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UNCERTAINTIES IN THE PRICE-RESPONSIVENESS OF ENERGY D

AN END-USE COMPARISON OF DENMARK AND SWEDEN

(Submitted to *The Energy Journal*)

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ABSTRACT

The role that prices play in shaping the demand for energy is widely de test the hypothesis that prices are a dominant determinant of energy demand, presents a disaggregated end-use analysis of price-demand relationships, b comparison of residential energy use in Denmark and Sweden during the 1980s. The perspectives of manufacturers of energy-using equipment investigated. The merits of the comparison include the similarities in culture, age and structure of the housing stocks, taxation, and standards of living countries. Residential electricity prices diverged sharply in the 1970s and are t than two-times higher in Denmark than in Sweden. Oil has been less exp heating than electricity in both countries over most of the period studied. instances, historic trends in relative fuel choices and end-use efficiencies con hypothesis. Numerous counter-price and non-price factors contribute to this c

1. INTRODUCTION

This article explores the subject of price-induced energy- improvements and fuel choice, with special emphasis on electricity in the sector. This topic is controversial and is important because policy ma judge the degree to which future energy price increases will contribu attainment of increasingly ambitious energy policy goals pertaining to ene and end-use efficiency. Among such goals are those stemming from the reducing carbon dioxide emissions now being set by many governments.

According to economic theory, if a marketplace for energy-using (cars, motors, heating systems, etc) is responsive to energy prices, const demand--and manufacturers will offer--equipment whose efficiency-rel costs are balanced by the value of the energy saved. The degree of price should be reflected in the level of average efficiencies available in the mar variations of efficiencies among similar energy-using products. With efficiency investment decisions ("cost-responsiveness"), consumers sh discount rates similar to the rates at which they can borrow money from adjusted for the perceived efficiency-related risks and benefits. Fuel choi also be made to minimize costs.

As a starting point, traditional measures of price responsiveness (e are reviewed and discussed. To supplement the perspective provided aggregate indicators such as elasticities, the article presents a highly disa analysis of various factors that affect energy demand, e.g. end-use activity, and intensity, using the illustration of Denmark and Sweden.[2] The article with discussions of non-price and counter-price factors and the implic policy assuming that the objective is to minimize the cost of energy services (illumination, warmth, motive power, information processing, etc).

2. ELUSIVE ELASTICITIES

In an attempt to isolate the effect of economic factors on energy use, economists have used the notion of demand elasticities. Elasticities can represent the effects of energy prices, incomes, and fuel substitution on final energy demand.

Short-run elasticities generally reflect price responses that can be made without changing capital stocks of equipment (e.g. temperature adjustments, changes in lighting levels or hot water consumption, or fuel substitution in multi-fuel heating systems) whereas long-run elasticities reflect more permanent changes (e.g. changes in insulation levels or choice of appliance efficiency). There is no general convention about the time period over which short- or long-run elasticities are supposed to take effect. In fact, the operational distinction between short- and long-run elasticities is blurred because the rates of capital turnover vary dramatically among end uses.

Elasticity estimates are commonly among the strongest determinants of demand in econometric energy forecasting models. When applied in forecasting, elasticities are normally assumed by economists to behave as constants over time. Forecast results are very sensitive to the assumed value of the elasticity.

2.1 A Review of Published Elasticity Estimates

The elasticity is--in theory--a tidy concept, but in practice it is problematic. Although by no means exhaustive, Table 1 demonstrates the large range in published energy price and income elasticities and a considerable overlap in short- versus long-run estimates. Tests of statistical significance and uncertainties rarely accompany published elasticity estimates.

Most studies focus on the residential sector. For residential electricity, the long-run elasticity estimates vary by a factor of fifty (-0.05 to -2.5) and short-run estimates (excluding two positive estimates) vary by a factor of seventeen (-0.05 to -0.88). One notable item in the Table is the pair of price elasticity estimates for specific appliances (refrigerators and freezers). The significant difference in the estimates suggests that price responsiveness may vary among energy end uses.

A review by Bohi and Zimmerman identified only two studies of commercial-sector elasticities for electricity demand.[3] The determination of industrial price elasticities is complicated by the great heterogeneity of the various sub-sectors, the difficulty of isolating the effects of structural change, and possibilities for self-generation of electricity and heat. Short-run industrial electricity price elasticities in the Table vary by a factor of seven (from -0.04 to -0.27) and long-run estimates vary by a factor of fifty (-0.12 to -3.55).

Estimates vary even when isolating the comparison to one styl
one end-use sector, and one fuel. Applying different models to the sa
can yield short-run price elasticity estimates that vary by a factor of m
The resulting dilemma is well summarized by Bohi:

> "If policy makers turn to research in this area for guidance, tl
> be confronted with a range of numbers that is frequently so
> offers little direction. These disparities can affect the enthusi
> a given analytical position, or they can be used to support
> disparate positions."[5]

Particularly striking are the results for one longitudinal stu
(Figure 1), where short-run residential electricity elasticities vary
+0.09 depending on the year. Variation in U.S. residential el
elasticities was observed for the United States by Chern and Bouis,
1955 and 1978 short-run elasticities steadily declined in absolute val
to -0.133 and long-run elasticities declined from -1.360 to -0.498.[6]

The origins of the variations in elasticity estimates are uncl
extent they reflect true differences in price responsiveness a
populations. But in addition, they reflect the quality and completenes
(prices and energy demand), weather-normalization procedures
characterization of the tariff structures. Often, due to lack of data, no
options are included or the costs of those options properly characte
often the case for district heating and wood-based heating.

3. AN END-USE PERSPECTIVE ON ENERGY PRICE-RESPON

The lack of consensus on elasticities points to the need for alte
of measuring and analyzing the effects of energy prices. Part of the re
that elasticity-based analyses are almost universally limited to ag
demand, which conceals the particular modes of price response. A en
approach can be valuable because energy forecasting models and pol
increasingly applied from an end-use perspective.

3.1 Cross-Country Comparisons: Denmark and Sweden

Since the early 1960s, Denmark has used 30% to 40% as muc
Sweden. In 1987, total electricity use in Sweden was 14,100 k
compared with 5,400 kWh/capita in Denmark. Averaged ov
population, electricity use for heating is eight-times higher in S
Denmark. These differences existed long before the energy crises of
electric space heating appeared in Sweden in the early 1960s, a decad
in Denmark. As of 1987, electricity met approximately 40% of fi
energy use in Sweden and 20% in Denmark, in each case rou
contribution in 1972.

This section compares historic relationships between energy prices and end-use data in Denmark and Sweden, with emphasis on electricity use in the household sector. The comparison provides one way to test the hypothesis that the presence of such price differences should have lead to corresponding differences in fuel choices and the efficiency of electricity use. Additional statistics for Sweden provide an in-depth view of inter-fuel competition between oil and electricity over a period of ten years. Results from a survey of the manufacturers of energy-using equipment, and their perspectives on the issue of price responsiveness, are also presented.

The cross-country comparison includes a time-span long enough to observe short-term as well as long-term price responses. The merits of the comparison include the similarities in culture, geography, age and structure of the housing stocks, and standards of living in Denmark and Sweden (Table 2). Aside from energy taxation, income taxes and value-added taxes on energy-using equipment are similar in the two countries. Where the end-use data allow, single-family statistics are separated from multi-family statistics to control for the bias of differing proportions of these housing types across time and between the two countries.

Residential electricity prices were similar in Denmark and Sweden between the mid-1960s and the first oil crisis. In the early 1970s, household electricity prices diverged sharply and by 1988 prices were more than two-times higher in Denmark (13 cents/kWh) than in Sweden (6 cents/kWh). Between 1970 and 1988, real prices declined by 0.7%/year in Sweden and increased by 2.5%/year in Denmark (Figure 2). Corresponding electricity-to-oil price ratios are shown in Figure 3. Because many more customers have the lower heating price in Sweden than in Denmark, the difference in consumers' *variable* costs between the countries is greater than that of average costs. Time-of-use pricing is so new in both countries that it does not enter the comparison presented here.

Electricity prices in Denmark are today among the highest of industrial countries whereas Sweden's are among the lowest. Given this difference, economic theory would predict electricity intensities in the 1970s to be similar in the two countries and then to decline more in Denmark than in Sweden. Concerning electric space heating, we would also expect efficiencies to be greater in Denmark and little or no increase in the percentage of new homes choosing electricity.

The statistical bureaus and utility associations of each country regularly compile energy-use data.[7] Primary data on appliance ownership and the electricity use per appliance in the stock have been compiled at Vattenfall by Malinen[8] and at the Danish Association of Electric Utilities Research Center (DEFU) by Moeller.[9] Both of these sources employ similar methods for gathering raw data, including national surveys, compilations of standardized test results (from *Konsumentverket* in Sweden and from *Statens Husholdningsraad* in Denmark), and from interviews with manufacturers. Both treat refrigeration appliances especially carefully, using stock-vintage models to trace year-by-year average efficiencies. Various primary data sources have been synthesized by Carlsson[10] and by the International E
group at Lawrence Berkeley Laboratory.[11]

3.1.1 Appliances and domestic hot water heating

A decade of changes in appliance electricity use are summarize
The base-year comparison of the two countries generally shows Denm
electricity per appliance than Sweden, although average electricity
similar at the time. In most cases, larger reductions in per-appliance
have occurred in Sweden than in Denmark (Figure 4). This is counter
in prices and considering that a greater proportion of appliances were
stock during the 1978-1987 decade in Denmark than in Sweden.

A combination of structural factors and energy intensities dete
demand. In 1987, total household appliance electricity use was appro
lower in Denmark than in Sweden. Half of the difference can be expla
numbers of appliances in Denmark, and half of the remainder is
smaller appliances (for refrigeration appliances). The overall intensit
electricity use is perhaps 5% lower in Denmark.

Figure 5 illustrates one instance in Sweden in which total elect
declined while prices *also* declined, even after adjusting for the effect
saturations. Since 1980, the number of refrigerators, freezers, and
units increased by approximately one million, while electricity use de
terawatt-hour. Had efficiencies remained at the levels of the 19
demand in 1987 would have been 12 TWh versus its actual valu
Between 1960 and 1987, real electricity prices declined by approximate

More detailed information, in the form of measured electricity
model of various appliances on the market are available for both cour
6, for example, shows one data point for each refrigeration app
available in Denmark and Sweden in 1988. Based on electricity pric
economic theory would expect the "clouds" of appliances offered in D
shifted unambiguously downwards and to be more tightly clustered
much less with Sweden's "clouds". However, no clear indication of the
be seen. Consumers in both countries are today buying refrigeration a
use approximately 20% less electricity than the average in the stock, an
new size-adjusted efficiencies (kWh/liter) are approximately the s
countries.[13]

The scatter of efficiencies at a given volume could be expec
trade-offs between high first cost and lower operating costs or the tend
and electricity use per unit volume to decline as overall volume increas
the most common sizes of refrigerators (150-200 liters) display a 3.5-fol
intensity for a similar price. This gap grows to 7-fold if the LER 20

both countries, is included (Figure 7). Note that the most expensive appliances are not the most efficient.

Tested consumption and purchase-price data are available for other appliances. Electricity use in clothes washers varies by a factor of two (from 0.5 kWh/kg clothes to 1.0 kWh/kg) and does not correspond with purchase price or washing capacity. The data for clothes dryers also reveal virtually no correspondence between the purchase price, washing capacity, and electricity per kilogram of laundry dried. Among the dish-washers recently tested, electricity use varied between 200 and 550 kWh/year (cool-wash cycle) and 400 and 1200 kWh/year (warm-wash cycle).[14]

Electricity is used to heat domestic tap water in both countries, and per-household consumption has been roughly unchanged throughout the 70s and 80s--at about 2600 kWh/year in Denmark and 3500 kWh/year in Sweden, pre-dating the divergence of prices. The saturation of separate electric water heating is 12% in Denmark, and 32% in Sweden.[15] Data for electric hot water heaters (tanks separate from space-heating equipment) currently sold in Sweden show an almost five-fold range in efficiencies (stand-by losses). Again, there is no correlation between purchase price and efficiency. In fact, the most efficient model is also one of the least expensive (Figure 8). It is significant to observe this effect for water heaters, which have little non-energy amenity value compared with other appliances.

3.1.2 Appliance manufacturer perspectives

To supplement the assessment of household appliance data, this section presents the results of a survey of appliance manufacturers.[16] To the extent that their expressed views reflect actual internal policies, the results indicate the role of energy efficiency and energy prices in product development, marketing, and consumer decisionmaking in the Swedish marketplace.

Among various amenities that affect consumer purchasing decisions, manufacturers ranked energy-efficiency lowest or next to lowest on a scale of 1 to 6 and purchase price highest or second to highest. Other factors ranked were color/style, reliability, function, and "name" of the maker. There was no consensus about whether payback time was a more important factor than "green" (environmentalist) values. In consumer decisions of whether or not to buy an efficient appliance, Cylinda, Brdr. Gram A/S, and Electrolux thought that payback time was of secondary importance.

The respondents answered affirmatively that the price paid for electricity by their customers had some influence on how appliances are currently designed but most hastened to add that marketplaces outside of Sweden have the greatest effect on their energy-related design decisions. All respondents indicated that the Swedish marketplace constituted a relatively small part of their worldwide sales. Some respondents felt that guidelines and standards in other countries affect
of models that they sell in Sweden.

Manufacturers differed widely on their rating of how important
projected 50% electricity price increase would be to the way con
among appliances currently on the market (providing scores from 2 t
where "5" represented the largest effect). Most manufacturers did n
energy price increases will determine whether or not they introdu
efficient appliances to the Swedish marketplace.

