Recent and Historical Product Energy Efficiency (EE) and Life-cycle Cost Improvement in Swedish Appliance Markets

January 2014

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Executive Summary

This report retrospectively analyzes some of the potential impacts of product energy efficiency policy in Sweden by examining possible correlations between policy implementation, historical and real-time price trends, energy efficiency improvement trends, and life-cycle cost trends for a variety of product markets including: (1) refrigerators, (2) clothes washers, (3) dishwashers, and (4) televisions.

This report is also an initial demonstration of some of the types of new analysis that may be possible using the real-time collection of high resolution market data on energy using products.

The use of real-time appliance model level price and efficiency data provides the following potential capabilities that may not be feasible using currently available aggregated/historical data from GfK or other sources:

1) Real-time Snap Shots of Energy Efficient Market Share,
2) Real-time Calculation of Statistical Price-Efficiency Curves, and
3) Real-time Analysis of the Minimum Life-cycle Cost Annual Energy Consumption for Different Discount Rates and Payback Periods.

The report begins with a description of the primary advantage of using real-time model-level market data on product prices and energy use: increased statistical precision. We argue that since all retrospective and real-time market monitoring of energy efficiency market conditions involves the estimation of statistics for data distributions, then the standard errors for these quantities will decrease with increasing data. This means that if policy makers want to monitor actual data with high precision, very large volumes of market data are needed.

We begin our technical analysis of markets with an initial technical and theoretical analysis of life-cycle cost minimum efficiency in a dynamic market. We show that by analyzing changes in the appliance price, electricity price, and the elasticity of price with respect to energy use, we can theoretically estimate the optimum rate of energy efficiency improvement for an appliance as a function of time. This reflects the desired rate of innovation for bringing more efficient appliances to market at a price level that is sustainable for long-term efficiency goals. The calculation of the optimum energy efficiency improvement rate allows one method for evaluating how well both current and historical policies have been calibrated to the dynamic conditions of Sweden's appliance markets.

What we also find for all four products is that inflation-adjusted price and operating costs are declining while efficiency is increasing over time when the features and capacity of the product are held constant. We also find that with accelerating improvements in energy efficiency, there does not appear to be any deceleration in the long term price decline of the appliance. This means that when new, more efficient products get adopted by the Swedish market, they are as affordable as the old, less efficient products: there is no real, inflation-adjusted increase in purchase price. In fact, both purchase price and operating cost are observed to decline at a similar rate.

While at any particular point in time, more energy efficient products may be priced higher than less energy efficient products, over time as the more energy efficiency products become adopted, we find that this price premium apparently disappears and there is no measureable adverse impact on long term quality-adjusted price trends.

We combine recently collected market data with long term price index data to provide a quick assessment of the four product categories: refrigerators, clothes washers, dishwashers, and televisions.

We find for refrigerators, the market appears to be progressing rather smoothly with a long term energy use decline of slightly more than 5%/year that appears to be sustainable over the long term. For clothes washers, we find that energy efficiency improvement might be below its theoretical potential (perhaps because of the lack of high efficiency level definitions, and/or consumer utility issues associated with increasing wash cycle times). For dishwashers in Sweden there appears to be a significant price premium for the highest efficiency products. And for televisions, they appear to be decreasing their active energy use at the amazingly rapid pace of 15% to 25% per year.

Introduction

As described in Directive 2009/125/EC of the European Parliament and of the Council, energy-related products account for a large proportion of the consumption of natural resources and energy in the Community, including Sweden. In the interest of sustainable development, continuous improvement in the overall environmental impact of those products should be encouraged. Many energy-related products have a significant and continually expanding potential for being improved in order to reduce environmental impacts and to achieve energy savings through better design which also leads to economic savings for businesses and end-users.

This report provides a preliminary examination of the energy efficiency and price dynamics of four products in the Swedish market: (1) televisions, (2) refrigerators, (3) clothes washers, and (4) dishwashers. Since 1994, Sweden and the rest of the EU have been implementing policies to promote increased energy efficiency of household appliances and equipment. The purpose of these policies is to help assure the "prudent and rational utilization of natural resources; whereas the rational use of energy is one of the principal means by which this objective can be achieved and environmental pollution reduced."[1] In this report we provide some new retrospective analysis that examines trends in appliance prices, energy efficiency and energy costs that may assist in evaluating the impacts of energy efficiency policies that have been implemented to date. In addition, we begin the development of data collection and analysis methods that may help in monitoring the progress of energy efficient product markets in real time. These methods are based in the real-time collection of data from the Internet through the use of computer programs and the development of specialized analysis techniques to estimate trends in prices, energy efficiency and market share with increased levels of statistical precision.

The policy impact analysis presented in this report evaluates progress in terms of rates of decline in product energy use and costs. Whereas historically most energy efficiency policy analyses have assumed that energy efficiency policies cause appliance prices to increase for the average consumer,[2] more recent empirical evidence—including the data provided in this report—indicates that this may not be the case. The picture arising from the more recent examination of the empirical evidence is that appliance markets are dynamic and energy efficiency policies impact dynamic market trends in price, efficiency, and operating cost. Sometimes energy efficiency policies will make appliance price trends accelerate their downward decline.[3] At other times the appliance price trends during the periods of

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[1] European Council Directive 92/75/EEC of 22 September 1992

[2] For a discussion of recent reforms to the policy analysis methods in the U.S. see: Desroches, L. B., Garbesi, K., Kantner, C., Van Buskirk, R., & Yang, H. C. (2012). Incorporating experience curves in appliance standards analysis. *Energy Policy*.

[3] See for example the detailed study of a standards impacts on in-model price trends for clothes washers at:

http://eaei.lbl.gov/sites/all/files/appliance_efficiency_standards_and_price_discrimination_lbnl6283e.pdf. This shows an example of standards apparently causing an accelerated decline of product prices with no bump-up in price.

energy efficiency policy are approximately the same as for earlier periods without energy efficiency policies.[4] But the most important consumer economic impact that energy efficiency policies appear to have on appliance ownership economics is that these policies cause the annual energy use and annual operating cost of the appliance to decrease over time. This is the specific impact from energy efficiency policies that this report examines.

The energy efficiency policies implemented in Sweden and the EU have been a combination of mandatory energy labels and minimum energy performance standards (MEPS). Both policies have complementary impacts. Labels can be very effective at encouraging consumer willingness to pay for energy efficiency.[5] Mandatory labels were initially implemented in the European Community through European Council Directive 92/75/EEC of 22 September 1992. This directive required member states to implement a labeling scheme on energy using appliances and equipment including refrigerators, laundry equipment, dishwashers, ovens, water heaters, lighting sources, and air conditioning appliances and to bring the scheme into force by 1 January 1994.

