	Gas, forced air	75% (AFUE)
	Gas, boilers	79% (AFUE)
	Oil, boilers	85% (AFUE)
	Oil, forced air	82% (AFUE)***
	Electric	100% (AFUE)

*Information is not available to determine the maximum technologically feasible energy efficiency level.
**Based on data obtained by using DOE test procedures
***Based on best available information

EP-energy factor
EER-energy efficiency ratio
AFUE-annual fuel utilization efficiency.
SEER-seasonal energy efficiency ratio.

NOTES

Source: 10 CFR Part 430, pp. 49-60; 1978 efficiency definitions are developed more completely in Saltzman [13].

Table II 1975 Appliance Efficiencies, Proposed Standards and Implied Efficiency Increases

	Efficiency Measure a)	1975[e]	Standard	Mean Efficiency Improvement Implied by Standard[g]
Room Air Conditioners	(EER)	8.79	8.997	2.36
Boilers	(AFUE)			
Oil		75.8	75.8[d]	0.0
Gas		80	80[d]	0.0
Electricity		98	100	2.04
Furnaces				
Oil		75[b]	83.5[c]	11.33
Gas		75[b]	75[c]	0.0
Electricity	(AFUE)	98[b]	100[c]	2.04
Ranges	(Energy into Food; EF)			
Gas		10	27.08	170.80
Electricity		39	49.88	27.90
Water Heaters	(Water Heat Content/Energy Used-EF)			
Gas		44	59	34.09
Oil		46	50	8.70
Electricity		80	89	11.25
Clothes Dryers	(Pounds of Clothes Dried/awh)			
Gas		2.15	2.46	14.42
Electricity[f]		-	-	14.42[f]
Refrigerators/Freezers	(ft^3/kwh/mo.)			
Electricity		0.12	.301	150.83
Freezers	(ft^3/kwh/mo.)			
Electricity		0.15	.4433	195.53

NOTES

a) See Table I
b) Due to data availability, based on steady state efficiency (SSE)
c) Based on AFUE
d) Standards not articulated by DOE in Table 1; 1975 mean efficiencies held constant
e) For 1975 efficiency and sales weights, see Saltzman [13].
f) Efficiency estimates for actual 1975 sales unavailable; gas improvement estimate used
g) (efficiency standard - 1975 efficiency)/1975 efficiency

appliances with fewer luxury options.

Let us now turn to the impacts of these standards on residential energy demand and compare those impacts to impacts generated by the three alternative scenarios. To that end, Table III tabulates the estimated mean efficiencies of newly purchased appliances for the four scenarios (baseline, 100% fuel tax, "rational household choice", and proposed DOE efficiency standards) in IIIa) - IIId) respectively for selected years over 1975-2000. 1981 and 1983 are included because the DOE standards are assumed[1] to be imposed through interim standards in three equal steps over the 1980-1985 period (in 1981, 1983, and 1985). The efficiencies are estimated by the ORNL model as "energy used" to perform a given task relative to 1970, which is set at 1.00. For example, for electrical space heating units in 2000, "average energy used" is .754 or a 25% efficiency increase over 1970 levels (1.00).

As a basis for comparison under baseline assumptions, we find the ORNL model predicts space heating efficiencies will be improved from 1975 levels of .948-.980 to 2000 levels of .754 to .834, improvements that range from 12% for oil to 22% for electricity. Room air conditioners purchased are predicted to increase 19% in mean efficiency. Gas and oil water heaters are predicted to be about 15-20% more efficient while purchased electrical water heaters are predicted to be only 8.6% more efficient. Refrigerators and freezers are approximately 25% more efficient in 2000. Finally, gas ranges/stoves are predicted to be considerably more efficient (30%) while electrical

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[1] See pg. 1-2 above.