3.1.3 Space heating

In 1970, before any sign of the impending oil crisis, electric he
appearing in Denmark while in Sweden a long-standing tradition of el
had brought the fraction to about 10% of the single-family housing st
the 1970s and 1980s, saturation rates continued to increase in
Denmark. By 1986, 41% of single-family homes in Sweden used elec
primary heating fuel versus 11% in Denmark. Between 1980 and 198
detached single-family homes had electric heating systems in Denmar
Sweden.[17] Almost no corresponding changes occurred in the multi-fa
the two countries. Today, electric space heating plays a large ro
electricity demand in Sweden and a relatively small role in Denmark
~10% of total electricity consumption).

For most of the 1970s and 1980s, the costs of heating with
Denmark and Sweden were higher than those of oil (on a useful h
Sweden there was a much greater effort to achieve fuel flexibility tha
Today, Sweden has a far lower saturation of oil-only heating system
homes) than does Denmark (50% of all homes) (Figure 9). One-thi
area in single-family homes in Sweden is heated with a combination
wood, and/or oil. In 1986, approximately 6% of Danish households u
in combination with other fuels, versus 30% in Sweden.

In contrast to the pronounced differences in structural factors, t
electric heating is relatively similar in Denmark and Sweden. For seve
is misleading to make such comparisons simply on the basis of pri
heating (MWh/house, averaged over all homes in the electric-heated
the proportion of electric-heated homes built in Denmark since th
stringent thermal standards is greater than that in Sweden. Second, el
has been introduced into older Swedish homes to a far greater extent
the case in Denmark. Third, household sizes and weather condition
that lead to lower heating needs in Denmark than in Sweden. Corr
third factor (but not the first two) results in a heating intensity (k
day) about 20% lower in Denmark than in Sweden.

To get a clearer view, the use of electricity in *new* homes should be compared over time. After normalizing for home size and weather conditions, the electricity intensity of new Danish and Swedish homes has been quite similar through the 1960s, 70s, and 80s (Figure 10). The thermal insulation levels in Swedish and Danish homes are today among the lowest in the world.[18]

Available evidence suggests that the difference in indoor temperatures is no more than 1-2°C between the two countries. Carlsson reports average indoor temperatures for Sweden at approximately 21°C during the 1970 to 1985 period.[19] In Danish surveys, 38% of households reported indoor temperatures of 21°C or higher in 1981 and a trend towards increasing indoor temperatures to 61% at 21°C or higher in 1987. Lower Danish indoor temperatures during the early 1980s likely reflect a combination of the response to rapidly increasing prices and to an active government campaign for keeping temperatures at or below 19°C.[20]

3.1.4 Inter-fuel competition

Inter-fuel substitution can be one of the most pronounced and rapid forms of price-responsiveness. Large historic swings in the relative prices of oil and electricity in Sweden provide an opportunity to examine this process in homes with multiple-fuel capabilities.

In 1978, 6% of the electricity used for heating single-family dwellings was consumed in multi-fuel boilers; the fraction grew to 35% (~7 TWh) in the mid-1980s. As oil prices escalated during the late 1970s and early 1980s, total electricity use in homes with multi-fuel heating systems increased from approximately 2,700 kWh/year to approximately 20,000 kWh/year. However, electricity was more expensive than oil (on an operating-cost basis) during this period. Subsequently, electricity became less expensive than oil for approximately four years (Figure 3).

Between 1985 and 1986, oil prices declined by one-third in Sweden and the ratio of electricity prices to oil prices rose sharply from 0.85-to-1 to 1.37-to-1, making oil the preferred fuel from a variable-cost standpoint. As the price ratio changed to favor oil, the share of total floor area heated only by oil increased by less than two percentage points. In 1978, 32% of single-family households reported using oil only versus 13% in 1986 (although 51% of the homes are *able* to use only oil). The ratio of electricity to oil prices was the same in 1978 and 1986.

Electricity and oil intensity trends in the ~300,000 homes that could use both forms of energy for heating confirms some substitution towards oil since 1985 (Figure 11). In 1979, such homes derived almost 95% of their combined space and water heating needs from oil, using electricity for the remaining 5%. In 1988 electricity and oil were used in equal proportions. During the 1980-1984 period when it was less expensive to use electricity, oil's contribution to heating remained between 45% and 85%. As a measure of the incentive to switch fuels, the exclusive use of oil after 1985 would save households approximately $400/year in heating
costs compared to the average actual mix of oil and electricity chos
fuel substitution did not occur after 1985, is surprising considering
investment was necessary to switch fuels in these homes.

The trends for homes that could use oil, wood, or electricity
to those just described. Notably, there is no clear indication of substi
wood in these homes. If this were the case, the slope of the curve sh

* * *

Given the large price differences, the comparison of Denma
showed numerous counter-intuitive trends in end-use efficiencies a
Structural changes, such as increases in the size of the housing stock
holdings have generally had a greater effect on aggregate electrici
have trends in energy efficiency. These structural changes general
savings resulting from increased efficiency. This is especially true
space heating demand, which, despite significant efficiency improven
in both countries. The main finding is that the degree of price-re
often very low in the residential sector. In an effort to better und
trends described above do not easily fit with economic theory, th
sections discuss counter-price and non-price factors.

4. COUNTER-PRICE FACTORS

Regardless of the level or structure of energy tariffs, various
factors can work to diminish the impact prices might have in a perfe
This section discusses counter-price factors related to tariff desi
information, and the effect of trade-offs between higher equipment
operating (energy) costs.

4.1 Tariff Structures That Inhibit The Price Signal

The quality and efficacy of the "price signal" depends on
Tariffs are sometimes engineered to attenuate the price signal, there
demand growth, as is evidenced by a quote from the early days o
industry:

> "[N]o matter how the tariffs are structured, the goal for a
> tariff is and will remain not only to make sure of giving th
> supplier that compensation which is required to cover his c
> also to promote as far as possible an intensive use of electri
> for all those various purposes which may come into question."

In Denmark and Sweden, residential electricity tariffs are co
and variable charges. Such tariffs can have an indirect demand-
because fixed charges lead to declining unit costs as consumption inc
turn, dilutes the economic reward for reducing demand at the marg
electric heating customers pay almost four-times the fixed charges
heat with fuel (and lower variable costs) and as a result the Swedis

energy efficiency less in electrically-heated homes than in homes that heat with fuel. In recent decades, the fixed-charge contribution to total Swedish electricity prices has been steadily increased through changes in rate design.

Compounding the problem of tariffs that dilute the price signal, energy bills are often uninformative and difficult to decipher. Further complicating the issue, residential consumers in Denmark and Sweden pay only one "real" electricity bill per year, before which they pay three estimated bills based on the previous year's consumption. A related problem arises if energy consumers do not pay for energy in proportion to their consumption, as is the case for apartment dwellers where total costs are commonly averaged over all tenants.

4.2 Insufficient Information about Energy Costs, Prices, and Savings Opportunities

In some cases consumers lack the most basic forms of information needed to facilitate price responsiveness. For example, in 1981 a survey of different regions in Sweden showed that up to 30% of the consumers did not know the price they paid for electricity.[22] A more recent survey of about 1000 Swedish single-family households revealed that only 30% would venture a guess at the price (and the average guess was 20% higher than the real price).[23] These households also tended to (incorrectly) think that electric heating was cheaper than oil heating. Among the customers with electric heating, 85% knew their consumption within plus-or-minus 25% (4000 kWh/year); 65% of the non-electric heating customers could estimate their demand within 25% of the actual value.

Kempton has noted counter-price factors related to misconceptions about energy. Consumers that focus on the costs, rather than the quantities, of energy they use can fail to see that they have been successful in attempts to reduce their energy use.[24] This occurs when energy prices are rising while demand declines. Consumers also have very imprecise perceptions of the importance and function of various end uses, e.g. the belief that lighting is a dominant load and that a thermostat is a "valve" rather than a "switch".

Even perfect information and clear price signals may fail to affect consumer behavior. When the aforementioned Swedish survey asked how households would react to a higher price, only about one-third said that they would use less electricity and more than 40% believed they could not save any electricity. Surprisingly, only 10% said that their response would depend on the *magnitude* of the price increase. Even in Denmark, with its higher prices, only about half of the households feel that the price of energy effects their consumption habits.[25] Part of the explanation is that consumers will display a limited response if the resulting energy *bills* are small compared to income and other household costs. For example, households in Denmark and Sweden spend about 2.5% of disposable income on electricity, on average, and 5% for electric-heated homes.[26]

4.3 Investment Inertia

Energy prices and efficiency investment costs together affect
assessment of the benefits of various kinds of price responses. The
price will be to some extent counteracted by the reluctance of consur
more on more-efficient end-use devices

Attempts have occasionally been made to quantify cost resp
estimating elasticities to the incremental purchase cost of energy-usi
(rather than to the price of the energy used by the equipment).
freezers (-0.79) and for refrigerators (-0.33) are in both cases
corresponding price elasticities.[27] In concurrence with this finding,
appliance manufacturers described in Section 3.1.2 indicated that fir
more important to all types of appliance buyers than operating costs.

Heating equipment is often the most expensive energy-using
home, and the cost varies as a function of the fuel(s) it uses. Figure
immediately preceding the 1973 oil crisis, individuals constructing n
Sweden installed electric heating equipment about 20% of the time
housing construction companies ("group-builders") chose electric heati
more than 70% of the time. The striking difference between these
home-builders suggests that the relatively low first cost of electric resis
equipment (over solid- and liquid-fuel systems) made it the system
construction companies.

Data on the behavior of households purchasing compact fluor
(CFLs) also shows a high level of first-cost sensitivity. For example,
approximately $10, about 90% of Danish households say they will pu
versus 28% at a price of $20. Figure 13 shows small differences
responsiveness of Danish, Swedish, and Dutch households participa
programs promoting CFLs. This is surprising considering that the payb
given price differs by a factor-of-two among these countries. Th
between Swedish households participating in the utility program a
participating shows that some energy consumer groups are more co
than others.

The strength of costs (versus prices) suggests that measures
price-elasticities could be used to quantify cost-responsiveness.
addressed this question by calculating an implicit market discount rate.
analyses showed these implicit discount rates to be quite high, wit
income consumers expressing the shortest time horizons.[28] Ruderma
that implicit discount rates ranged as high as ~800% (versus a 6% real
typically used by energy supply industries) with most of the values in
20% to 200%.[29] Importantly, during the entire post-oil-crisis period t
rates did not decline (and even increased in some cases), suggesti

increases and extensive information programs directed at consumers did not stimulate a more "rational" market for energy efficiency.

The acceptable payback time is an analogous indication of consumers' willingness to invest in energy efficiency. According to annual surveys, approximately 20% of Danish households report that they will invest in conservation measures with a payback of one year.[30] Similar behavior is displayed by service-sector[31] and industrial-sector[32] energy consumers. The existence of such short implicit payback times translates into a perceived potential for saving energy that is on the order of one-fifth the size of the potential defined from a societal-economic perspective.

The perception of consumer's willingness to pay more for efficient appliances is important to manufacturer's design decisions. Among the appliance manufacturers who were interviewed in the previously mentioned survey, there was general agreement that owner-occupants require a three- to five-year payback when they invest in more efficient appliances and that landlords require a three-year payback. Electrolux noted that landlords who pay the bill might be satisfied with a payback time between four and five years, but those who don't pay the energy bill would not tolerate any extra investment. The answers for home builders ranged from zero years to three years. The Swedish Consumer Product Agency (*Konsumentverket*) estimates that the owner-occupant's payback at two or three years, but that "green" (environmental) values are more important than the payback time.

One factor that contributes to limited willingness to accept even short payback times is the existence of situations where the costs and benefits of increasing efficiency are paid and received by different actors. Such split incentives occur, for example, when intermediaries (building designers, developers, construction contractors, appliance manufacturers, landlords, and others) make first-cost energy decisions but do not pay for the ongoing energy costs. In Denmark and Sweden, landlords own 16% and 9% of all single-family dwellings and 80% and 68% of all multi-family dwellings. An even smaller percentage of the new dwellings are owner-occupied.[33]

5. NON-PRICE FACTORS

Non-price factors can influence energy demand in ways that either amplify or offset price-related reductions in energy intensities. Non-price factors may be grouped into the following categories.[34] Most of these factors have a price-related dimension, but here only the non-price aspects are discussed.

o Changes in equipment stocks (e.g. appliance saturations)
o Changes in activity levels (e.g. composition of economic activity)
o Technological advancement (e.g. miniaturization; reduced materials intensity)
o Introduction of new end uses (e.g. electrothermal processes)
o Policies (e.g. thermal standards for buildings; conservation programs)
o Demographic trends (e.g. the climate-related distributions of the housing stock)
o Lifestyles (e.g. the number of people per household; time budgets)
o Consumer preferences (e.g. convenience; safety; "green" consumeris
o Non-energy benefits from improved efficiency (e.g. reduced labour
o Ease of access to efficient products (e.g. availability of money or pr
o Infrastructure planning (e.g. master-planning of electric-heated neig
o Environmentally-driven decisions (e.g. reduced use of CFC-based i
o Insufficient competition (e.g. disincentives to commercialize new pr
o Income-related effects (e.g. amount of capital available for efficienc

As a suggestion of the strength of non-price factors in the Swe
sector, annual electricity use among single-family homes with d
heating displays a factor of two-to-four (and more at the extreme
energy use for homes of the same size, vintage, and climate zone.[35]
especially significant considering that homes using electricity in co
other heating fuels are not included.

5.1 Technological Change

The "natural" course of technological change often resu
efficiency gains. Such features can become popular if they decre
costs, increase control or provide some other amenity. Energy savi
incidental benefit, rather than as the primary motivation for
improved product. Substitution among materials also has
implications. The switch from fiber insulation to foam insulation i
appliances is an often-cited example. This change--which occurred
period shown in Figure 5--was made to reduce wall thickness and p
rather than to save energy.