While it would be both interesting and useful to systematically describe changes in appliance costs and energy use associated with the different elements of energy efficiency policy, unfortunately such a detailed analysis is beyond the scope of the current study. The purpose of the retrospective analysis in the current study is to examine long term trends in energy efficiency improvement and prices spanning ten years or more to help validate the basic equations of dynamic market optimization and energy efficiency trends. Over such long periods, it may not yet be possible to distinguish or disentangle the effects of labels and MEPS. None-the-less with the future availability of dramatically larger sets of data describing market dynamics at very high time resolution, it may be possible to perform statistically very precise analyses of policy impacts over very specific time periods. Such future analyses may be able to attribute very specific market impacts to specific features and components of energy efficiency policy. But for now, an analytical capability of such precision remains one to several years in the future.

Benefits of Real Time, Model Level Data

This report provides an initial analysis that utilizes model-level market data that is collected in real-time over the Internet. In this section, we provide an explanation of the benefits of the use of real-time data. The key benefit to real-time market data is the ability to conduct more precise and in-depth policy analysis in higher time resolution at a significantly lower cost because of lower unit data collection costs.

There is a basic concept in statistical analysis called standard error[6] that describes the errors and precision of average values calculated from noisy data. The definition of this concept is:

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[4] Weiss, M., Patel, M. K., Junginger, M., & Blok, K. (2010). Analyzing price and efficiency dynamics of large appliances with the experience curve approach. *Energy Policy*, *38(2)*, 770-783.

[5] For a recent empirical study on the quantitative effectiveness of energy efficiency labels, see: Newell, R. G., & Siikamäki, J. V. (2013). Nudging Energy Efficiency Behavior: The Role of Information Labels (No. w19224). National Bureau of Economic Research.

[6] http://en.wikipedia.org/wiki/Standard_error, Date accessed: December 15, 2013

> The standard error is the standard deviation of the sampling distribution of a statistic. The term may also be used to refer to an estimate of that standard deviation, derived from a particular sample used to compute the estimate.
>
> For example, the sample mean is the usual estimator of a population mean. However, different samples drawn from that same population would in general have different values of the sample mean. The standard error of the mean (i.e., of using the sample mean as a method of estimating the population mean) is the standard deviation of those sample means over all possible samples (of a given size).

Most policy-makers may not fully realize that when they are reading reports on energy efficiency progress, most of the quantities that they are reading about in these reports are a "statistic" of a sampling distribution of market data. As such, the accuracy and detail of any scientific measurement of quantities and policy impacts derived from this data is determined by the concept of standard error and statistical error.

Currently, most retrospective analyses of energy efficiency policy impacts look at simple market averages of market distributions. These market averages might perform shipments-weight averages, or model-weighted averages, but if one carefully reviews the technical concept of standard error, one can find that population averages and other quantities derived from the market data distributions can in fact be calculated with theoretically much greater precision. Greater statistical precision can be obtained most easily for statistical estimates if much greater volumes of data are collected at relatively low cost.

The accessibility to a large volume of real-time market data at a more affordable data price is the primary benefit of real-time market monitoring.

With weekly collection of market data there is an added benefit of being able to examine market statistics with much higher time resolution. Where as previously it was difficult to assess the immediate impact of a new MEPS or energy class level on appliance price and market share, it is now possible to track changes as they happen on a weekly or monthly basis. Additionally, the rate of energy efficiency improvement can be benchmarked against other market indicators, such as the price and electricity index, at any given point in time.

Figure 1 shows an example of the type of observation that can be made with the collection of a single day's worth of market data from the Internet for the Swedish market. This data allows the calculation of the correlation between refrigerator price and annual energy use for bottom-freezer refrigerators in a particular limited size range on a particular day of the year. The statistical correlation between price and energy use on this day corresponds to a price elasticity with respect to energy use of -0.545, which we will show in subsequent sections of this report may have a set of specific implications about the performance of this sector of the refrigerator market with respect to energy efficiency policy goals.

One of the goals of this report is to more clearly characterize the analytical potential for real-time collection of very large volumes of market data, and to begin the development of analysis techniques customized to this new data source. It is hoped that with this added information, policy-makers and policy analysis planners will have a much better sense of the potential for real-time market monitoring to enhance and expand on existing policy analysis techniques.

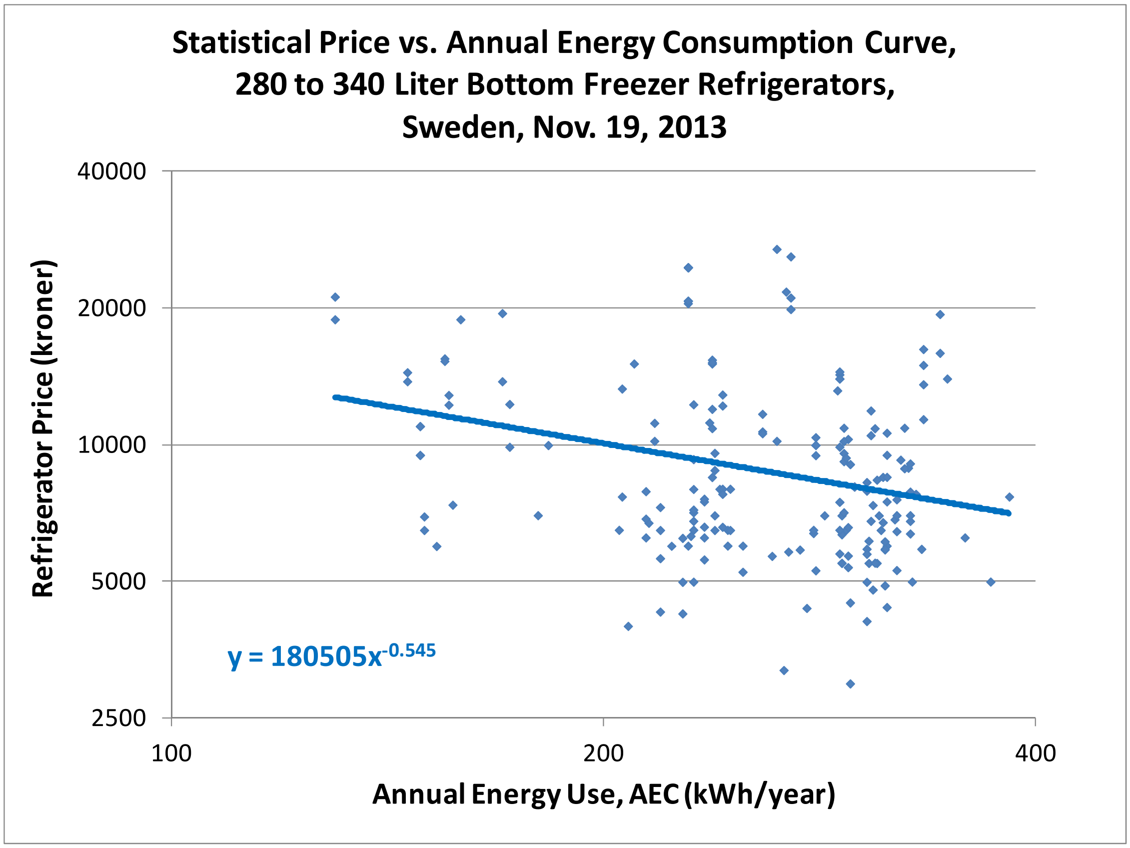

Figure 1: Illustration of the statistical determination of a price-efficiency curve based on real-time market data. Note that the both axes in the figure are logarithmic scale. On a log-log plot, a straight line is a power law curve. The equation for the best fit power law for this data is ***Price*** (in kroner) ***= 180505 * (AEC)***$^{-0.545}$.