Table III

Average Efficiency Estimates For Newly Purchased Appliances

	1975	1980	1981	1983	1985	1990	2000	1975-2000 % increase
a) <u>Baseline</u>								
Space Heating								
Electricity	.969	.893	.876	.844	.816	.782	.754	22.19%
Gas	.980	.912	.899	.876	.856	.831	.808	17.55%
Oil	.948	.894	.887	.877	.869	.855	.834	12.03%
Air Conditioning								
Room	.980	.9.9	.905	.878	.853	.820	.795	18.88%
Water Heating								
Electricity	.991	.959	.953	.940	.928	.914	.906	8.58%
Gas	.981	.906	.892	.866	.845	.816	.794	19.06%
Oil	.940	.870	.862	.849	.838	.821	.798	15.11%
Refrigerators	.972	.882	.862	.825	.791	.750	.727	25.21%
Freezers	.971	.876	.856	.817	.782	.739	.716	26.26%
Cooking								
Electricity	.995	.979	.975	.968	.961	.952	.947	4.82
Gas	.970	.856	.934	.795	.762	.717	.682	29.69%

Table III (cont'd)	1975	1980	1981	1983	1985	1990	2000	1975-2000 % increase
b) Double Fuel Prices								
Space Heating								
Electricity	.905	.726	.709	.683	.665	.643	.630	30.39%
Gas	.947	.834	.822	.804	.791	.775	.763	19.43
Oil	.928	.835	.827	.816	.809	.800	.791	14.76%
Air Conditioning								
Room	.925	.761	.745	.721	.703	.682	.670	25.57%
Water Heating								
Electricity	.964	.883	.876	.864	.856	.846	.842	12.66%
Gas	.946	.821	.807	.787	.773	.755	.744	21.35%
Oil	.916	.800	.790	.775	.766	.754	.743	18.89%
Refrigerators	.896	.667	.645	.613	.590	.565	.554	38.17%
Freezers	.893	.657	.635	.602	.579	.554	.544	39.08%
Cooking								
Electricity	.978	.926	.920	.911	.905	.898	.984	8.59%
Gas	.916	.722	.701	.669	.646	.617	.599	34.61%

Table III (cont'd)	1975	1980	1981	1983	1985	1990	2000	1975-2000 % increase
c) <u>Rational Household Choice</u>								
Space Heating								
Electricity	.918	.762	.738	.701	.674	.644	.627	31.70%
Gas	.943	.840	.828	.809	.796	.780	.769	18.45%
Oil	.904	.826	.820	.810	.804	.797	.789	12.72%
Air Conditioning								
Room	.939	.803	.782	.748	.723	.694	.679	27.69%
Water Heating								
Electricity	.970	.903	.893	.877	.865	.851	.845	12.89%
Gas	.952	.847	.834	.811	.795	.775	.765	19.64%
Oil	.898	.805	.797	.784	.776	.765	.754	16.04%
Refrigerators	.907	.704	.675	.628	.595	.559	.544	40.02%
Freezers	.898	.680	.651	.603	.570	.535	.521	41.98%
Cooking								
Electricity	.992	.969	.965	.957	.950	.941	.937	5.54%
Gas	.916	.747	.726	.692	.668	.639	.621	32.21%

Table III (cont'd)	1975	1980	1981	1983	1985	1990	2000	1975-2000 % increase
d) Maximum Technologically Achievable Efficiency Standards								
Space Heating								
Electricity	.969	.950	.950	.950	.950	.950	.950	1.96%
Gas	.980	.980	.980	.980	.980	.980	.980	0%
Oil	.948	.897	.897	.897	.897	.897	.897	5.38%
Air Conditioning								
Room	.980	.958	.958	.958	.958	.958	.958	2.25%
Water Heating								
Electricity	.991	.959	.936	.913	.891	.891	.891	10.09%
Gas	.981	.906	.848	.790	.732	.732	.732	25.38%
Oil	.940	.870	.865	.865	.865	.865	.865	7.98%
Refrigerators	.972	.882	.717	.553	.388	.388	.388	60.08%
Freezers	.971	.876	.694	.511	.329	.329	.329	66.12
Cooking								
Electricity	.995	.979	.912	.845	.778	.778	.778	21.81%
Gas	.970	.856	.690	.524	.358	.358	.358	63.09%

ranges/stoves will be only 4.8% more efficient.