For decades before the first energy crisis, the energy inten
materials and of many energy-using devices were declining, s
rapidly.[36] The long-term trends in residential appliance efficienc
reflect an average (pre oil-crisis) annual reduction in electricity use of
refrigerators and 0.7%/year for freezers between 1960 and 1972. Bet
1975 in Denmark, electricity use declined by 1.8%/year in refrigerat
in freezers, 1.8%/year in combination refrigerator-freezers, 0.9%
washers, 1.3%/year in clothes-washers, and 0.8%/year in clothes-drye

5.2 Heating Policies

Contrary to the price signals, the thermal integrity of new Sw
today higher than that of Danish homes. One can look to thermal s
possible explanation of these trends, but standards did not begin to
until the late 1970s, well after the thermal integrity of new homes beg
It was not the standards that lead these improvements, but ra
construction industry improved its techniques and then the codes wer
match current practice.[38]

Policies that promoted substitution of electricity for oil used methods other than standards or manipulation of relative oil and electricity prices. The combination of tax-deductible interest, lower down payments, and availability of government financing to all types of home buyers enabled the National Housing Board (*Bostadsstyrelsen*)to influence the heating systems and thermal integrity in the vast majority of homes built. The loan system encouraged electric heating by helping to finance the cost of heat pumps and of thicker walls. Heat pumps were rarely used in 1981 but reached about 30% of new single-family homes by 1987.[39] The transition to electric boilers and multifuel systems was partly stimulated by the introduction of the ELAK thermal standard, which required homes with electric-resistance heating to use more insulation than other homes.

In addition, during the 70s and 80s, national programs helped to directly finance the purchase of electric-using heating equipment in single- and multi-family homes. Roughly 200,000 homes participating in this program between 1977 and 1983 received $200 million (~1150 MSEK) in government loans and/or grants.[40]

Today, about 80% of new homes in Sweden are partly or completely electric-heated. The Swedish Building Norm (SBN) was revised in January 1989 to require all buildings, regardless of fuel type, to conform to the relatively high thermal integrity levels formerly required only of electrically-heated buildings. The result of this will likely be an increasing share of new buildings with electric-only heating systems because the relatively high cost of central heating systems was to some extent previously offset by lower insulation costs.

As electric heating was becoming the driving force of Swedish electricity demand in the 70s and 80s, Denmark initiated a number of policies--aside from pricing and thermal standards--that no doubt curbed the numbers of electric heated homes and increased their energy efficiency. These policies included:[41]

(1) Extensive information programs.

(2) The Act on the Reduction of Energy Consumption in Buildings (1981), which supported a goal of 20% reduction of space heating in residential buildings. The Act also required retrofits of all public buildings. The goal was to be attained with the help of government-trained energy auditors, a building certification scheme, and subsidies to pay for the improvements recommended by auditors. The Act contained a provision to guarantee the incremental loan costs related to energy-saving retrofits.

(3) Grant programs (implemented in two phases) included almost 1 billion Danish kronor ($130 million).

(4) A 1982 amendment to the "Law of Rent" required multi-family building owners to install individual meters if called for by a majority tenant vote.

(5) The installation of primary electric heating systems in new homes has long been actively discouraged and was recently banned in many areas of Denmark. In the areas where it is allowed, electric-heated homes must be more
than other homes.

5.3 Infrastructure Planning

In the past two decades, various infrastructure-related facto
the heating market, working in opposite directions in the two countri
the effect of infrastructure planning on the structure of space heatin
the earlier comparison of the single- and multi-family housing sto
The main difference between Denmark and Sweden is in single-famil

For decades, cultivating the expanded use of electricity has
with the goals of the Swedish government (e.g. stimulating the nucle
decreasing oil dependence) and those of electric utilities (e.g. inc
share and revenues). This commonalty of goals gave tremendo
momentum to the development of electric heating. In certain areas,
policy inhibited expansion of the market for district heating. Centra
plants competed with combined-heat-and-power (CHP) plants by
penetrating the heating market (all sectors) and the electricity sup
part of their marketing efforts, utilities induced the housing construc
choose electric space heating in return for guaranteed long-
electricity.[42]

At the root of the tug-of-war between policies encouraging
and those encouraging electric heating in Sweden are the long-stand
interest between local distributors/municipalities and the national po
Decades ago, the use of CHP became attractive to many cities, wh
control and flexibility. Meanwhile, Sweden's nuclear power
blossoming and came into direct competitive conflict with propos
plants. No doubt part of the reason some cities implemented grea
district heating than others was their success in this "battle". The
collectively-built homes with district heating fell from 50% in the lat
by 1987. This difference was made up with electric heating (Figure 1

In Denmark, on the other hand, oil independence was sought
of intensive conservation, promotion of renewables, and use of C
Sweden delivered roughly 6 TWh_{th} of district heating in cog
electricity, or 16% of all district heating, while Denmark delivered
cogeneration, or 50% of district heating supply.[44] Denmark's m
development of CHP, and higher densities of single-family home co
allowed for more competition between district heating and electric h
been the case in Sweden. In Denmark, 27% of single-family homes
district heating versus 5% of Swedish single-family homes. District
in approximately 60% of multi-family homes in both countries.

5.4 Lifestyles, Consumer Preferences, and Manufacturer Behavior

Consumer lifestyles have a direct effect on energy demand but little relation to energy prices.[45] For example, a declining number of people per household (as has been the case in both Denmark and Sweden) translates into higher per-capita energy use. The amount of time spent in the home is also important. As an example, between 1970 and 1985 the time spent in Swedish vacation homes tripled (as did the use of electricity).[46]

Household composition also has a direct relevance to energy use. In Sweden, people living alone have one-third fewer appliances than households with children. Among pensioners living alone, there are 7.6 dish-washers per 100 households versus 63 per 100 households for families.[47]

To characterize the varieties of consumer preferences, the Electric Power Research Institute (EPRI) has suggested a "taxonomy" of six electricity consumer types and a corresponding set of nine motivations for energy-related decisions.[48] According to EPRI's evaluation, the price of electricity is never the single strongest motivation for consumers.

During a field test 2000 super-efficient LER-200 refrigerators were put on the market in Denmark. According to follow-up market research by the manufacturer, only a small segment of the population bought the refrigerators.[49] Environmentally-oriented personal values were a the most important characteristics of the buyers. People buying the LER-200 (it has a $50 price premium over the manufacturer's comparable conventional model) generally did so with no knowledge of, or interest in, the economic payback. The buyers were not responding to the price of energy or to the size of the efficiency investment involved.

Another variable that may contribute to sub-optimal efficiency is insufficient competition among manufacturers of energy-using equipment. For refrigeration appliances, there are roughly 15 "different" makers acting in the Swedish market. The market, however, is not as heterogeneous as it appears. The implications of alliances such as that of Electrolux, Electro-Helios, and Husqvarna are hard to interpret. How concentrated is a market where Zanuzzi (an Italian subsidiary of Electrolux) makes two of the AEG units; Derby makes a Bosch unit and all Belindha units; Electrolux in turn manufacturers four Siemens units; those Siemens units not manufactured by Electrolux are made instead by Bosch-Siemens; and Vestfrost manufacturers two Philips units and many Cylinda units?[50]

6. IMPLICATIONS FOR POLICY AND PLANNING

6.1. Limitations of the Elasticity Approach

As discussed earlier, demand elasticities are fundamental to econometric methods for energy demand forecasting. The elasticity approach has serious limitations, both practical and conceptual.

The large range of published elasticity estimates shown in T that it is difficult to select the "right" elasticity. The consequences are illustrated in Figure 14. The beginning value on the graph hypothetical estimate of Sweden's demand for electricity in 2 economic growth but no improvement in end-use efficiencies. T sloping curves show demand assuming various elasticities. The u large. For example, with a 50% real price increase actual dem anywhere in the range of 135 TWh and 175 TWh for elasticities betw 0.25. To put his in perspective, the 40-TWh "gap" is the electrical large 1-GW power plants operating at a 60% capacity factor.

Further complicating the problem, for practical purposes ela be viewed as *variables,* rather than fixed *parameters*. The indicatio hysterisis effect in Figure 11 suggest that cross-price elasticities als time. Thus, the value of the forecasting and planning methods base comes into question. After Kouris,

> "In this respect projecting energy demand would necessit projection of [changes in] elasticities first ... Thus the notio 'true' elasticity is more an illusion than a reality ... it is cer moving target and not a value that remains unaltered through It is this uncertainty of future parameter values that have led forecasters to follow the scenario approach and also construct with judgmental elasticities."[51]

A family of problems emerge when elasticity estimates (by d on historic data) are used to model future price responsiveness:

1. An elasticity estimate resulting from a model fit over many represents an average value for a range of price levels that prevai time period. Such an estimate can mis-state price responses if the is itself a function of price level. Various authors have found that oil demand elasticities are higher during periods of declining pric periods of increasing prices.[52]
2. Price-responsiveness may be expected to decline as en improvements are made. As consumers "skim the cream" by c payback measures, marginal investments will require relative increases to be considered cost-effective.
3. On the other hand, technological advances and/or policy-based stimulate price responses not previously possible. As policies or trends lead to reduced incremental efficiency investment costs, will be made at a faster rate, even if prices are unchanged.
4. Other factors affecting elasticities change over time, including cons the consumer information environment, and the format and fre

price "signal", i.e. the utility bill. Historic elasticity estimates can lose their value if future tariff structures differ from historic tariff structures. Moreover, diverse tariff structures make it increasingly problematic to develop the basic data sets from which elasticities are to be estimated.

Aside from the problems with their predictive power, elasticity analyses do not shed light on the possibilities of how to increase the existing level of price responsiveness, on which end uses are most likely to be affected, or on the attractiveness of reducing demand by a given amount. As a result, elasticity-based forecasts can not reveal potentially "desirable" or possible energy futures.

An elasticity estimate taken alone does not help policy makers to understand the investment behavior of energy consumers. An elasticity of -0.5 may correspond to a sector where energy consumers have a tendency to make efficiency investments with five-year paybacks while another -0.5 elasticity (e.g., for a different end use or fuel or country) may reflect efficiency investments corresponding to a 1-year payback. This could come about if the two groups face different investment costs, or have differing access to information, capital, and technical options.

In summary, aside from uncertainties in their estimation, elasticities do not always convey the types of end-use-based information on consumer decisionmaking and modes of price responsiveness that are important to energy planners. Innovation in energy demand modeling can help to resolve some of these issues. Modelers should endeavor to incorporate a higher degree of market segmentation in order to treat different consumer groups (e.g. renters versus owners), improve the understanding of asymmetries in fuel-substitution behavior (which seems to favor conversion towards electricity), account for counter- and non-price factors, and more explicitly tracking the end-use dynamics in the stocks of energy-using equipment. Especially important is the inclusion of modeling of the interaction of energy prices and equipment costs, as has been done with the market-discount-rate approach.[53] Depending on the marketplace being modeled, the influences on equipment manufacturers emanating from outside that market can also be important.

6.2. Price-Enhancing Strategies

Energy policy analysis is becoming increasingly goal-oriented, as evidenced by the frequent use of scenarios of *desired* energy demand rather than forecasts of *likely* energy demand. This shift in emphasis raises questions of the likely contribution that higher energy prices can make towards achieving energy-related goals. In Sweden, for example, electricity demand may have to be reduced in absolute terms in order to achieve government goals for a nuclear phase out by 2010, halting expansion of hydroelectric power, and holding CO_2 emissions at current levels. In a recent set of scenarios for Sweden, cost-effective ways have been shown for meeting these objectives.[54] According to the power industry's own

forecast, however, the planned 50% price increase achieves onl
efficiency improvement needed to reach the government goals.[55]

There appear to be many opportunities for new "price-enhanc
such as improving the poor energy information environment in wh
make decisions. A logical place to begin is with improved tariff de
billing methods, and more frequent billing.[56]

An important "lever" that can be used to enhance the effect
mechanism that reduces initial efficiency-related investments and/or
the costs out over time. Recent European lighting programs targ
households in Austria, Denmark, Germany, Sweden, and the Netherl
such financial incentives can affect the first-cost sensitivity of co
Sweden, residential programs were responsible for a 30% increase in
sales and 80% to 90% increase in sales to households.

It must be stressed, however, that over-reliance on a stri
rationale can lead planners to overlook non-economic factors es
success of conservation programs.[58] This is evidenced by the fact th
financial incentives in the European programs correlates poorly
participation rates. Lowering costs was the commonly the primary r
about 50% of the participants. In one program, other reasons for par
to try the new technology (20%), use the rebate check (10%), cha
often (10%), or to get brighter light (10%).

In addition to energy consumers, the manufacturers and sell
using equipment also display a low level of price responsiveness.
express mixed opinions about whether higher prices would
commercialization of new, more-efficient products. As we saw in
difference in electricity prices between Denmark and Sweden did nc
presence of more efficient appliances in the Danish marketplace.
government-sponsored initiatives in which financial incentives
manufacturers have more than doubled the efficiencies of their p
example is the Gram LER-200, which was designed with research su
European Community. In Sweden, the National Energy Adm
cooperation with the large buyers of appliances, orchestrated an inn
competition and guaranteed order for 500-2000 of the winning
competition lead to the design and planned commercialization o
freezers that are 35% and 55% more efficient than the previously
models. Gram and Electrolux claim that they would not have
commercialized these appliances on their own.