Data Sources

The data used in this report and analysis is derived from three primary sources: (1) Enervee Internet-based data collection programs, (2) Swedish government statistical agencies, and (3) GfK, a market data and research company. Much of the GfK data was obtained from secondary sources (e.g. TopTen reports or government contacts).

Enervee Data Collection

Enervee captures current product prices, technical specifications, energy consumption, efficiency class, and sales rank data from international shopping comparison web sites that have a significant presence in Sweden via the use of Application Programming Interfaces (API) and web scraping. The following are the sites we utilize:

Kelkoo (www.kelkoo.se): use of API
Pricerunner (www.pricerunner.se): use of web scraping
Price Spy (www.prisjakt.nu): use of web scraping
Price Bomb (www.pricebomb.se): use of web scraping

Enervee identifies unique products based on Manufacturer/Brand and Model Number. This enables aggregation of pricing and sales rank data from multiple data sources. When available, Enervee captures the lowest and mean price for each product. Enervee stores a date stamp on all price and sales rank data that is collected.

Enervee captures sales rank from one or multiple data sources. Sales rank is an ordering of products based on their popularity. The study assumed a power law scaling to relate sales rank to sale weight. Further research will further refine this relationship over the next year using model-level sales data from other sources and other markets.

We also capture technical specifications that are available on the shopping comparison web sites, such as type, size/capacity, color, and noise level. In addition, energy consumption (kWh/yr) or efficiency class information is captured. Enervee's data platform contains a powerful data quality framework, providing the capability to specify the quality of each data source and use automated validation logic to identify outliers. This allows us to identify manufacturer data as higher quality than retailer data, meaning that when we have conflicting technical specs, energy consumption, or efficiency class from multiple data sources we always use the highest quality value.

To ensure that we have the full range of technical specifications, energy consumption, and efficiency class for each product we also scrape product data from manufacturer web sites (Samsung, LG, Bosch, Miele, Cylinda, Siemens, etc). Any data captured from shopping comparison sites will be replaced with the manufacturer data as it is deemed of higher quality. Where data is not available for some products on the manufacturer page, we capture the missing data from Swedish online retail web sites such as: www.whiteaway.com, www.netonnet.se, www.siba.se and others.

The Enervee data was used to support all of the current analysis: Life-cycle Costs, Cost of Conserved Energy, Capacity Adjusted Price by EEI, Market Share by efficiency class, Evolution of Refrigerator Energy Use.

Data collected by the Swedish Government Statistical Agency

The Swedish government has a very robust consumer price data collection and price index calculation capacity that is operated by an agency called in English: Statistics Sweden (http://www.scb.se). The methods of price index calculation are well documented in a handbook (http://www.scb.se/statistik/pr/pr0101/handbok.pdf) and the detailed price indices for specific product categories are available for purchase. Enervee purchased monthly price index data from Statistics Sweden for the following products:

- Refrigerators
- Clothes washers
- Dishwashers
- Light bulbs
- Small televisions
- Large televisions
- Microwaves

In addition to these specific products, the agency provides at no charge price index data for electricity and consumer goods in general.

GfK Data

GfK is another source of primary data on product sales and prices that was acquired and used indirectly. Literature searches were performed for relevant data that was gleaned from a variety of market assessment reports. The reports published by TopTen using GfK data were a particularly valuable resource in this regard.

Technical Background

In this section we provide some technical background on some of the new analysis methods that can be applied to product market trends that are enabled by access to larger volumes of market data. As mentioned in the previous section, access to large volumes of data through the real-time collection of market prices allows the statistical calculation of product price-efficiency relationship with potentially much higher precision and resolution in time. This greater statistical precision can provide access to product market characteristics that have previously not been readily available. This section describes in detail some of the quantities that can be mathematically and statistically calculated and analyzed when the relationship between product price and energy use can be explained using real-time market data.

Definition of Life-cycle Cost (LCC)

If markets are operating efficiently, the market will provide consumers with products that maximize consumer value with respect to the cost of an appliance. The cost of an appliance includes not only its purchase price but also is influenced by its operating cost. If efficiently operating markets are minimizing the total ownership cost of an appliance including the purchase price and the operating costs, then we need to understand the structure of these costs.

The total consumer impact is often calculated using the energy-related life-cycle cost (LCC), which is the sum of the purchase price P_A and a discounted sum of energy-related operating costs $OC(t)$. Assuming a yearly compound interest rate *i,* the present value of an expense *n* years in the future (in the year y_n) is discounted to $OC(y_n)/(1+i)^n$.[7] The sum of price and operating costs throughout the appliance lifetime is:

$$LCC = P_A + \sum_{n=1}^{L} \frac{OC(y_n)}{(1+i)^n} \quad (1)$$

where L is the lifetime of the appliance, *i* is the interest or discount rate, and y_n are a discrete number of L years over which the appliance is in operation.

The operating cost can be decomposed into cost components. The operating cost of an appliance can be written in terms of the price of energy, $P_E(y)$, which can vary from year to year, and annual unit energy consumption (AEC), which we assume for simplicity is the same from year to year for a given appliance. This means that the equation for LCC can be rewritten as:

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[7] If operating cost is measured in inflation-adjusted dollars, the inflation-adjusted interest rate is used. We assume operating costs and interest are charged at the end of the year in which they occur.

$$LCC = P_A + AEC\sum_{n=1}^{L}\frac{P_E(y_n)}{(1+i)^n} \ , \tag{2}$$

It is next possible to define the lifetime-weighted average electricity price for the appliance as:

$$\overline{P_E} = \frac{\sum_{n=1}^{L} P_E(y_n)/(1+i)^n}{\sum_{n=1}^{L} 1/(1+i)^n} \ , \tag{3}$$

The economic payback period (PBP) can be defined as the ratio of the present value of operating costs to annual operating cost discounted at interest rate i over a lifetime of L years. This quantity this is the function of interest or discount rate that converts annual costs over a lifetime L into a present value:

$$PBP = \sum_{n=1}^{L}\frac{1}{(1+i)^n} = \frac{1-(1+i)^{-L}}{i} \ . \tag{4}$$

We show in table 1 below the dependence of PBP on interest rate and product lifetime.