In Table IIIb) the efficiency effects of a 100% fuel tax across the 1975-2000 period are indicated. The discussion in Section 1 indicated that such increased operating costs will cause households to utilize their equipment less and to substitute toward more efficient appliances. These expectations are corroborated. Mean space heating efficiencies are predicted to increase 15, 19 and 30% for oil, gas and electricity devices respectively. Room air conditioner efficiency is predicted to increase 20%. Water heating efficiency increases range from 13-21% and refrigerators and freezers are forecasted to be approximately 38% more efficient at the mean. Electrical stoves/ranges will be 9% more efficient while such gas appliances will be 35% more efficient.

Table IIIc) presents estimates of appliance efficiencies when consumers make rational choices, responding to the true cost of capital rather than discount rates well above the true cost of capital. Hausman [6] and other authors have discussed (and empirically corroborated) the fact that consumers demonstrate effective discount rates well above actual costs of capital; the effect of such discount rates is to bias consumer choice to less efficient, energy intensive appliances. Because such high discount rates have characterized past residential consumer choice, they are incorporated into the baseline results. However, the Oak Ridge model structure can be easily altered[1] to approximately incorporate the true cost of capital

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[1] See [8], pp. 39-44. In the notation of [8] values of n=10 and n=15 were incorporated to make the actual choice approximately equal to the optimal choice. Values of n>15 generated nonsensical results.

into household efficiency decisions. When that is done, the results in Table IIIc) obtain. As expected, the efficiency increases suggested by such rational consumer behavior are all above baseline increases, the increases for electric space heating (32%), room air conditioning (28%), electric water heaters (13%), and refrigerators/freezers (40-42%) are substantially above baseline. Furthermore, the efficiency results are greater than those suggested by a 100% fuel tax in 5 categories and fairly close in the remaining 6 categories. Thus, any educational or informational program would be quite effective if the program could effectively eliminate the difference between consumer discount rates and the true cost of capital when the difference is due to consumer ignorance.

Using these three scenarios as background, let us finally turn to the appliance efficiency standards suggested in Table II. Table IIId) presents the efficiency results that obtain from imposing the DOE maximum technologically achievable efficiency standards in equal steps in 1981, 1983, and 1985. The results are striking in several cases. In particular, projected space heating efficiencies rise 2% for electricity, 0% for gas, and 5% for oil - all well below baseline results. The higher efficiencies predicted under these three other scenarios do not seem to explicable through changes in the composition of appliances purchased; the range of possible efficiencies is too narrow. The mean efficiency of room air conditioners is projected to rise only 2% under DOE standards, about 1/10 the increase estimated under the baseline scenario and about 1/15 of the increase estimated in the fuel tax and the "rational consumer choice" scenarios. Increases larger than 2% are probable due to the compositional changes in the air conditioners purchased; that is, the distribution of efficiencies will most probably be skewed toward greater efficiency over the 1975-2000. However, it is unclear that compositional effects will raise mean efficiency increases to the 20-30% levels. These large disparities between the standards and the simulation results for space conditioning appliances suggest that the DOE engineering estimates of maximum technologically achievable efficiency standards are extremely conservative and in need of review.[1]

The efficiency results for the remaining end-uses are more plausible. The imposition of maximum technologically achievable standards raise water heater efficiencies 10, 25, and 8% for electric, gas, and oil water heaters. These results suggest that there is room for greater efficiency increases for gas water heaters than is generated by the other three scenarios. For electric water heaters, increases in mean efficiency are somewhat higher under the double fuel price and rational household choice scenarios than are estimated to be technologically achievable; however, such increases can be explained by shifts in the distribution of purchased appliances toward more efficient appliances. The increases estimated for oil water heaters under baseline conditions are approximately double the mean levels considered to be technologically obtainable. The increases estimated for the double fuel prices and rational household choice

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[1] On the other hand, technological trade-offs built into the Oak Ridge model may be overly optimistic and in need of review.

scenarios are even higher than baseline results. Such results would require so substantial a shift in the distribution of sales by efficiency that I feel that the maximum technologically achievable standards may be in error.[1]