7. SUMMARY AND CONCLUSIONS

This article explored the hypothesis derived from economi
historic trends in energy efficiencies and fuel choices are to a

explainable (and predictable in the future) in terms of energy prices. The comparison of Denmark and Sweden and other data suggest that factors other than price have had substantial influence on the historic development of residential energy demand. The key findings are:

- End-use energy intensities converged or stayed the same in the two countries as prices diverged. Improvements in efficiency often occurred faster in Sweden than in Denmark. Instances where intensities differ significantly (e.g. water heating) pertained throughout the period of changing relative prices.
- The clearest difference between Sweden and Denmark is in the space heating markets. To the extent that prices have had an effect, it has manifested in the structural development rather than in intensities. Confounding the comparison, non-price factors have been especially strong in the heating market.
- Many Swedish households with multi-fuel capabilities choose to heat with electricity rather than with oil even when it is significantly more expensive to do so. Substitution from oil into electricity seems to occur more readily than substitution in the opposite direction.
- Even when oil is less expensive than electricity, there is significant use of electric heating in new home construction and in existing homes with multi-fuel heating systems.
- The magnitude of the observed effects varies considerably among consumer types (e.g. single-family versus multi-family households) and end uses.
- Manufacturers of energy-using equipment perceive a low level of price sensitivity among their customers and thus do not make energy efficiency a high priority in product design or marketing.

These results are attributable to a host of pervasive counter-price and non-price factors. The small cost burden often imposed by the use of energy (especially electricity) makes investments in savings a low priority, except when households and firms that wish to conserve energy for reasons other than economics. Constrained availability of district heating and various quirks of tariff design and billing practices can reinforce the reluctance to invest in efficiency or to switch among fuels.

The comparison of Denmark and Sweden also illustrates how government policy has shaped the energy supply and end-use markets, although with opposite objectives. Importantly, the approach in Denmark can be characterized as one of addressing total energy demand, whereas in Sweden the orientation was more towards oil import independence and the (related) objective of encouraging the use of electricity. Energy prices were only one of many tools used to achieve these goals.

Heavy reliance on price effects as a tool of demand-side management needlessly limits the ability to identify ways of effecting energy demand and injects substantial uncertainties into demand forecasting. In some cases, no
aimed at achieving increased energy efficiency offer more permane
price-induced behavior. Moreover, likely price increases will sti
fraction of the efficiency improvements now being identified as cos
desirable.

Achieving goals for energy and environment requires a
traditional paradigm to a more flexible and diverse approach to er
With this shift comes new (non-price) tools for affecting energy effi
choice. Such policies can enhance the effect of often weak pri
decrease uncertainties. On the demand side, this calls for improve
access to capital, market incentives, minimum efficiency standards,
research, development, and demonstration of energy-efficient techno
end, higher energy prices are probably necessary but certainly not suff

Table 1. Published energy demand elasticities.

		Price		Income	
	Sector	Short-Run	Long-Run	Short-Run	Long-Run
Electricity					
Dargay and Lundin[a]	R	-0.09	-0.62	+0.46	+0.68
(Sweden 1962-1976)					
DFE (Sweden 1950-1976)[b]	R	0.14			
Hjalmarsson and Veiderpass[c]					
(Sweden 1960)	R	-0.52		+0.68	
(Sweden 1976)	R	+0.09		+1.18	
SEAS (Denmark 1986)[d]	R	-0.15	-0.55		
ELSAM (Denmark 1988)[e]	R,C,I	-0.05 to -0.10	-0.5 to -1.0		
Hjalmarsson[f]					
(Norway, 1957-1975)	R	-0.19 to -0.24	-0.24 to -1.46	+1.1	
Bohi and Zimmerman (Review)[g]					
	R	+0.04 to -0.88	-0.05 to -2.5	-0.214 to +2.00	+0.12 to +3.00
	I	-0.10 to -0.27	-0.12 to -3.55	+0.04 to +0.87	+0.30 to +1.04
Kahn *et al* (USA 1970-1980)[h]	R	-0.06 to -0.16	-0.47 to -0.57		
EPRI (USA)[i]	R	-0.101	-1.052	+0.077	+0.802
Lundin (USA)					
(Range of 11 studies)[j]	R	-0.07 to -0.61	-0.78 to -2.50	+0.03 to +0.30	-0.46 to +1.94
Parti and Parti (USA 1980)[k]	R	-0.58		+0.15	
BChydro (Canada)[l]					
(Electric heating)	R		-0.41		
(Non-electric heating)	R		-0.28		
ORNL[m]					
(USA refrigerators, 1976)	R	-0.20			
(USA freezers, 1978)	R	-0.34			
Andersen (Denmark)[n]	I	-0.04 to -0.78			
Aggregate Energy					
IEA (1973-1982)					
(North America)	R,C		-0.60		
(Pacific OECD)	R,C		-0.70		
(Europe OECD)	R,C		-0.55		
(All OECD)	R,C		-0.59		
Chern *et al* (1960-1979)					
(8 OECD countries)[o]	R		-0.513		+0.771
Pindyck (1960-1974)[p]					
(9 OECD countries)	R		-1.05 to -1.15		+1.00
Griffin (1960-1972)[q]					
(18 OECD countries)	R,C		-0.8		+1.39
Nordhaus (7 OECD countries)[r]	R,C		-0.7		+1.09
Matsui[s]					
(Japan 1965-1972)	R,C		-0.220		+1.70
(Japan 1965 to 1977)	R,C		-0.022		+1.11
Baughman and Joskow[t]					
(USA 1968-1972)	R,C	-0.16	-0.63	+0.20	+0.80
Chern (USA 1972)[u]	R,C	-0.71		+0.44	
Parikh and Rothkopf (1970)[v]					
(Space heating)	R		-0.371		
(Non space heating)	R		-0.1		
(Total)	R,C,I		-0.118		
Kouris (UK 1961-1979)[w]	R,C,I	-0.120 to -0.539		+0.523 to +1.000	

Notes to Table 1

a. Dargay, J. and A. Lundin. 1978. *Hushaallens Energiefterfraagan: Emperiska Studieer* Energy Demand: Empirical Studies Concerning Sweden). Stockholm University, Energisystestudier, p 63.

b. DFE Rapport nr 34. 1980. *At Styra Energianvaendningen. Problem och Mojlighete* (To Affect Energy Demand: Problems and Possibilities for Swedish Energy Policy) cited in Hjalmarsson and Veiderpass.

c. *Op cit*, Ref 59.

d. SEAS estimate is for 1983 and shown here are the averages of the rates -0.5 to -0.6 0.18 (short run), as reported by the Danish Ministry of Energy (1986) in (Redego tariffer), p. 68.

e. Personal communication, J. Mikkelsson, ELSAM, May 20, 1988.

f. Hjalmarsson, L. 1979. Elefterfragans Priskansleghet. In *Elanvaendningens U* Development of Electricity Demand) Rapport fran Konsekvensutredningens B-Grup

g. *Op cit*, Ref 3.

h. E. Kahn, J. Sathaye, and D. Robbins. 1986. An Engineering-Economic Approach Elasticity of Residential Electricity Demand. *Energy Economics,* April, pp. 118-126.

i. Electric Power Research Institute, (EPRI). 1982. *Residential Demand for Electrici* 1572.

j. Lundin, A. 1978. *Hushaallens Energiefterfraagan: En Ekonometrisk Metodstudie* (Ho A Study of Empirical Models). February 1977. Stockholm University Report No. Swedish).

k. Parti, M. and C. Parti. 1980. The Total and Appliance-Specific Conditional Dem Household Sector. *The Bell Journal of Economics*, vol. 11, no. 1, pp. 309-321.

l. S.E. Gai. 1990. *Analyzing Electricity Demand Elasticity in the B.C. Hydro System: Ph* Hydro.

m. Freezers: W. Lin et al. 1976. *Fuel Choices in the Household Sector.* ORNL Report Hirst and J. Carney. 1978. *The ORNL Engineering-Economic Model of Residential E* CON-24.

n. Andersen, Fritz Moeller. (undated). *A Technical-Economic Model for The Industria Denmark.* Risoe National Laboratory. Tables 2 & 3, pp. 10-11, shows estimates for ni

o. Chern, W.S., A. Ketoff, L. Schipper, J.S. Rosse. 1983. *Residential Demand for E Cross-Sectional Analysis for Eight OECD Countries.* Lawrence Berkley Laboratory Re

p. Pindyck, R.S. 1980. International Comparisons of the Residential Demand for Ene *Review.* vol 3, no. 1, pp. 1-24. Cited in note o.

q. Griffin, J.M. 1979. *Energy Conseration in the OECD: 1980-2000*, Cambridge, Mass, B

r. Nordhaus, W.D. 1975. The Demand for Energy: An International Perspective. *Pro on Energy Demand*, W.D. Nordhaus, ed. Laxemburg, Austria. IIASA. Cited in note o

s. Matsui, K. 1979. Income and Price Elasticities of Eneryg Demand in Japan, En Report No. 46. September. Cited in note o.

t. Baughman, M.L and P.L. Joskow. 1976. Energy Consumption and Fuel Ch Commercial Customers in the United States. *Energy Systems and Policy*, vol 1. no. 4.

u. Chern, W.S. Demand and Conservation of End-Use and Primary Energy in the Res Sectors, *Energy Systems and Policy*, vol. 2. no. 3. Cited in note o.

v. Parikh, S.C. and M.H. Rothkopf. 1980. Long-run Elasticity of U.S. Energy Dem Approach. *Energy Economics*, pp. 31-36 (January).

w. The range shown corresponds to the results from applying six estimation method consumption data series.

Table 2. Comparative residential-sector statistics for Sweden (S) and Denmark (DK).

	S 1970	DK 1970	S 1980	DK 1980	S 1986	DK 1986
Population (millions)[a]	8.043	4.929	8.311	5.125	8.369	5.116
Dwellings (1000s)[b]						
Single-family	1311	1008	1618	1197	1772	1192
Multi-family	1789	735	1967	813	1953	908
Persons/dwelling[c]						
Single-family	2.91	2.96	2.81	2.76	2.75	2.68
Multi-family	2.07	2.07	1.77	1.78	1.71	1.73
Dwelling size (m^2 heated area)[d]						
Single-family	134.5	125.3	145.3	130.8	146.1	131.7
Multi-family	74.8	74.0	76.0	75.0	77.2	75.6
Percentage renter-occupied[e]	52%	53%	41%	44%	40%	43%
Single-family	19%	19%	7%	15%	9%	16%
Multi-family	76%	96%	70%	87%	68%	80%
Consumer price index[a]	100	100	242	255	387	387
Gross domestic product/capita[a] (constant 1980 SEK)	53792	42169	63181	54926	69371	75316
Disposable income/capita[f] (constant 1980 SEK)	29489	30014	33726	35323	34052	46188
Household savings rate as a percentage of disposable income[g]	4.2%	6.3%	5.0%	6.0%	-1.0%	---
Heating degree-days 18°C (average)					4090	2950
Useful energy[h]						
Space heating (Wh/m^2-degree day)						
Single-family	38.3	61.1	29.1	39.1	26.7	34.3
Multi-family	41.9	45.1	36.4	37.4	31.2	27.8

Notes to Table 2

a. *OECD National Accounts, 1960-1986.* Volume 1. 1988 Paris.

b. Sweden--SCB *Energistatistik foer flerbostadshus* (corrected printouts from Kenni Petersen), SCB *Energistatistik fore smaaahus*, and L.G. Carlsson (Ref. c). Denmark--Danmarks Statistik. *Befolkning og valg.* 1989:1, p. 7

c. L.G. Carlsson. 1989. *Energiavaendning och strukturomvandling i byggnader 1970-1985*. Byggforskningsraadet. The values shown are for the years 1974, 1982, and 1985, pp. 236-237.

d. See ref. c, pp. 238-239; years shown are 1974, 1982, and 1985)

e. Sweden--*Bostads- och byggnadssstatistisk aarsbog 1982,* pp. 230-231, and 1989, p. 262; (1985 value shown). Denmark--*Statistisk aarbog 1988.* Danmarks Statistik, pp. 48-49 and other Danmarks Statistik data.

f. Approximated as [private household consumption * (1 + savings as % of disposible income)] from Ref a.

g. *OECD Economic Outlook #45,* 1989, p. 183 (Sweden), the initial value is for 1972. Values for 1971 and 1981 for Denmark are from the *Statistisk Aarbog* (Ref. e), page 169.

h. "Useful energy" includes weather-normalized energy delivered to the home, less losses in combustion appliances. See Ref. c, pp. 250-251; years shown are 1974, 1982, and 1985.

Table 3. Structure and intensity of electricity use in residential appliances in Denmark (DK 1978-1987.[a]

	Refrigerator	Freezer	Combi Ref/Frz	Dish-washer	Clothes-washer	Clothes-dryer	Lighting	Cooking
Saturation 1978 (% of households)								
DK	77	58	29	18	56	8	100	72
S	98	64	15	24	61	18	100	90
Saturation 1987 (% of households)								
DK	75	65	35	26	64	17	100	81
S	88	79	33	30	57	27	100	93
Unit consumption 1978 (kWh/house)								
DK	348	640	758	525	433	563	600	650
S	611	1338	924	400	500	600	625	600
Unit consumption 1987 (kWh/house)								
DK	298	508	590	388	358	475	600	635
S	439	878	704	281	376	242	660	526
Change in unit consumption (%)								
DK	-17	-26	-28	-35	-21	-18	0	-2
S	-28	-34	-24	-30	-25	-60	6	-12
Change in total electricity demand (%)								
DK	-13	-7	-1	11	-2	92	4	14
S	-34	-17	74	-12	-28	-36	8	-7

Notes to Table 3: Unit energy consumption refers to electricity use in homes that have
Limited comparative appliance utilization data are reported by DEFU and Vattenfa
Sweden): clothes-washing, 265 versus 208 loads/year; clothes drying 160 versus 104 loads/
222 versus 365 loads/year. In Denmark 8% of new refrigerators have a volume grea
versus 63% in Sweden. The corresponding values for freezers are 50% and 66%, and for
26% and 80%. Data on changes in the sizes of refrigeration appliances over time are
there is no reason to suspect that there would be systematic differences in such trends
countries.

a. Data from Moeller 1989, *op cit,* Ref 9 and Matti Malinen, Vattenfall Market Branch and
CDL, *Op Cit. Ref* 7, p 56.