Table 1: An illustration of PBP as a function of product lifetime and interest rate.

Product Lifetime	Interest Rate					
	1%	2%	3%	4%	5%	6%
10	9.47	8.98	8.53	8.11	7.72	7.36
15	13.87	12.85	11.94	11.12	10.38	9.71
20	18.05	16.35	14.88	13.59	12.46	11.47
25	22.02	19.52	17.41	15.62	14.09	12.78

With these variable definitions, then the LCC is given by a relatively simple formula:

$$LCC = P_A + PBP \cdot \overline{P_E} \cdot AEC = P_A + PVOC \tag{5}$$

This formula says that the total cost of an energy-using appliance is the sum of purchase price and the present value of operating costs ($PVOC$) which are equal to the annual energy use times the price of energy times the economic payback period.

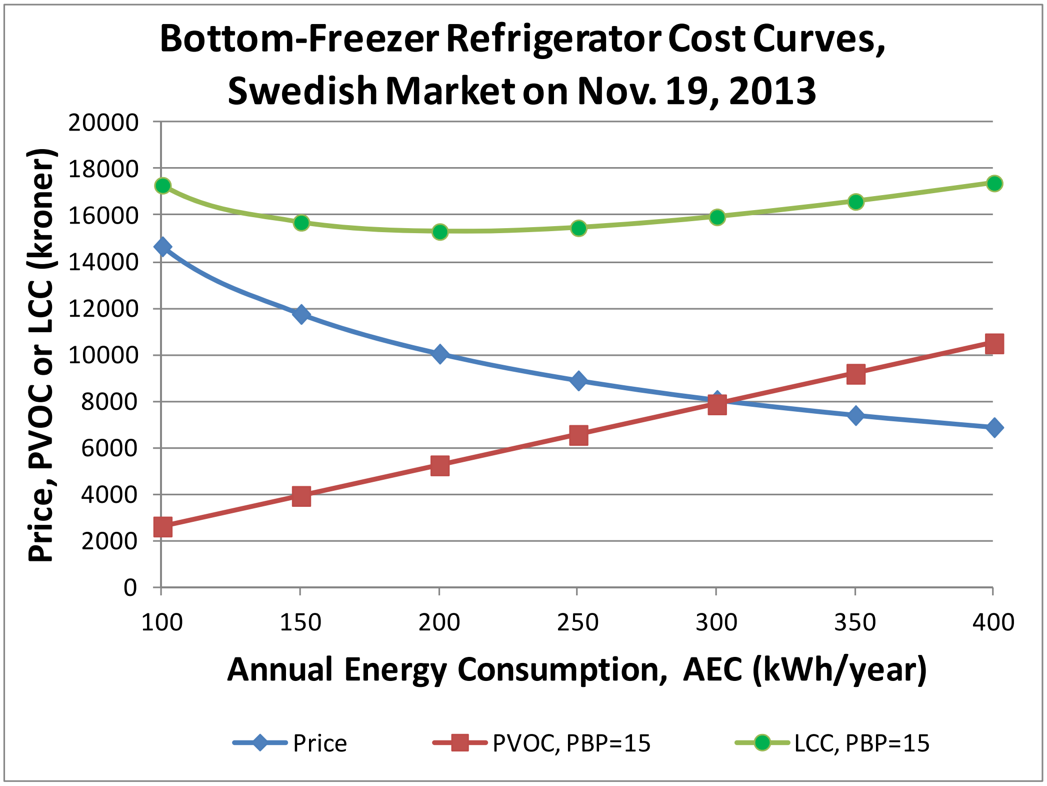

Figure 2: An illustration of equation (5) with data from the Swedish refrigerator market. Average price as a function of efficiency is characterized by the statistical fit to a power law curve provided in figure 1, the present value of operating costs is proportional to an annual energy use estimate, and the sum provides the life-cycle cost (LCC). The $PVOC$ and LCC calculation assumes the value of PBP to be 15 years, and the marginal residential electricity price is assumed to be 1.75 kroner/kWh.

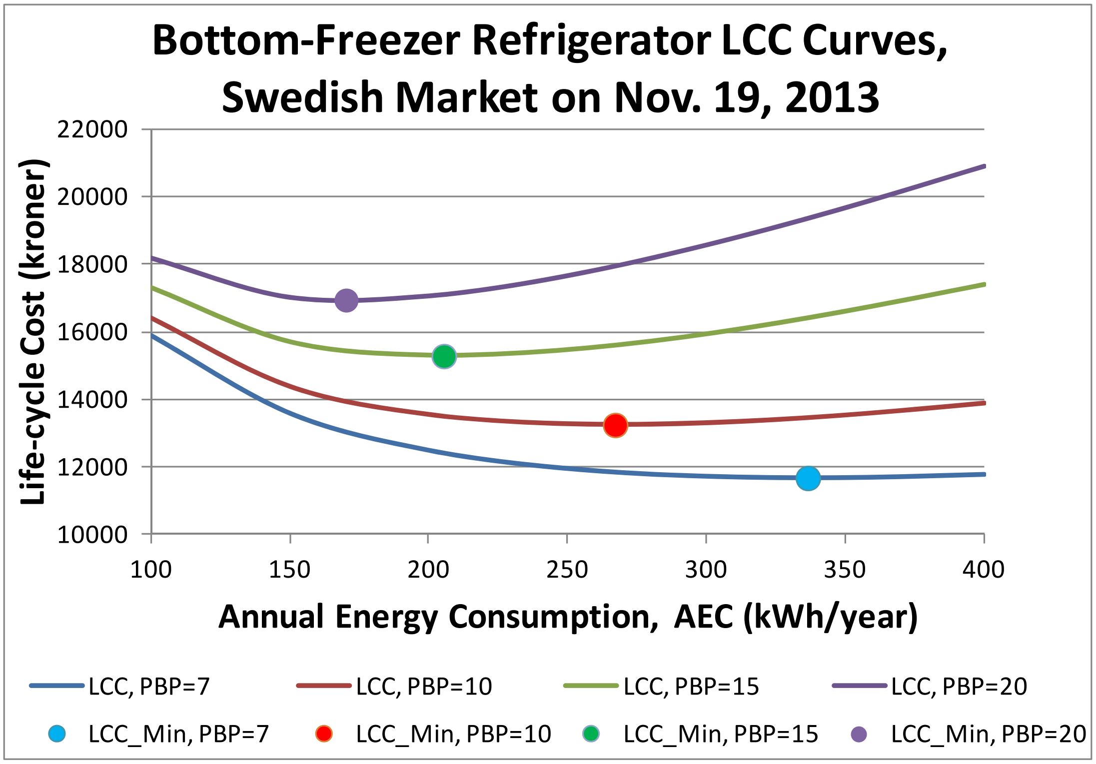

Figure 3: An illustration of equation (5) with data from the Swedish refrigerator market for different values of PBP. Average price as a function of efficiency is characterized by the statistical fit to a power law curve provided in figure 1, the present value of operating costs is proportional to an annual energy use estimate, and the sum provides the life-cycle cost (LCC). The LCC calculation is made for several values of PBP ranging from 7 to 20 years. The marginal residential electricity price is assumed to be 1.75 kroner/kWh.