Under all three scenarios, estimated mean efficiencies are below maximum technologically achievable levels for refrigerators, freezers, and electric and gas stoves. Rational consumers would choose refrigerators and freezers with mean efficiency levels approximately twice those obtained under baseline conditions. However, even with discount rates that approximate capital costs, consumers will not choose maximally efficient refrigerators and freezers. Similarly, rational choice generates mean efficiency levels substantially below maximum levels for stoves/ranges. The reason seems to be that for these particular end-uses (refrigeration/freezing, cooking) that the cost of capital services includes not only appliance efficiency, but also consumer luxury accessories (e.g., self-cleaning oven, automatic defrost, etc.). As a result, given a discount rate for a consumer across all end-uses, his cost of capital services will be higher for refrigerator/freezers and stoves/ranges and his chosen technology more fuel intensive (e.g., further from maximum technologically achievable levels).

Table IV compiles the estimates of fuels consumed over 1975-2000 for the four scenarios. The fuel tax scenario of double fuel prices will lower short-run appliance utilization and shift long-run appliance

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[1] Or again, there may be some over-optimism built into the ORNL model.

choice toward more efficient appliances. These results are reflected in Table IV where fuel use is 8% lower for electricity, 26% lower for natural gas and 31% for oil. Under the rational household choice scenario, fuel prices remain at baseline levels while consumer discount rates are set at the cost of capital; thus, utilization will be unaffected but long-run appliance choice will reflect the actual trade-off of capital cost and operating cost for each fuel in each end use. Under this scenario, electricity use declines even further (9%) below baseline. The biggest surprise, however, comes in estimated fuel use under the maximum technologically achievable efficiency standards. Table III indicated that the baseline, double fuel price and rational consumer choice scenarios generated mean efficiency levels well above technologically achievable levels for the major residential fuel using appliances (space conditioning and water heating). Only for refrigeration/freezing and cooking were estimated efficiencies well below technologically achievable levels. As a result, total fuel use under the efficiency standards scenario is only 2% below baseline for electricity and 1% below for natural gas. Furthermore, oil use is above baseline by 11% because the baseline and other two scenarios estimate mean efficiency gains that DOE apparently deems as technologically impossible.

Finally, the Oak Ridge model can be utilized to estimate the extent of mean appliance subsidies required to achieve mean efficiency levels deemed to be maximum technologically achievable.[1]

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[1] See the technology trade-off curves in [8] pp. 17-25.

The introduction discussed the fact that either standards or taxes/ subsidies can be used to affect consumer purchases of efficient appliances. Each tool may be more useful in certain situations. I have estimated the effects of standards above. The extent of efficiency subsidies required to attain those standard efficiency levels can also be indicated. Since mean space heating and cooking efficiencies and oil water heating efficiencies are higher under baseline than deemed technologically possible, no amount of subsidy will generate greater efficiencies if DOE is correct in its measurement of maximum technologically feasible efficiency increases. However, for electric and gas water heaters, refrigerators and freezers and for stoves/ranges, levels of subsidies are indicated in Table V that are required to attain maximum mean efficiency levels over 1981-1985 and beyond. The subsidies are expressed as the percentage of the mean appliance price under the baseline. The largest subsidies are required for those end-uses that offer the largest potential efficiency gains - refrigeration/freezing and cooking.

Table IV Fuel Consumed (QBTU*)

	1975	1980	1985	1990	2000
Baseline					
Electricity	7.31	9.09	10.52	12.10	15.03
Gas	5.60	5.35	5.05	5.03	5.10
Oil	2.49	2.30	2.39	2.54	2.68
Double Fuel Prices					
Electricity	6.99	8.21	9.46	10.99	13.90
Gas	5.11	4.44	4.10	3.94	3.76
Oil	2.23	1.78	1.79	1.87	1.84
Rational Household Choice					
Electricity	7.25	8.74	9.87	11.17	13.65
Gas	5.56	5.21	4.85	4.78	4.77
Oil	2.48	2.24	2.26	2.36	2.44
Maximum Technologically Achievable Efficiency Standards					
Electricity	7.31	9.12	10.46	11.93	14.79
Gas	5.60	5.37	5.05	5.01	5.06
Oil	2.49	2.32	2.46	2.70	2.97