Figure 1. Short-run elasticities for Sweden.[59]

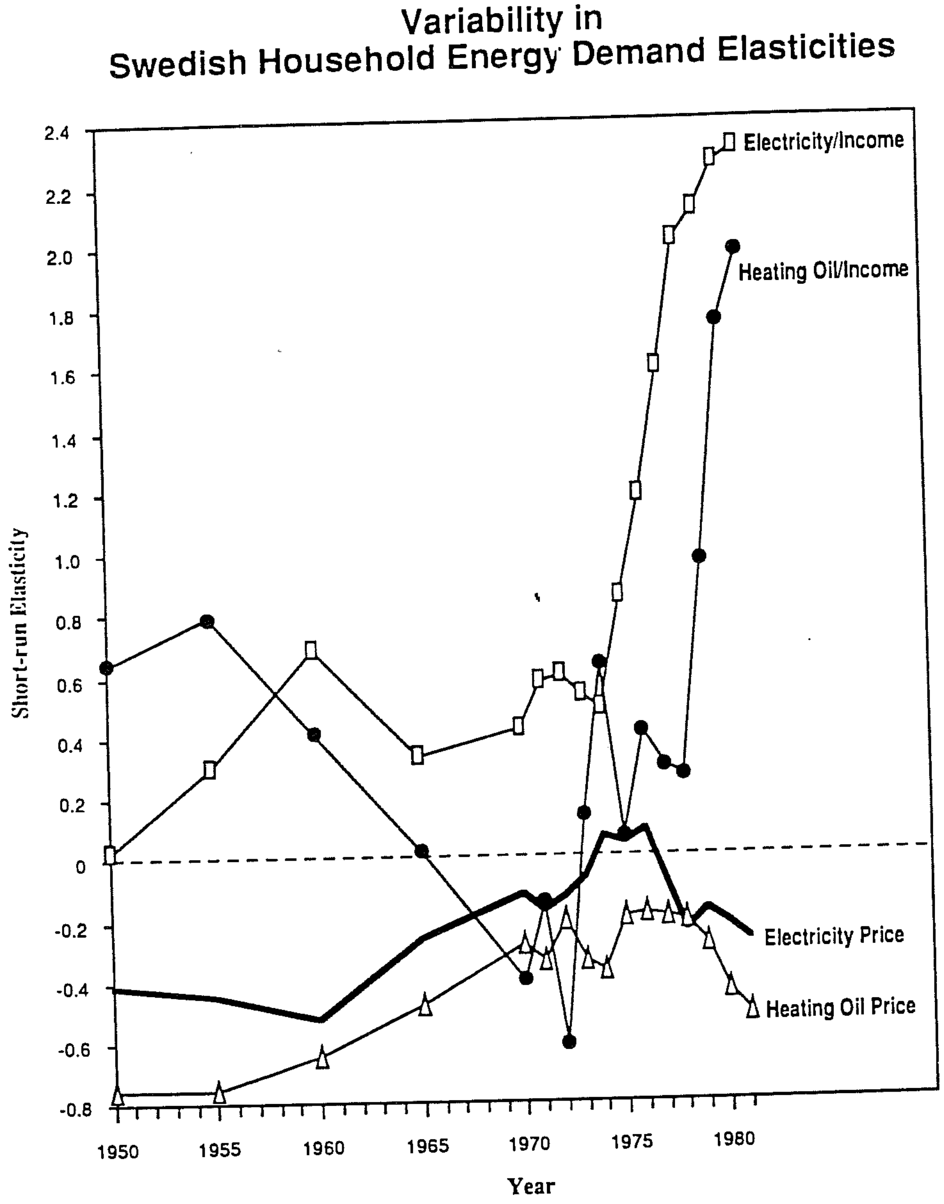


Figure 2. The prices shown are an average of the tariffs paid by electric-heatir customers (single- and multi-family buildings), weighted by the number of consume in each year, including fixed costs, variable costs, and taxes. Prices in 1970 were 24 27 oere/kWh (DK), in 1980 Swedish currencies. In 1970, electric-heating tariffs (DK) and 17 oere/kWh (S). The exchange rate in 1980 was 75.31 SEK/100 Dkr.

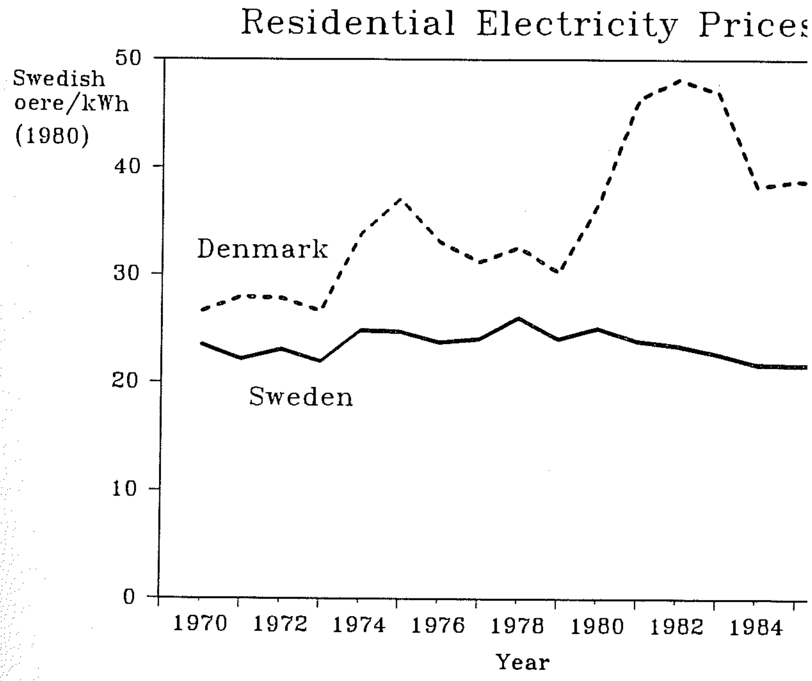


Figure 3. The price ratios include operating costs, but not equipment costs. Where the value is > 1, electricity is the less expensive heating fuel. To convert the prices of purchased energy to the price of useful energy delivered to the living space in the form of heat, the nominal price is divided by an assumed heating system efficiency of approximately 70% for oil and 90% for combination boilers that can use electricity or oil). In Denmark, both electricity and oil prices were increased after the collapse of the world oil price in 1985.

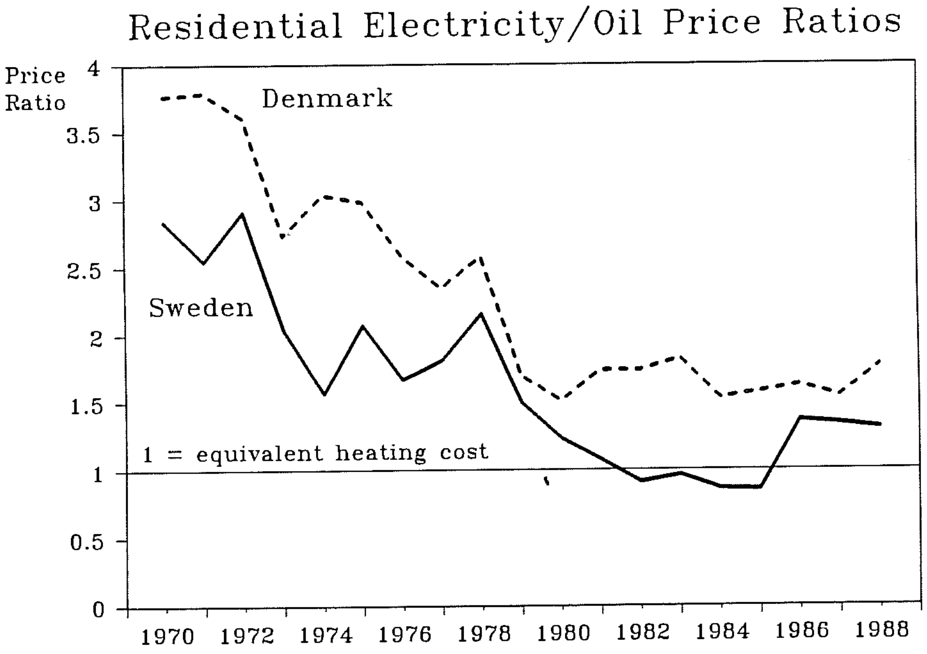


Figure 4. Values shown represent the average electricity use for appliances in the stoc consortium of manufacturers, average volumes of appliances sold were largely unck period shown in the diagrams.

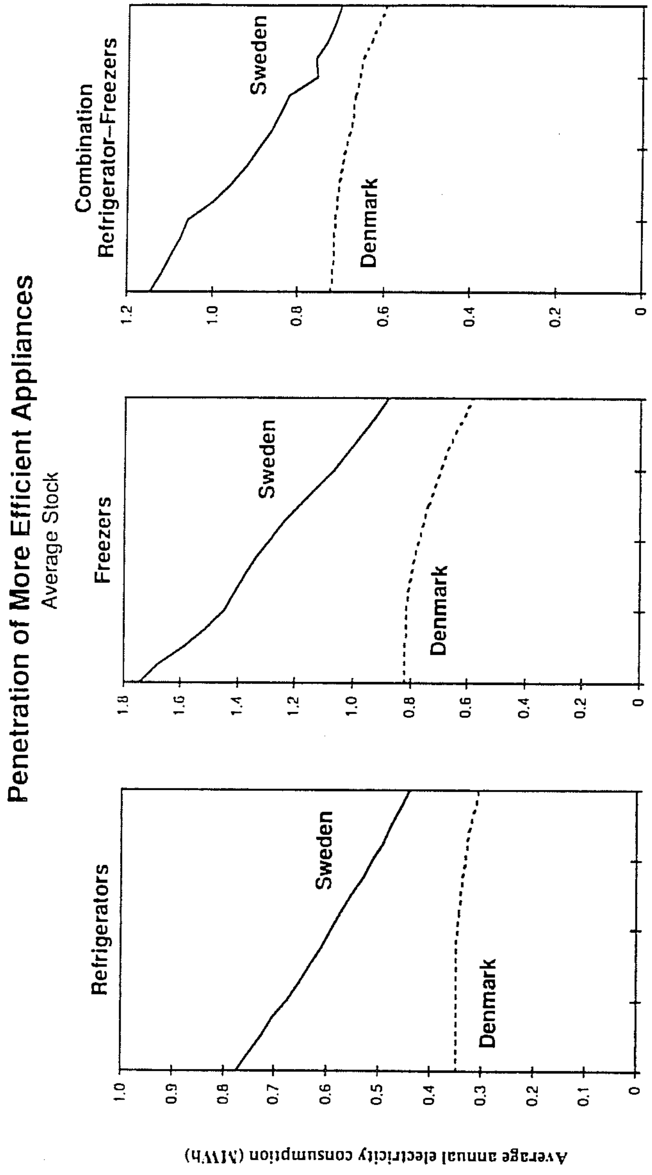


Figure 5. The effect of structural change and decreased intensity on electricity used for Swedish refrigeration appliances. The curves show cumulative electricity demand, e.g. all three classes of appliances consumed just under 5 TWh in 1987.