Price Trends and EE Improvement

In this section we use the LCC minimization concept described above to derive relationships between appliance price and appliance energy use when a market is properly minimizing costs for the consumer.

At any particular point in time, the price of an appliance may be a function of annual energy consumption, AEC. Typically the price observed in the market for products with similar features but greater efficiency may be higher, i.e. price increases with decreasing AEC. We can approximate this price vs. AEC relationship with a power law equation with a negative exponent:

$$P_A = P_0 \cdot \left(\frac{AEC}{AEC_0} \right)^{-\varepsilon} \qquad (6)$$

Where P_0 is a reference price at which the annual energy use of the appliance is equal to a reference energy use AEC_0.

A power law, also known as a scaling law, is used to explain the functional relationship between two quantities and is often used in economics, as the distribution of a wide variety of quantities such as income, wealth, size of cities and firms, and financial variables tends to follow the power-law form.[8]

Note that when we approximate the relationship between price and annual energy consumption by a power law then the change in price with respect to annual energy use is given by the following simple equation:

$$\frac{dP_A}{dAEC} = -\varepsilon \cdot P_0 \frac{AEC^{-(1+\varepsilon)}}{AEC_0^{-\varepsilon}} = \frac{-\varepsilon \cdot P_A}{AEC} \tag{7}$$

Where $-\varepsilon$ is often referred to as the elasticity of price with respect to annual energy use.

This provides a straightforward way to determine the price premium of a more energy efficient appliance by calculating the increase in price per decrease in kWh/yr.

Specifically, we can use this equation to calculate the incremental cost of conserved energy (CCE)[9] as a function of elasticity, price, annual energy consumption and payback period:

$$\begin{aligned} CCE &= -\frac{1}{PBP} \cdot \frac{dP_A}{dAEC} = \frac{\varepsilon \cdot P_A}{PBP \cdot AEC} \\ &= \frac{\varepsilon \cdot P_o \cdot AEC_0^{\varepsilon}}{PBP \cdot AEC^{1+\varepsilon}} \end{aligned} \tag{8}$$

This allows us to determine whether the higher purchase price for a more efficient product is a good investment versus paying the local electricity rate for the increased energy use of the less efficient product.

For example, we can compare whether it makes sense to invest in an LED TV that consumes 75 kWh/yr versus an LED TV that consumes 125 kWh/yr. If we assume a five year payback period, then we have an energy use difference of 250 kWh (50 kWh/yr). If we then assume a cost of electricity of €0.20 per kWh, this would translate to a total operating cost difference of €50. This means that the feature-adjusted price for the more efficient LED TV should not be more than €50 higher than the less efficient TV to realize a CCE of €0.20 per kWh or less.

In figure 4 below, we illustrate the cost of conserved energy for the Swedish refrigerator case that we previously discussed in figure 1.

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[8] Gabaix, Xavier. “Power laws.” (2008).

[9] Meier, Alan Kevin. "Supply curves of conserved energy." (1982).

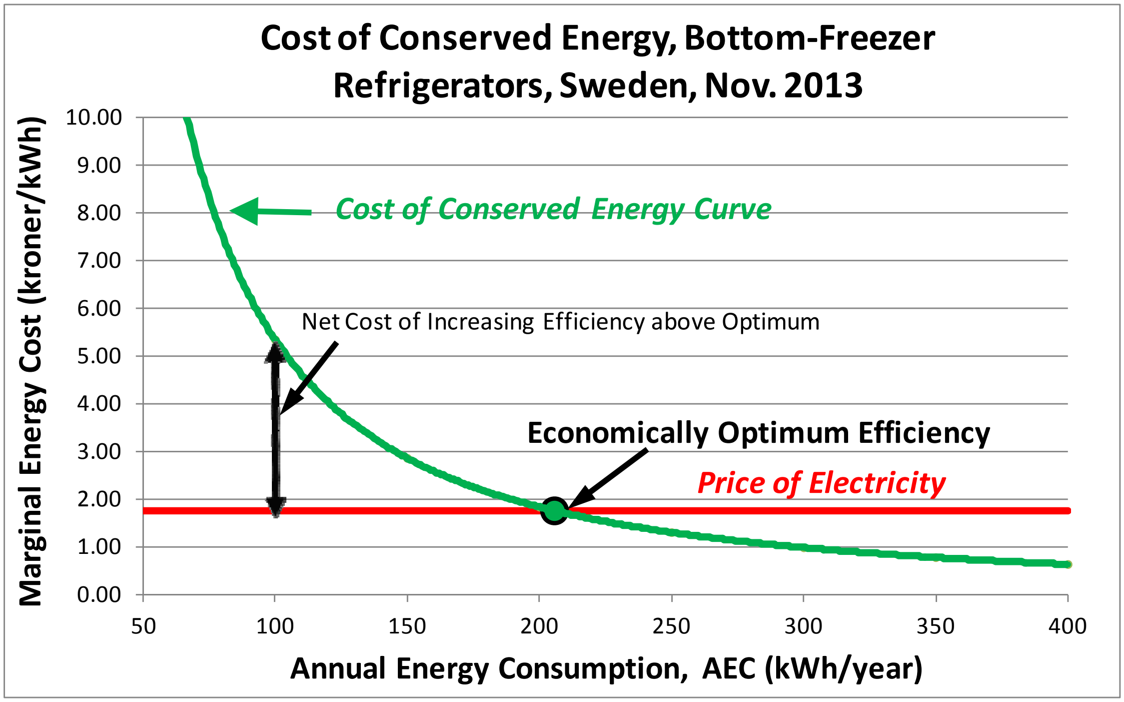


Figure 4: An illustration of equation (8) and the calculation of the cost of conserved energy (CCE) with data from the Swedish refrigerator market. PBP is assumed to be 15 years for this calculation. The price of electricity in the Swedish market at this time is approximate 1.75 kroner/kWh.