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*QBTU is Quadrillion BTU

Table V Estimated Appliance Subsidies to Achieve Maximum Technologically Achievable Standards*

	1975-1980	1981	1983	1985	1990	2000
Space Heating						
Electricity	-	-	-	-	-	-
Gas	-	-	-	-	-	-
Oil	-	-	-	-	-	-
Air Conditioning						
Room	-	-	-	-	-	-
Water Heating						
Electricity	-	2.28	4.19	6.70	3.90	2.83
Gas	-	3.84	9.26	23.63	19.76	16.12
Oil	-	-	-	-	-	-
Refrigerators	-	2.46	7.74	23.76	22.92	22.33
Freezers	-	2.95	10.95	23.52	22.57	22.09
Cooking						
Electricity	-	6.69	27.89	108.80	107.10	106.10
Gas	-	3.91	31.65	54.82	52.76	50.75

*expressed as percentage of mean appliance prices obtained under the baseline.

3) The Potential Impact of Residential Appliance Efficiency Standards on Solar Photovoltaic Commercialization

The Department of Energy has undertaken analysis to help commercialize solar photovoltaics [11]. However, DOE may not fully recognize the effects that its effort for improving appliance efficiency will have on PV commercialization. Section 2 estimated the efficiency impacts and energy demand resulting from DOE standards and three other scenarios. Let us examine how those impacts will affect PV desirability.

The decision to provide part of the residential electricity load through solar photovoltaics will depend upon the factors identified in Section 1: the level of residential electricity demand (q_t^e), the price of grid-connected electricity (p_t^e), the discount rate of the household (d_t), weather/climate (w_t), household income (y_t) and other socioeconomic factors (se_t). Using analysis developed elsewhere [5], we can indicate the important determinants of this decision. Figure 2a indicates that a given level of electricity (q_i^e, $i = 1 \ldots 3$) used by a household can be supplied by an array of technologies $\phi(q_i^e)$ which includes grid-connected electricity and electricity supplied by alternative sources such as storage or direct solar PV devices. If grid electricity is used entirely, households will be choosing technologies at the bottom right of the technology trade-off curves in Figure 2a). However, the household can decide to supply electricity by utilizing more capital and less grid power (through PV and storage). The technology trade-off curves ($\phi(q_i^e)$) indicate the choices available to a household where ϕ will depend upon q_i^e and weather/climate. In this choice, the household will minimize costs by equating the marginal rate of technical substitution to the relative factor prices (p_t^e and d_t)[1]; optimal choices 1, 2, and 3 result, involving a combination of grid electricity and solar PV [5].

The effects of climate, utility buy-back schemes, changing discount rates, the divergence of household discount rates from the cost of capital, the scale of electricity demand, and changing the price of electricity (peak load pricing, taxes) have been analyzed elsewhere [5]. Based on that analysis and the insights above, we can state that the estimated impacts of the energy scenarios in Section 2 will affect PV potential through p^e, q^e and d. These variables will be altered under the four scenarios as in Table VI. The baseline assumptions incorporate p_b^e and d_b. Under the 100% fuel tax, $p^e = 2p_b^e$ while $d = d_b$; the result is q^e at levels of about 92% of q_b^e over 1975-2000. Under the scenario of rational consumer choice, $d = r$ where r is the cost of capital and $r < d_b$ while $p^e = p_b^e$; the result is q^e at levels about 94% q_b^e. For the standards scenario, $p^e = p_d^e$, $d = d_b$ and q^e is essentially unchanged (.99 q_b^e).

The impacts of these four scenarios are illustrated in Figures 2a) - 2b). Let Figure 2a) reflect Baseline conditions so that the budget line slope is determined by p_b^e/d_b and $q_1^e - q_3^e$ reflects the

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[1] To be precise, the cost of capital services should be used here. A major factor in determining that cost of capital services is the discount rate; I use it in the heuristic discussion here. For the more formal development, see [5].