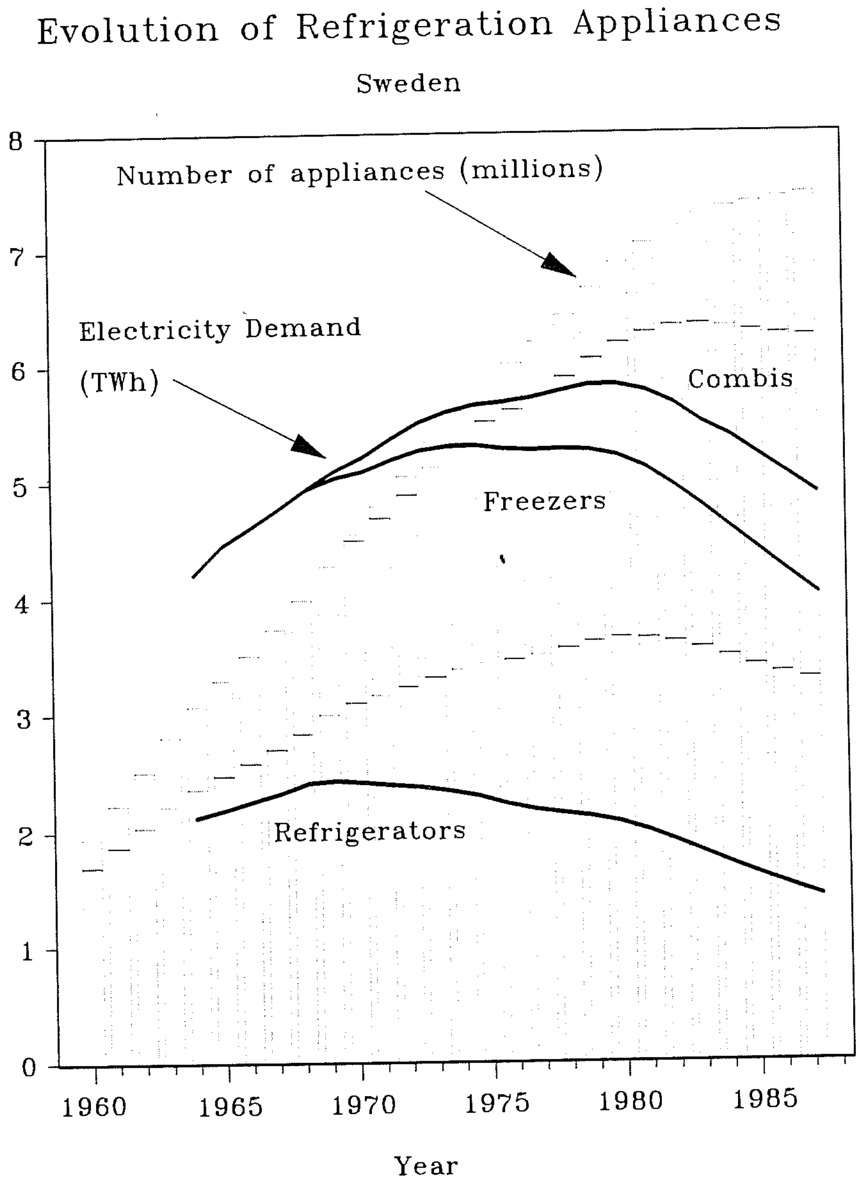


Figure 6. All refrigerator models available in each country as of 1987/88 are shown use the same test procedure. To improve comparisons, for appliances with both freezer volumes, the freezer volume is multiplied by an adjustment factor (AF equivalent refrigerated volume. AF = (room air temperature - freezer temper temperature - refrigerator temperature). Similar statistics have been documente Switzerland.[60]

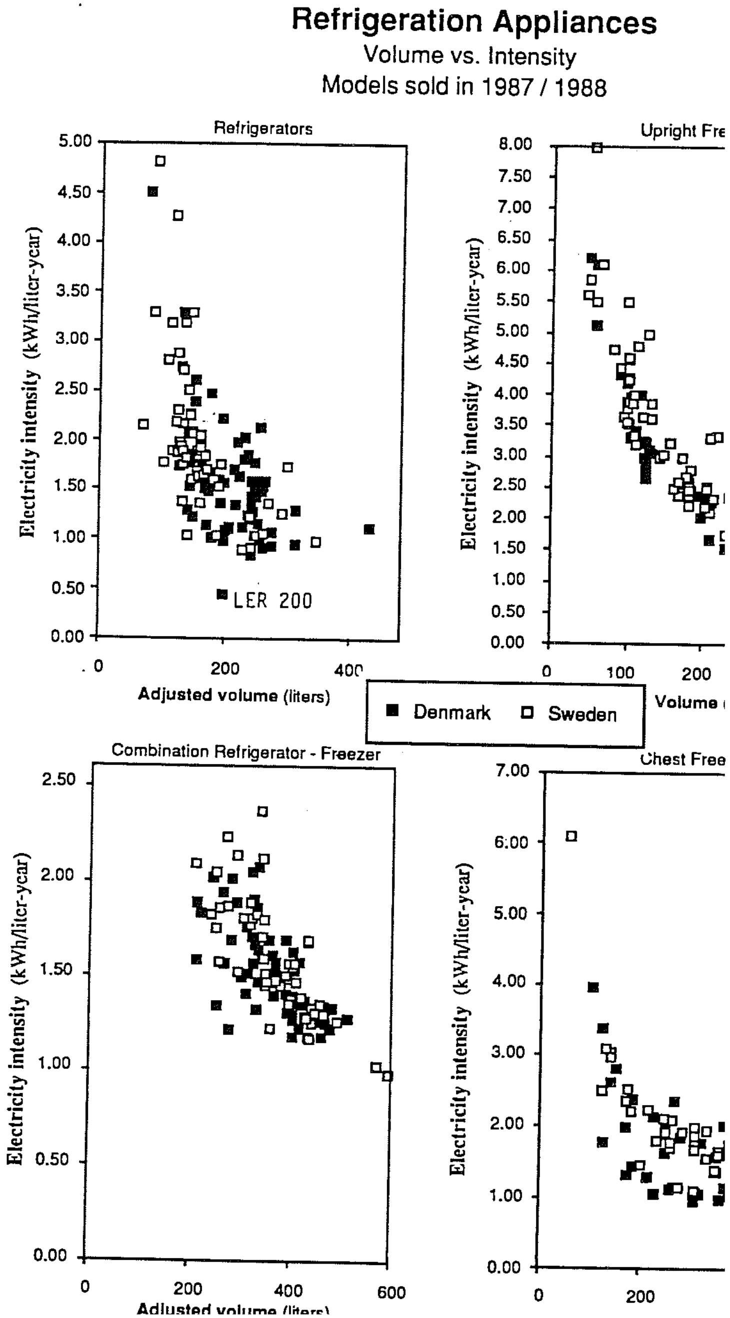


Figure 7. Same sources as Figure 6.

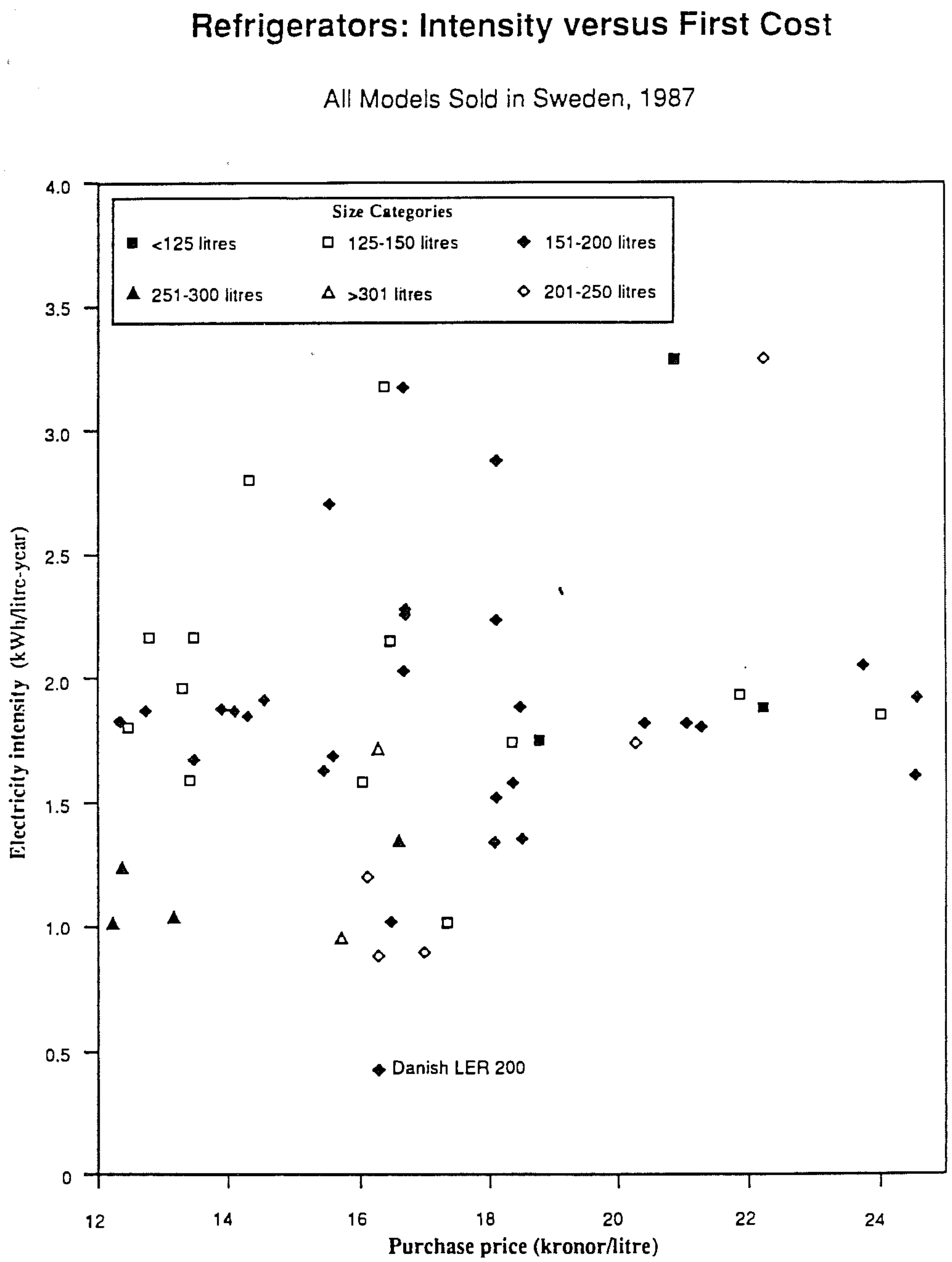


Figure 8. Data are for models available in 1982 and 1986. 1982 prices inflated to 1986 consumer price index for household appliances.[61]

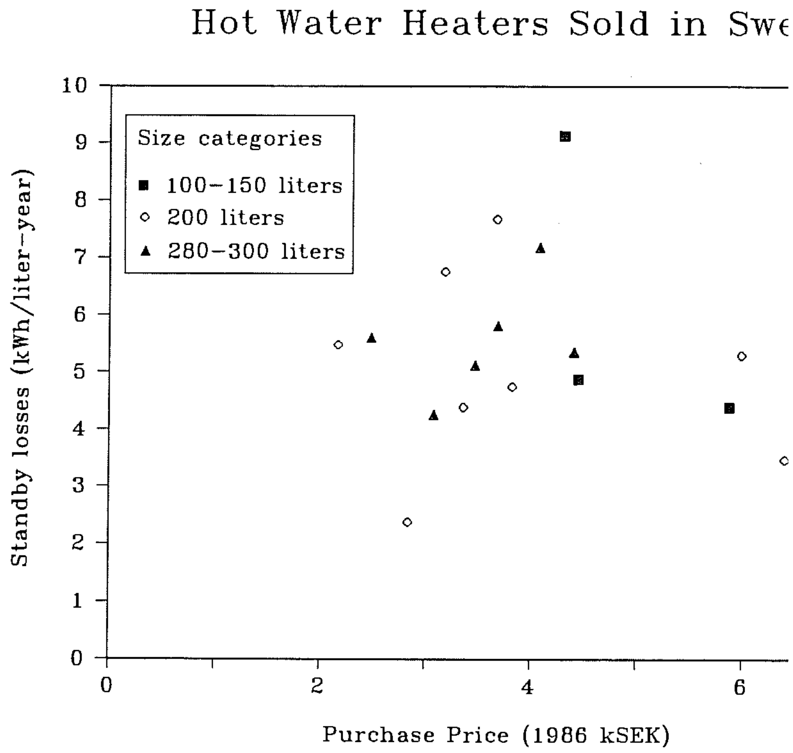


Figure 9. Heating structure in Denmark and Sweden.

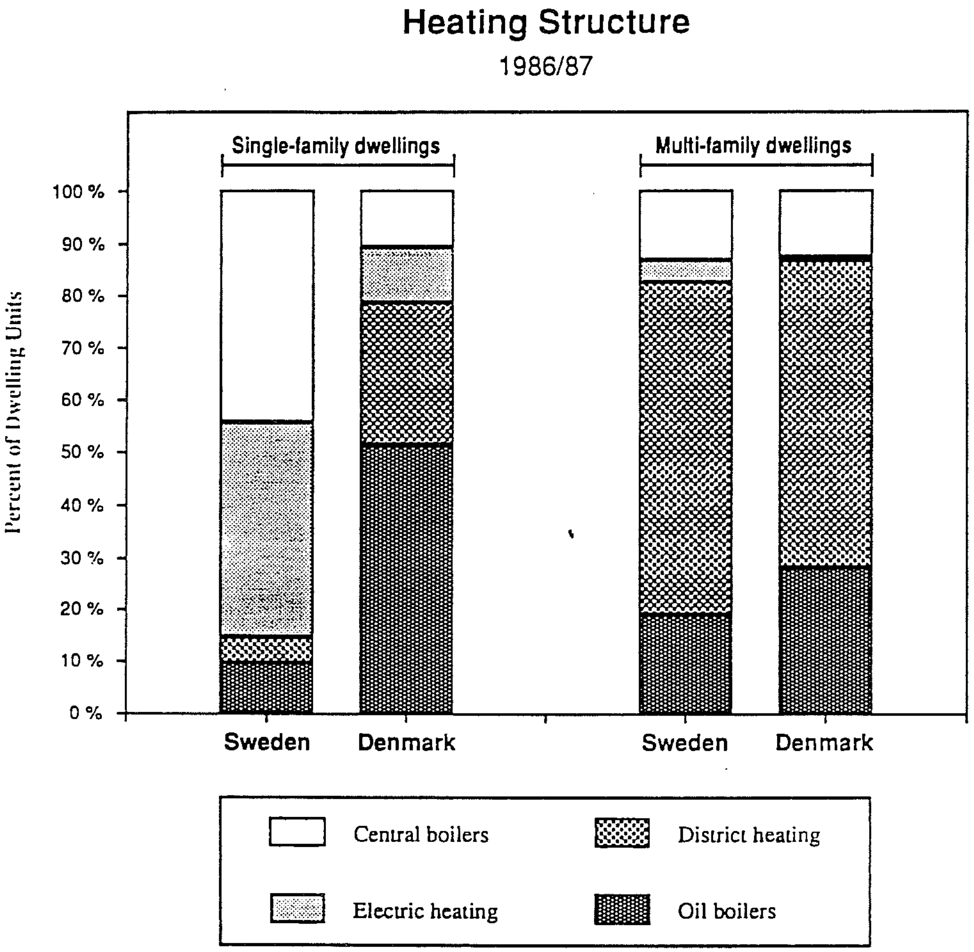


Figure 10. Historic trends in intensity of useful electric space heating energy use in Danish homes built during the indicated periods. The data reflect single-family h with electricity. To reflect the energy services delivered, boiler efficiencies of 90% homes with electric hydronic systems. Excludes farm houses.[62]