Note that if we want to find the value of AEC that minimizes the life-cycle cost of an appliance, this occurs when the marginal benefit of decreasing annual energy consumption is equal to the marginal cost of the more expensive appliance. Or equivalently, this occurs when the marginal cost of conserved energy is equal to the price of energy. This occurs when the following relationship is satisfied:

$$\frac{dPVOC}{dAEC} = PBP \cdot \overline{P_E} = -\frac{dP_A}{dAEC} = \frac{\varepsilon \cdot P_A}{AEC} \tag{9}$$

Using this relationship, we can calculate the relationship that the annual energy consumption needs to satisfy when it is minimizing the LCC for the consumer:

$$AEC_{MinLCC} = \frac{P_A}{\overline{P_E}} \cdot \frac{\varepsilon}{PBP} \tag{10}$$

This equation can be used to determine if the annual energy use of a product is at its economic optimum. If the annual energy use is equal to the price times the elasticity divided by the price of electricity times the economic payback period, then the energy consumption is at the life-cycle cost minimum for that economic payback period.

This is the key relationship that we verify for Swedish market for televisions, refrigerators, clothes washers, and dishwashers to determine whether the long term trends of decreasing energy use for these appliances are economically efficient. More specifically, we can use long term price index data to calculate the trend in the ratio of appliance price to electricity price. For all four appliances this ratio trends downward over time at rates ranging from 3% per year to 29% per year. For periods where there is an effective policy of labeling and minimum energy performance standards, we find that the annual energy use of the appliances trends at rates that are correlated with the trend in appliance price to electricity price ratio.

We can also calculate the value of AEC_{MinLCC} even more explicitly in terms of P_0 and AEC_0:

$$AEC_{MinLCC}(t) = \left(\frac{P_0(t) \cdot AEC_0^{\varepsilon(t)}}{\overline{P_E}(t)} \cdot \frac{\varepsilon(t)}{PBP} \right)^{\frac{1}{1+\varepsilon(t)}} \qquad (11)$$

This last equation is useful when we know how the price of an appliance at fixed energy use or efficiency (P_0) is changing over time. If at fixed energy use or efficiency the price of an appliance relative to the price of electricity is decreasing at *X*% per year, then the minimum LCC energy use should decrease at a rate of *Y*% per year where $Y = X/(1+\varepsilon)$.

Refrigerator Market Results

We begin our retrospective review of efficiency trends and policy impacts with residential refrigerators. Figure 5 illustrates the rate of energy use decline for residential refrigerators for 11 countries in the European market. To calculate these trends with some level of robustness and precision, we utilized slightly sophisticated mathematical techniques described in Appendix A of this report.

What can we see from this data is that at the very beginning of the period shortly after 1995, refrigerator energy use was decreasing at a rate of only 3% per year. With the implementation of the standards and labeling policies which came into full force in the 1998 to 2000 period, there was a fairly dramatic acceleration of the energy use decline to a rate of 6% per year. This trend moderated to about 4% per year in 2005, but then has accelerated again to a rate of nearly 8% per year in Switzerland and Sweden in the last few years.

In figure 6, we examine the corresponding impact of efficiency improvement on the ratio of appliance price to electricity price. If energy use is decreasing too fast, we might expect appliance prices to increase relative to electricity prices, but while we see some fluctuations in price, the long term trend in appliance price to electricity price ratio is consistently downward over the long term. It is possible that with the acceleration of efficiency improvement in the last few years there has been some moderation in the long term decline of refrigerator price, but more data is probably needed to accurately measure a change in the long term trend.

We next illustrate how to use recent market data in combination with extrapolation of long term historical trends and a minimum LCC energy use calculation to provide a picture of potential future energy use trends.

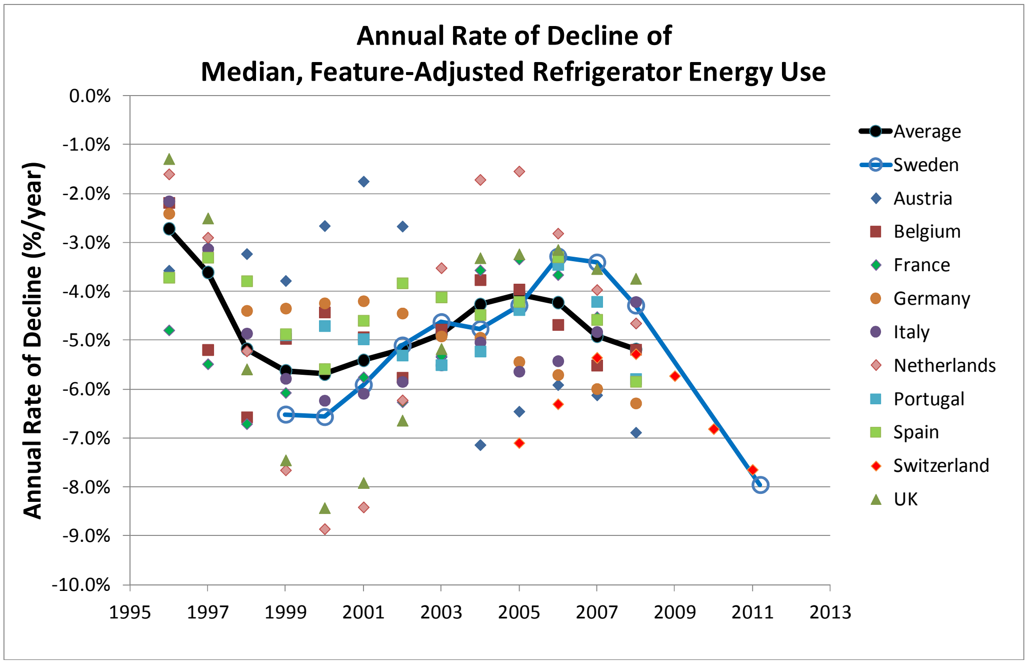


Figure 5: Estimates of annual rates of decline in refrigerator energy use. We illustrate results for 11 countries in the EU. What is notable is that since energy efficiency policies came into force after 1995, the rate of decline has been approximately 5%/year. Swedish trends have followed the rest of Europe with an apparent acceleration in annual energy use decline to approximately 8%/year.