TABLE 1: Relative Changes in p^e, d and q^e' for the Four Scenarios

	p^e	d	q^e
Baseline	p_b^e given by Brookhaven National Laboratory and Oak Ridge National Laboratory Projections	$d_b > r$ (cost of capital	$q_b^e = 7.31$ QBTU in 1975 to 15.03 QBTU in 2000
Double Fuel Prices	$p^e = 2\ p_b^e$	$d = d_b$	$q^e \approx .92\ q_b^e$
Rational Household Choice	$p^e = p_b^e$	$d = r < d_b$	$q^e \approx .94\ q_b^e$
DOE Efficiency Standards	$p^e = p_b^e$	$d = d_b$	$q^e \approx .99\ q_b^e$

NOTES: QBTU is Quadrillion BTU's

average for household energy demand generated by dividing 7.31 - 15.03 QBTU by the number of households. In Figure 2a), some photovoltaics will be purchased; it is probable in most regions that the current technology trade-off curves are closer to those in Figure 2b), given p_b^e and d_b. In that case, no photovoltaics will be purchased. Whether 2a) or 2b) is the correct approximation of current technology and factor prices is an empirical matter; the effects of the alternative scenarios relative to Baseline will be the same whether 2a) or 2b) describes the initial set of conditions.

Figure 2c) indicates the effects of a fuel tax or rational consumer choice. In both cases, the relative cost of grid electricity rises while the average scale of household demand drops 6-8% (assuming the same number of households). If the technology trade-off curves are non-homothetic (and capital using), the lower scale will reduce the desirability of solar photovoltaics [5]. At the same time, the shift in relative prices will make PV more desirable (points $1_c'$ and $2_c'$) conditional on q_i^e. This increased desirability will obtain whether 2a) or 2b) is the appropriate summary of Baseline conditions.[1] Whether the fuel tax or the rational consumer choice case will generate greater PV potential will depend upon the exact values of p^e/d in both cases, the shape of $\phi(q_i^e)$ and the extent of non-homotheticity in $\phi(q_i^e)$ [5].

Under the DOE standards scenario, Baseline conditions obtain.

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[1] Of course, it is possible that the relative shift in p^e/d will still result in a corner solution in Figure 2b); in that case, PV potential has increased but it is still not purchased.