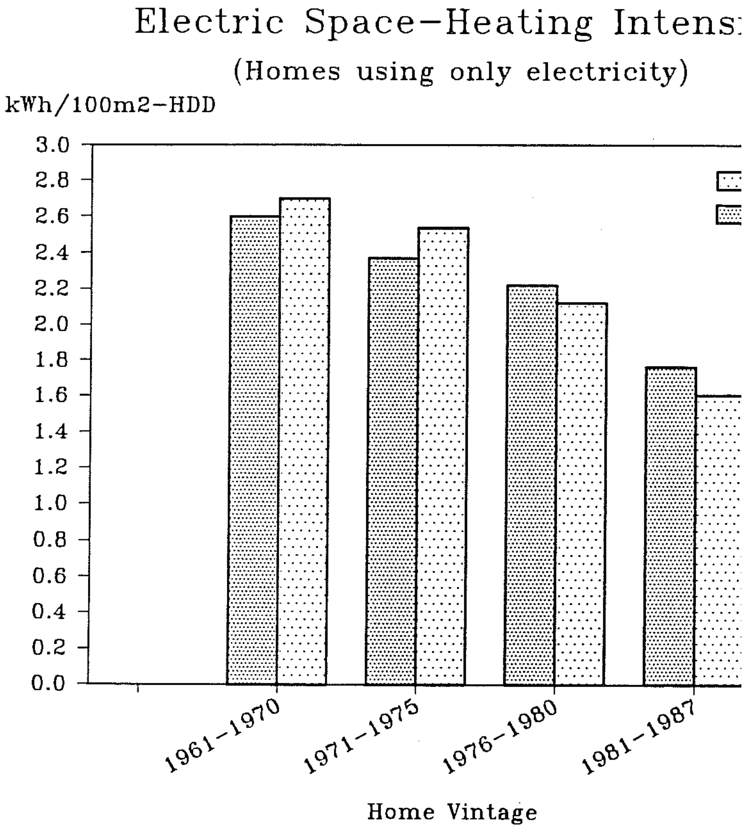
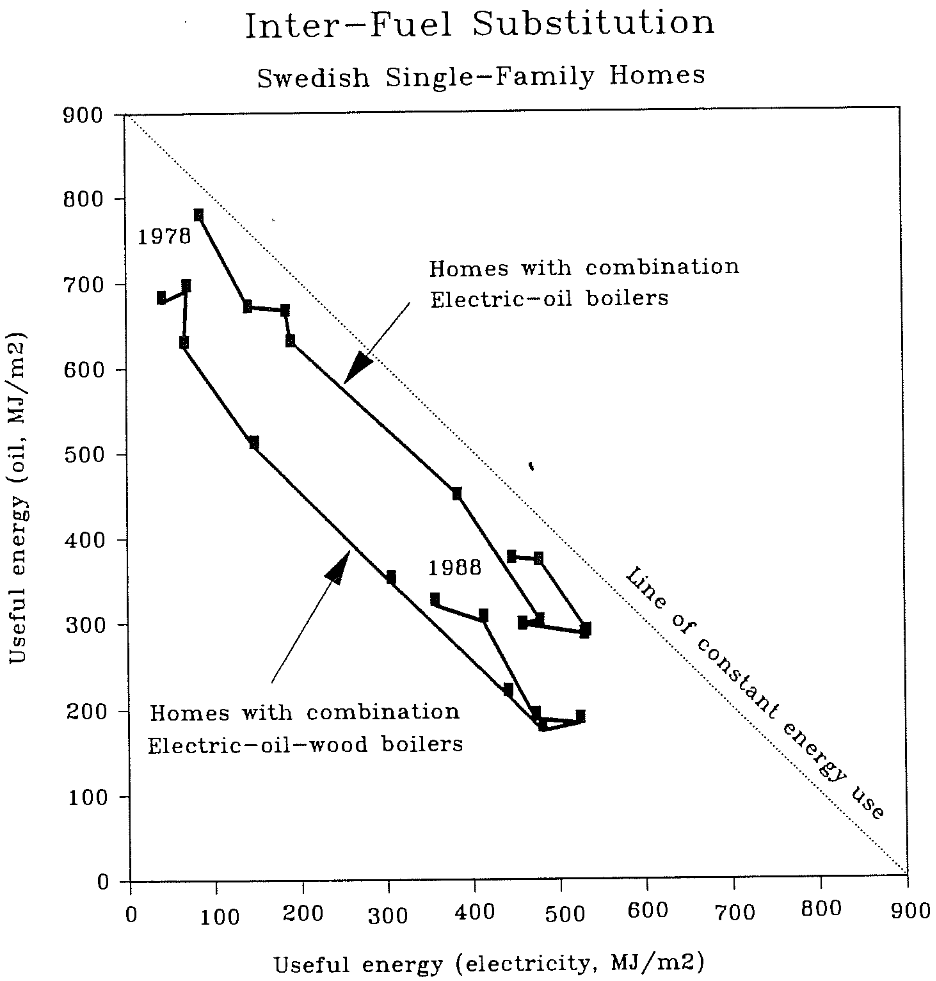
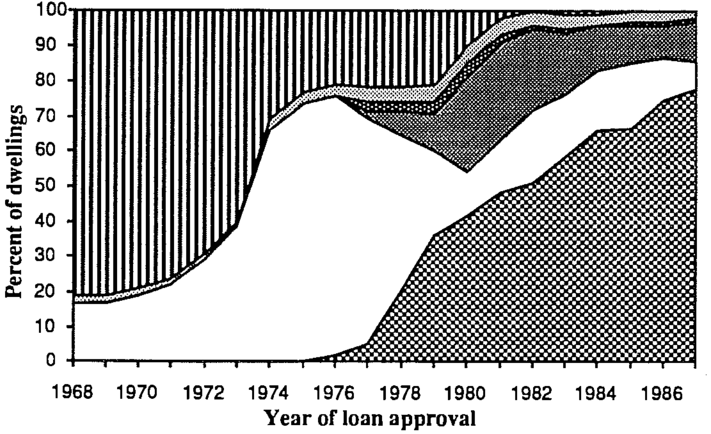


Figure 11. Each point shows the mixture of useful heating energy (plus appliances) delivered to the living space by electricity and oil in homes with multi-fuel boilers.[63] Each point represents a year between 1978 and 1988, beginning at the upper left-hand region of the diagram. The dotted diagonal line represents constant energy use for various combinations of oil and electricity. That the two curves remain roughly parallel to the constant-energy line indicates that little if any conservation has occurred in these homes. As expected, homes with the capability to use wood consume less electricity and oil than those homes with no option to use wood. Excludes farm houses.

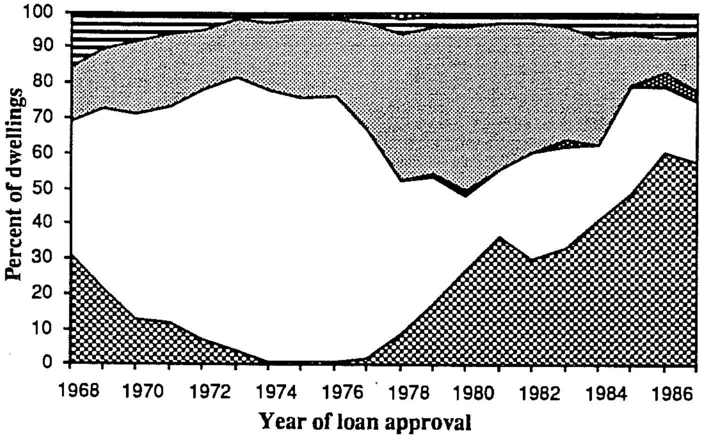


Heating Systems in New Homes

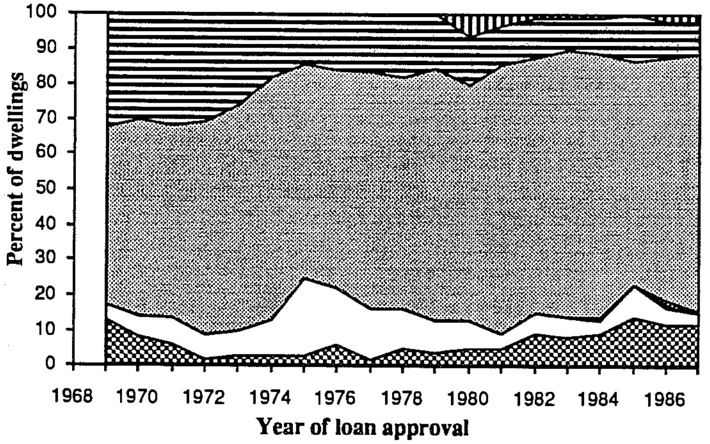
Individually built 1 & 2-dwelling units



Collectively built 1 & 2-dwelling homes



Multi-family dwellings



- ▥ Oil c boile
- ▤ Neig distr
- ▨ City
- ▦ Non com
- ▩ Elec coml boile
- ☐ Dire resis
- ▩ Elec Eartl heat

Figure 13. Consumer self-reported willingness to purchase compact fluorescent lamps as a function of lamp price.[65] A larger fraction of the program non-participants were undecided on the price they would be willing to pay.

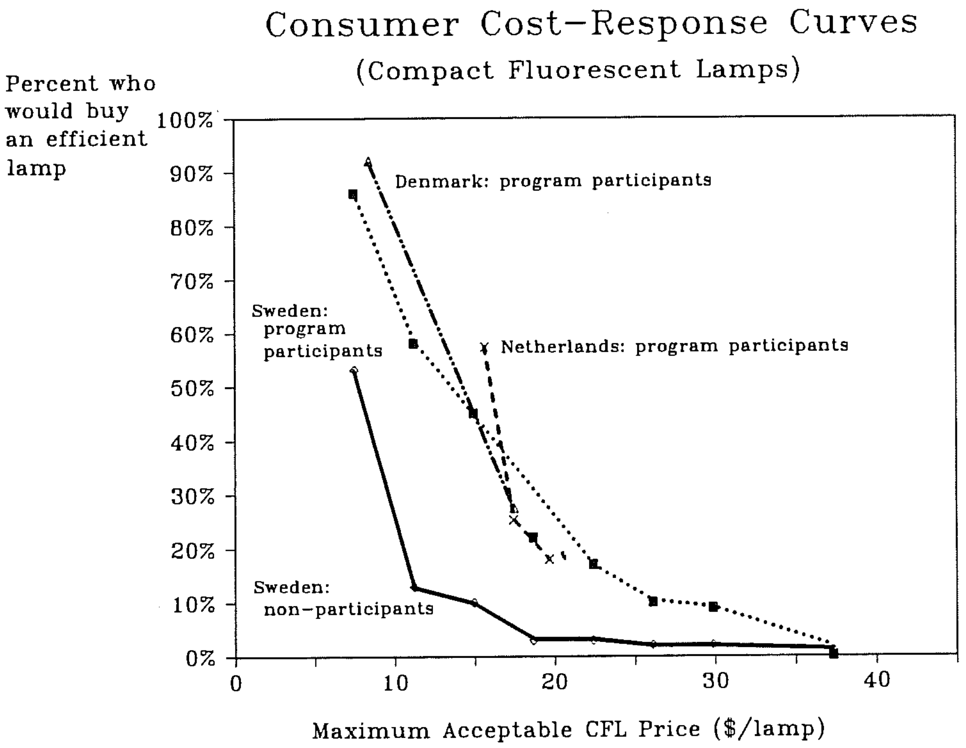
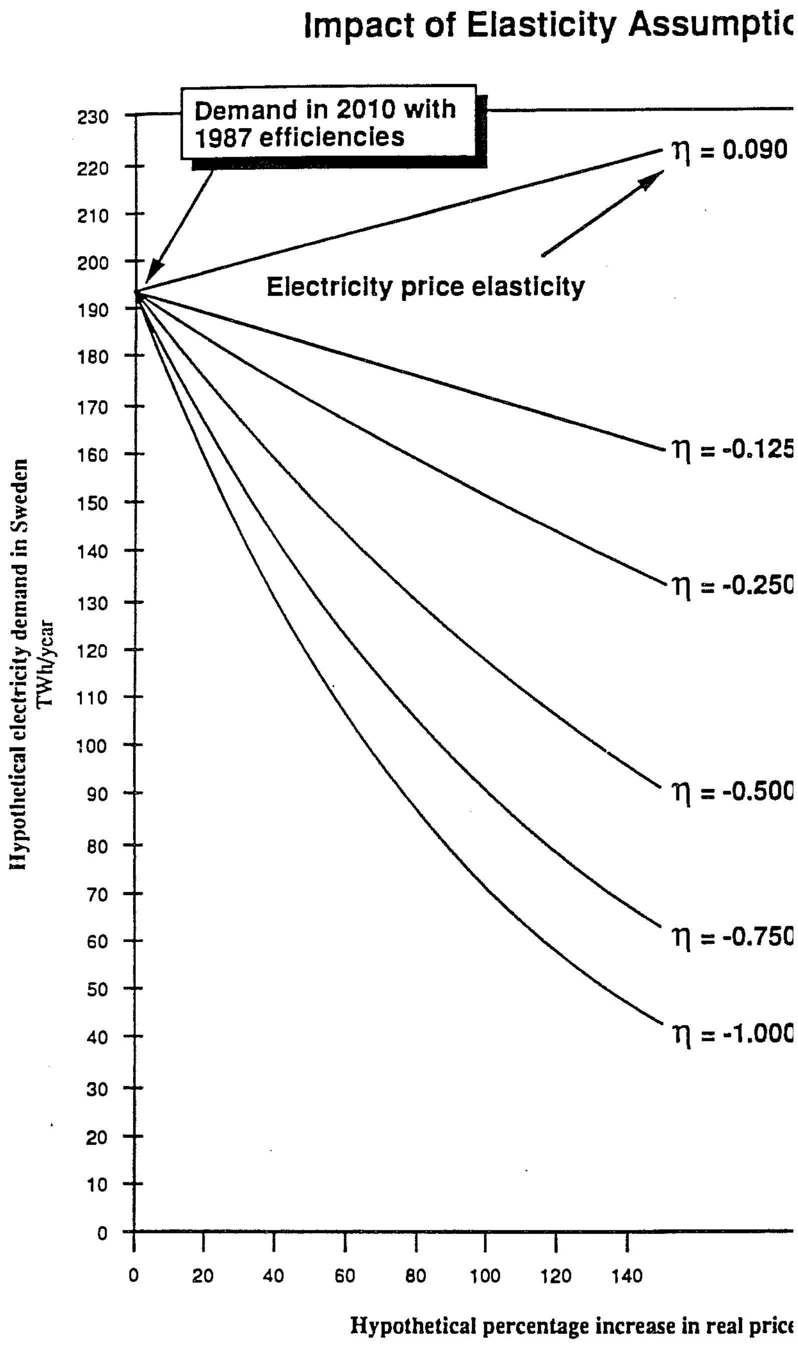


Figure 14. Hypothetical electricity demand resulting from various assumptio
elasticities.