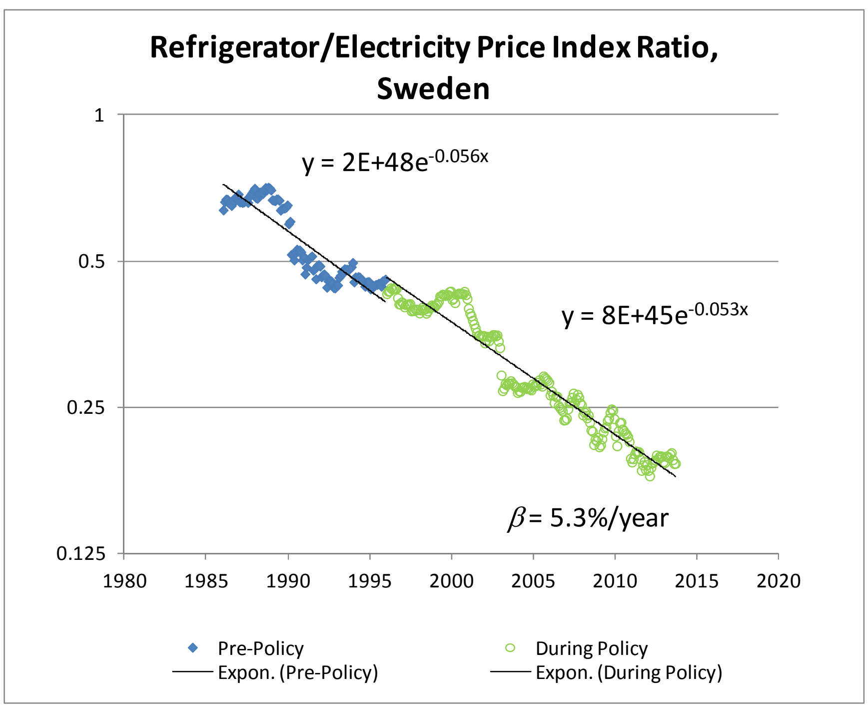


Figure 6: Refrigerator price index trend relative to the price of electricity. We note two trend periods: An earlier period before 1995 when there were not MEPS or labeling policies when the trend in

refrigerator price relative to electricity was -5.6 %/year, and a more recent period since energy efficiency policies were begun where the trend is a similar -5.3 %/year.

Figure 7 illustrates a calculation derived from market data collected in real-time from the Internet. Market data provides model-by-model estimates of energy use and price for hundreds of different refrigerator models. One of the most popular types of refrigerator in the Swedish market is the bottom-freezer style. For this style a correlation analysis is performed to calculate the power law equation relating energy use and price as described by equation (6) described above. The parameters of this equation are then used in equation (11) to calculate the minimum LCC annual energy use for different economic payback periods. The results of this calculation for four different values of PBP are shown as four different colors of "X" in figure 5. Then consistent with equation (10) we project that the minimum LCC value of AEC will decline at the same rate as appliance price over electricity price (i.e. 5.3%/year). These trend lines for the different values of PBP are then illustrated over time along with the AEC values for the different efficiency levels so show in what year the minimum LCC value of AEC is expected to be at the different efficiency levels. The median annual energy use in the current market is shown with a large black dot.

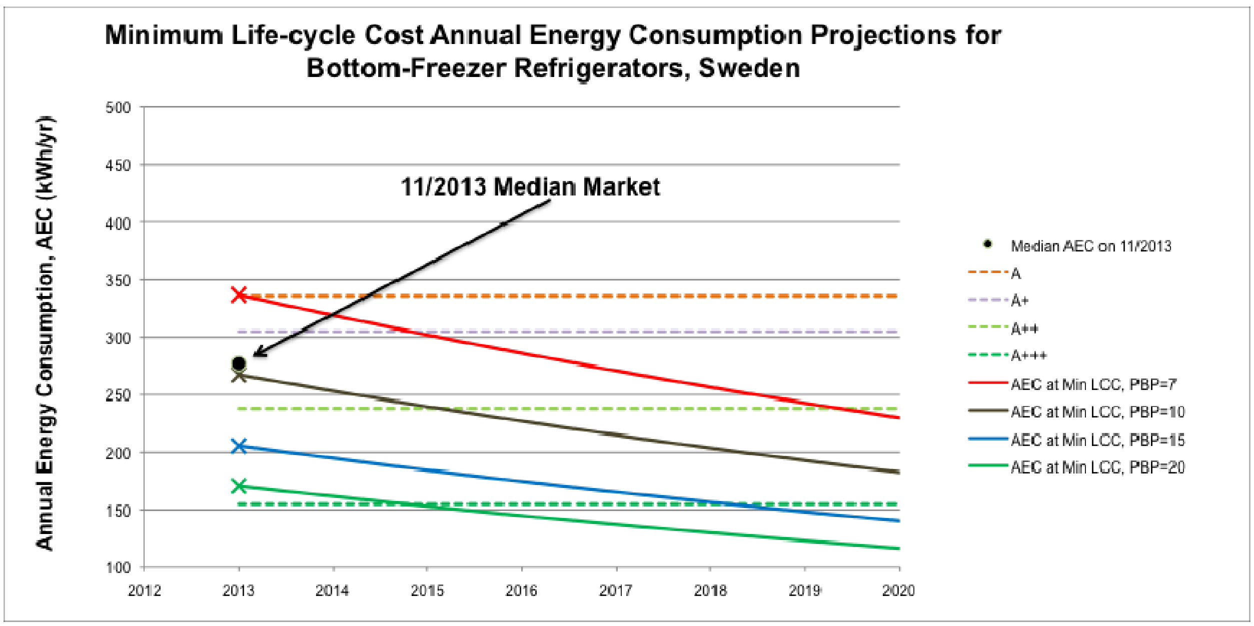


Figure 7: Prospective projection of potential improvements in refrigerator efficiency for the Swedish bottom-freezer refrigerator market. Efficiency levels are represented by dashed horizontal lines. The large black dot represents the median market energy use in October 2013. The "X" marks represent the minimum LCC annual energy consumption for different economical payback periods (7, 10, 15, and 20 years) estimated in October 2013. Solid curves provide projections of minimum LCC energy consumption assuming that the average appliance price to electricity price ratio (described by equation

(10)) continues to decline at 5.3% per year and the elasticity of price with respect to energy use stays constant.

Clothes Washer Market Results

For the Swedish clothes washer market we provide a somewhat more cursory analysis compared to the refrigerator results. Figure 8 illustrates the ratio of clothes washer price index to electricity price index for the Swedish market for periods both with and without energy efficiency policies. We see that if anything, the long term trend in clothes washer quality-adjusted price decline has accelerated during the period of energy efficiency policies.