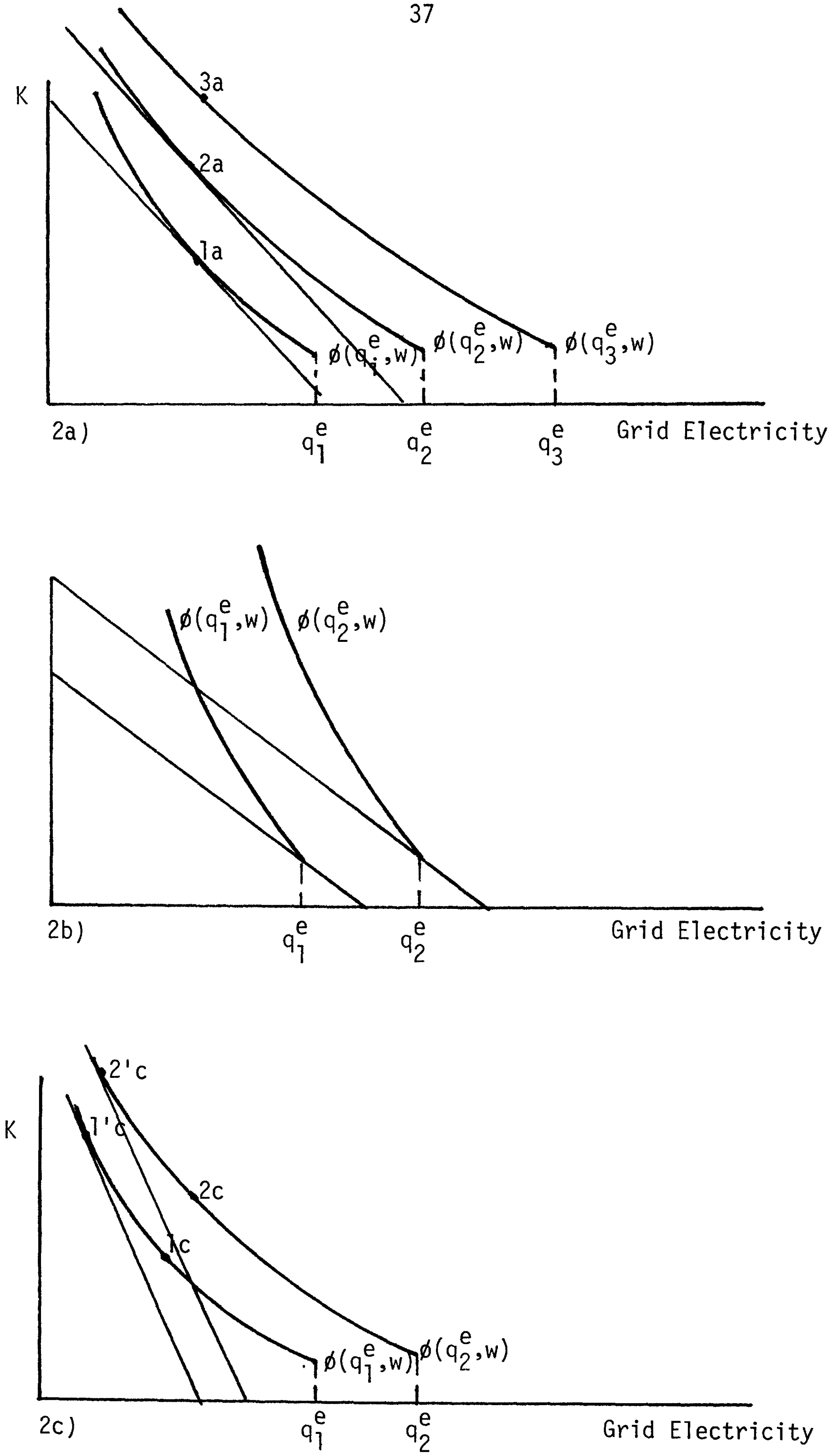

Figure 2: Alternative Photovoltaic/Grid Electricity Technology Trade-Off Curves

p^e and d are at Baseline levels while q^e is essentially unchanged. As a result, appliance efficiency standards will have nearly no effect on PV potential compared to Baseline. Furthermore, if the DOE maximum efficiency estimates are too conservative for space heating and water heating, as is suggested possible in Section 2, then q^e is too high under the standards scenario. If this is indeed true, then $p^e = p_b^e$, $d = d_v$ and $q^e < q_b^e$; in this case, standards will have a negative effect on PV potential compared to the Baseline. More importantly, the appliance efficiency standards will have a greater negative impact upon PV potential than the fuel tax or programs aimed at consumer information (i.e., getting $d = r$). We may conclude, therefore, that if DOE can accomplish appliance efficiency gains and energy demand levels considered desirable using fuel taxes or programs aimed at changing household discount rates (that can include capital subsidies), it should use those policy tools before efficiency standards in order to increase PV commercialization potential.

4) Conclusions

The preceding results strongly suggest their own conclusions. In the first place, Baseline conditions suggest appliance efficiency choices well above standards set at the maximum technologically feasible levels for space heating, space cooling and oil water heating. Efficiency gains under the other two scenarios are even larger for these end-uses. As a result, I must conclude that DOE has underestimated efficiency potential for those end-uses, or else the ORNL model has incorporated overly optimistic technological analyses. In the second place, other policy tools such as fuel taxes and information programs aimed at making consumer choice rational ($d = r$) will generate efficiency gains well above Baseline (with the same qualifications for space conditioning and oil water heating); however, these policy tools will have a positive effect on solar PV commercialization potential; appliance efficiency standards will have either no effect or a negative effect. Finally, even if the efficiency and demand results generated by the standards are felt desirable as opposed to the fuel tax or consumer information, it may be appropriate to obtain those results via appliance subsidies. The necessary appliance subsidies are estimated.

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