Notes and References

1. The author is a Visiting Research Scientist with the Department of Environmental and Energy Systems Studies, the University of Lund, Sweden. Financial support for the research described in this article was provided by the Swedish State Power Board (Vattenfall) and the Swedish National Energy Administration. For additional background, see E. Mills. 1989. *An End-Use Perspective on Electricity Price Responsiveness*, Prepared for Vattenfall's Uppdrag-2000 project. This work benefited from discussions with Sarita Bartlett, Evald Broend, Lars-Goeran Carlsson, Thomas B. Johansson, Per Olof Hallin, Peter Hoffman, Jon Koomey, Jan Moeller, Lee Schipper, Jane Summerton, and Karin Widegren-Dafgaard.

2. Measurements of energy use can be made on a per-household, per-appliance, intensity, or efficiency basis. For concise definitions of these and other end-use indicators, see the appendix in S. Tyler and L. Schipper. 1990. The Dynamics of Electricity Use in Scandinavian Households. *Energy--The International Journal*, vol. 15, no. 10., p. 862.

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10. L.G. Carlsson. 1989. *Energianvaendning och Strukturomvandling i Bygnader 1970-1985* (Energy Use and Structural Change in Buildings 1970-1985). Swedish Buildings Research Council: Stockholm. Carlsson has also provided extensive unpublished data on electricity use.

11. See, for example, L. Schipper. 1983. Residential Energy Use and Conservation in Denmark, 1965-1980. *Energy Policy*, pp. 13-323 (December); L. Schipper. 1984. *Internationell Jaemfoerelse av Bostaedernas Energifoerbrukning* (International Comparison of Energy Use in Households). Byggforskningsraadet report R131:1984 (in Swedish with English appendices); L. Schipper. Residential Energy Use and Conservation in Sweden. *Energy and Buildings* vol. 6, pp. 15-38; S. Tyler and L. Schipper, *op cit*, Ref. 2, p. 841.

12. This is the trend in prices for non-electric heated homes (the majority at the time). The electric heating price dropped approximately 30% during this period. See L.G. Carlsson. 1984. Energianvaendningen i Bostaeder och Lokaler 1970-1982 (Energy use in homes and the service sector 1970-1982). Byggforskningsraadet report R132:1984, p. 80-82.

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separate electric water heaters. Kraftsam. 1990. Smaahusens Uppvaermning (H
Family Homes). Publication 11. Stockholm. Moeller and Nielsen, 1991, *op cit*, Ref 9.

16. Based on interviews conducted during Summer and Fall 1989. Responses
Electrolux, Siemens, Bosch, Cylinda, and Brdr. Gram A/S. The results of the intervie
described by Mills, *op cit*, Ref 1.

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reproduced as Table 18 in D. Wilson, L. Schipper, S. Tyler, and S. Bartlett. 19
Programs for Promoting Energy Conservation in the Residential Sector: Lessons fr
Countries. LBL report 27289. show 74% of the single- and multi-family home
temperatures between 20°C and 23°C during the 1975-1976 period.

20. Annual surveys prepared by Scan Test for the Danish Ministry of Energy a
made an effort to keep temperatures low: 45% answered "yes" in 1974, 71% in 1981,
Befolkningens Energisparebestraebelser (The Public's Energy Conservation Decisions),

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23. Koljonen and Waltin, *op cit*, Ref 22.

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International Journal, vol. 7, no. 10, pp. 817-827; W. Kempton. 1987. Variation in
Consequent Behavior. *American Behavioral Scientist*, vol 31. no. 2, pp 203-218.

25. Scan Test surveys, *op cit*, Ref 20.

26. The same situation exists in the Swedish service sub-sectors where electr
between 0.1% and 2.4% of sales value. At the 3-digit SNI level, industrial consumers
represent between 0.6% and 15% of value added.

27. U.S. DOE, 1988, U.S. Department of Energy, (DOE). 1988. *Technical Su*
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Assistant Secretary, Conservation and Renewable Energy, Building Equipment D
DOE/CE-0239, p. C-43.

28. J.A. Hausman. 1979. Individual Discount Rates and the Purchase and Utiliz
Using Durables. *The Bell Journal of Economics*, vol. 10. no. 1, pp. 33-54.

29. H. Ruderman, M.D. Levine, J.E. McMahon. 1987. The Behavior of the Ma
Efficiency in Residential Appliances Including Heating and Cooling Equipment. *The*
vol. 8, no. 1, p. 114.

30. See Scan Test surveys, *op cit*, Ref 20. Note, this is a more pessimistic estimate
the lower end of the curve (Figure 12) for willingness to purchase CFLs, which corre
year payback time.

31. There is often a formal corporate policy limiting the acceptable payba
conservation investments, as is the case for Sweden's IKEA (almost 100 stores w
requires paybacks less than three years (personal communication, ELFRED AB, N
which oversees electrical design and components specification for many IKEA stores
even investments for public-sector buildings often must pay back in less than one y
policies exist at the Carlsberg Brewing Company and the Prince Tobacco Compan
efficiency investments with only be made if payback times are less than two
communication, Ib Winther-Evers, NESA A/S power company, April 5, 1991).

32. An example of the difference between a firm's perspective (2-year payback
broader public-sector perspective (10-year payback) is given by an assessment of conse
from retrofitting the pumps at one of the Holmen Paper company's factories in Swe
company would only retrofit two of the 16 eligible pumps, thereby reducing electricity

societal perspective would result in the retrofit of all of the pumps and reduce electricity use by 38% (average payback time 3.2 years). Notably, from the paper company's perspective, a 50% price increase would not increase the number of pumps in the two-year-payback category. See *Elhushaallningsprojekt vid Holmen Paper AB, Wargoens Bruk: Energikartlaeggning Pumpar* (Energy Conservation Project at Holmen Paper AB, Wargoens Bruk: Energy Audit of Pumps). 1989. Vattenfall (Western Sweden)/Holmen Paper Report nr. 2000 89 1050 (in Swedish).

33. *Statistisk Aarbog 1988* (Statistical Yearbook 1988) Danmarks Statistik, pp 48-49 and other Danmarks Statistik data; *Bostads- och Byggnadsstatistisk Aarsbok 1989* (Yearbook of Housing and Building Statistics 1989) Statistiska centralbyraan. 1989. Stockholm, p. 262 (in Swedish).

34. Tyler and Schipper (*op cit,* Ref 2) also note various non-price factors operating in Scandinavian countries.

35. Statistically representative sample of Swedish household electricity use, prepared by the Swedish Central Statistics Bureau.

36. R.H. Williams, E.D. Larson, and M.H. Ross. 1987. Materials, Affluence, and Industrial Energy Use. *Annual Review of Energy,* vol 12, pp. 99-144; B. Giovannini and D. Pain, 1990. *Scientific and Technical Arguments for the Optimal Use of Energy,* Centre Universitaire d'Etude des Problemes de l'Energie (CUEPE). University of Geneva.

37. For Denmark, see Moeller, 1989, *op cit,* Ref 9, p. 14; for Sweden, see Figure 4.

38. L. Schipper, S. Meyers, and H. Kelly, *op cit,* Ref 18, p. 8.

39. A. Elmroth. 1989. Building Design and Electricity Use in Single-Family Houses. In *Electricity: Efficient End-use and New Generation Technologies, and Their Planning Implications,* T.B. Johansson, B. Bodlund, and R.H. Williams (eds). Lund University Press, p. 238.

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41. Wilson *et al.* 1989, *op cit,* Ref. 19 and Schipper 1983, *op cit,* Ref 11.

42. See chapters 7 and 8 in M. Loennroth, *et al. op cit,* Ref 21.

43. *Electricity Supply Act 1976.* Statute no. 54 of 25th February 1976. Monopoltilsynet, p. 7.

44. Statistical bureaus of each country.

45. For a review of this topic, see L. Schipper, S Bartlett, D. Hawk, and E. Vine. 1989. Linking Lifestyles and Energy: A Matter of Time? *Annual Review of Energy,* vol 15, p. 273-320.

46. L.G. Carlsson, *op cit,* Ref 10, p. 109, 161. This growth reflects changes in usage patterns and addition of more vacation homes added to the stock.

47. L.G. Carlsson, *op cit,* Ref 10, p. 276.

48. The consumer types include: resource conservers, value seekers, lifestyle simplifiers, appearance conscious, pleasure seekers, and hassle avoiders. Motivations identified were: low price/conservation, least shopping around, personal control, convenience of use, latest technology, comfort, safety, personal (and brand) status, and energy focus (area versus task). See, *EPRI Journal,* 1989. Is Cost the Only Measure of Electricity Value? January/February, pp. 22-29.

49. Toksvig Larsen, Brdr. Gram A/S, personal communication. July 7, 1988.

50. In the United States the degree of concentration is extremely high for some appliances. For refrigerators and freezers, the top two firms control 57% and 73% of all sales, respectively, and the top four control 91% and 96% of the market. White Consolidated--recently purchased by Electrolux--is among the top two. Increasing internationalization of the marketplace may lead to a continued reduction in competitiveness. See U.S. Department of Energy, *op cit,* Ref 27, pp. 7-9.

51. G. Kouris, *op cit,* Ref 4, p. 69.

52. This phenomenon has also emerged in oil demand following the 1986 price collapse; short-run U.S. price elasticities shifted from -0.08 during 1985 to -1.8 during the first half of 1986 and M. Rodekohr. 1987. *Falling World Oil Prices: An Assessment of the Impact on Petroleum Demand.* Energy Information Administration. U.S. Department of Energy. A key reason for this effect is that sustained periods of low prices can contribute to long-lived structural decisions (e.g a change to electric heating) which are not quickly reversible in the event of subsequent price increases.

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54. B. Bodlund, E. Mills, T. Karlsson, and T.B. Johansson. 1989. The Ch
Technology Options for the Swedish Electricity Sector, in *Electricity: Efficient*
Generation Technologies, and Their Planning Implications. T.B. Johansson, B.
Williams, (eds), *op cit,* Ref 39, pp. 883-947.

55. Efficiency increases by approximately 50%, but demand grows as a result of
in the numbers of appliances in homes (a non-price factor). As an example for s
the presence of second refrigerator-freezers is expected to increase from 6% to 45
of electric clothes-dryers is expected to increase from 18% to 85%.

56. H.L. Wilhite. 1988. Initiatives to Improve the Nordic Energy Bill As A
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Asilomar, California.

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Michel and H. Despretz. 1987. *Maitrise des Usages Specifiques de l'Electricite* (M
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61. *Raad & Roen* 8/82 (pp. 4-7); and *Raad and Roen.* 1986. "TEST: Varmv
med Laaga Foerluster" (TEST: Hot Hater Heaters Profit from Low losses), no. 8. (

62. Sweden--derived from the 1989 SCB annual survey, *op cit,* Ref 7, pp. 13, 2
5100 kWh/year appliance use and 3500 kWh for domestic hot water heating. Den
Nielsen, 1991 (Tables 2 and 4) and Moeller 1989, *op cit,* Ref 9, p. 35, plus unpublish
provided by Moeller. The stock-average value in 1970 is taken as representativ
period. Floor areas for electric-heated homes are used, rather than the average ove

63. SCB *Energistatistik foer Smaahus,* 1978-1989 editions. Seasonal system effici
Predeco data bases, provided by Lars Goeran Carlsson, Predeco Inc. Average
slightly over the 10-year period and in 1988 are 87% (electricity) and 74% (oil).

64. *Bostads- och Byggnadsstatistisk Aarsbok 1989, op cit,* Ref 33, p. 108.

65. Survey results prepared by the Swedish survey agency SIFO, Kista, Swed
surveyed); ELSAM, 1990, *Rapport for Pilotsfosoeg for Lavenergilamper* (Report on
Energy-Efficient Lamps), Odense, p. 25. (~2000 households surveyed); and S. Bosm
Evaluatie Spaarlampenactie PEB Friesland en Frigem: Resultaten Inwoneronder
the Energy-saving Lamp Program in PEB-Friesland and Frigem: Results of a
Exchange rates: 6.7 Swedish kronor/USD, 7.735 Danish kronor/USD, and 2.24 Du