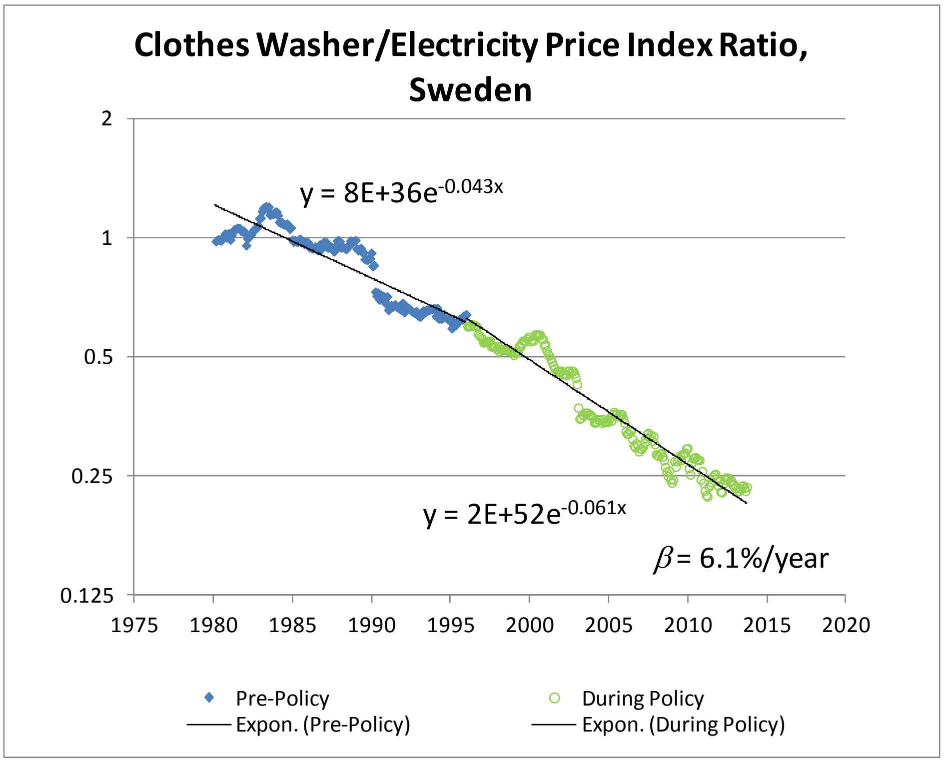


Figure 8: Clothes washer price index trend relative to the price of electricity. We note two trend periods: An earlier period before 1995 when EcoDesign policies were established when the trend in refrigerator price relative to electricity was -4.3 %/year, and a more recent period since the EcoDesign policies were established where the trend is a similar -6.1 %/year.

An examination of more detailed recent market data provides an indication that price declines may have been outpacing efficiency improvements in this product market. Figure 7 illustrates the price/efficiency relationship observed in this market and shows that the highest efficiency levels garner little or no price premium.

An accounting of efficiency level market shares provides a potential explanation of this lack of price premium. The market share data indicates that a majority of products are at the top energy efficiency level which apparently is not difficult for the market to reach. This suggests that new higher efficiency levels need to be defined to create a level of efficiency that requires a price premium to obtain.

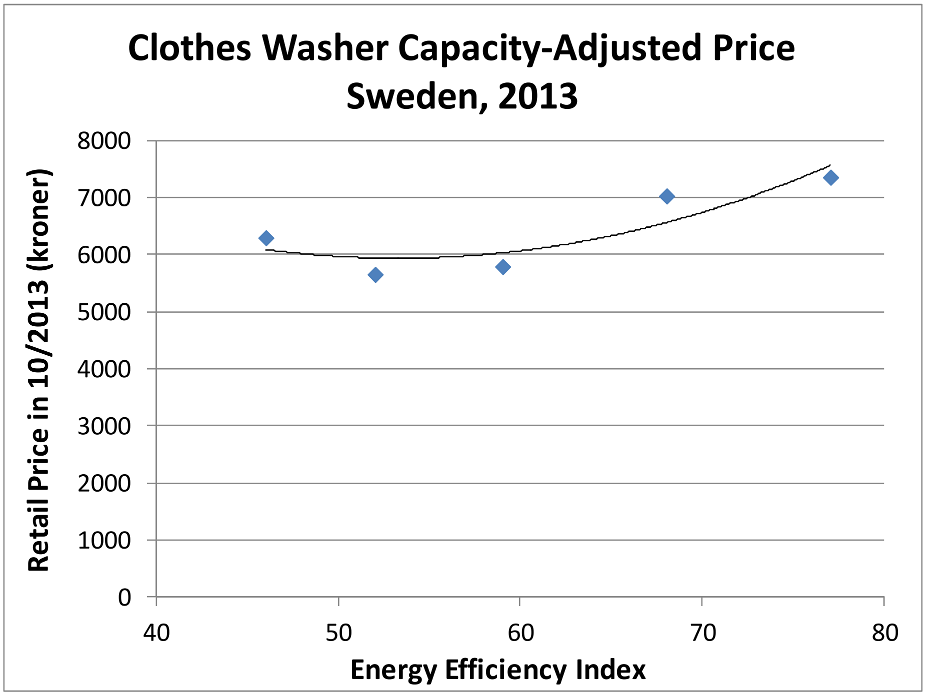


Figure 9: Capacity-adjusted market price as a function of Energy Efficiency Index (EEI). There does not appear to be a substantial price premium for energy efficiency in the market at this time.

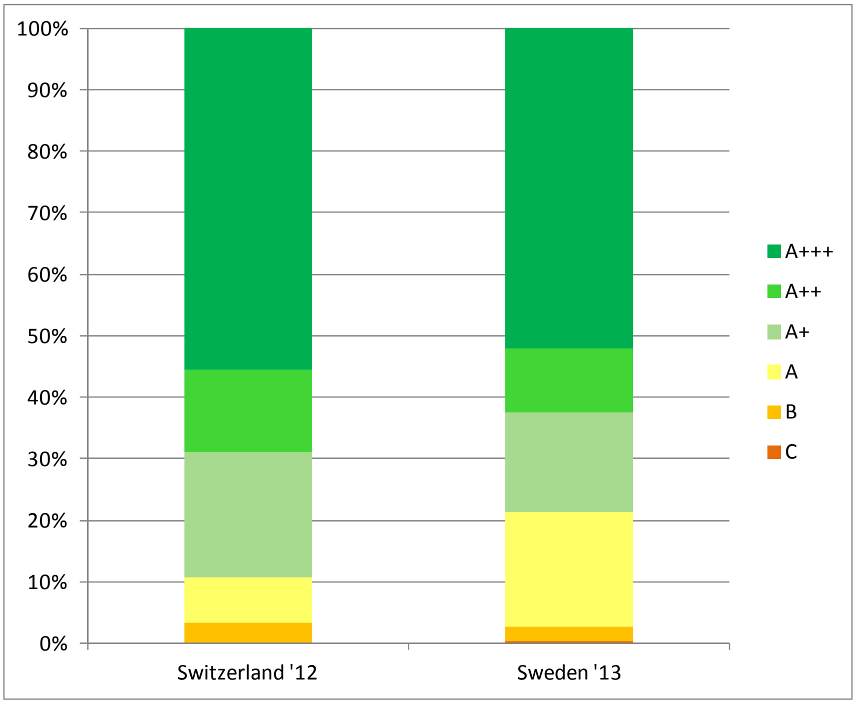


Figure 10: Comparative energy efficiency market shares for Switzerland in 2012 and Sweden in October 2013. Note that the top efficiency level garners more than 50% market share in both markets. Swiss data is obtained from a recent Top Ten report.[10]

Dishwasher Market Results

For the Swedish dishwasher market we provide a similar, cursory analysis compared to the refrigerator results. Figure 11 illustrates the ratio of clothes washer price index to electricity price index for the Swedish market for periods both with and without energy efficiency policies. We see that if anything, the long term trend in dishwasher quality-adjusted price decline has accelerated during the period of energy efficiency policies.

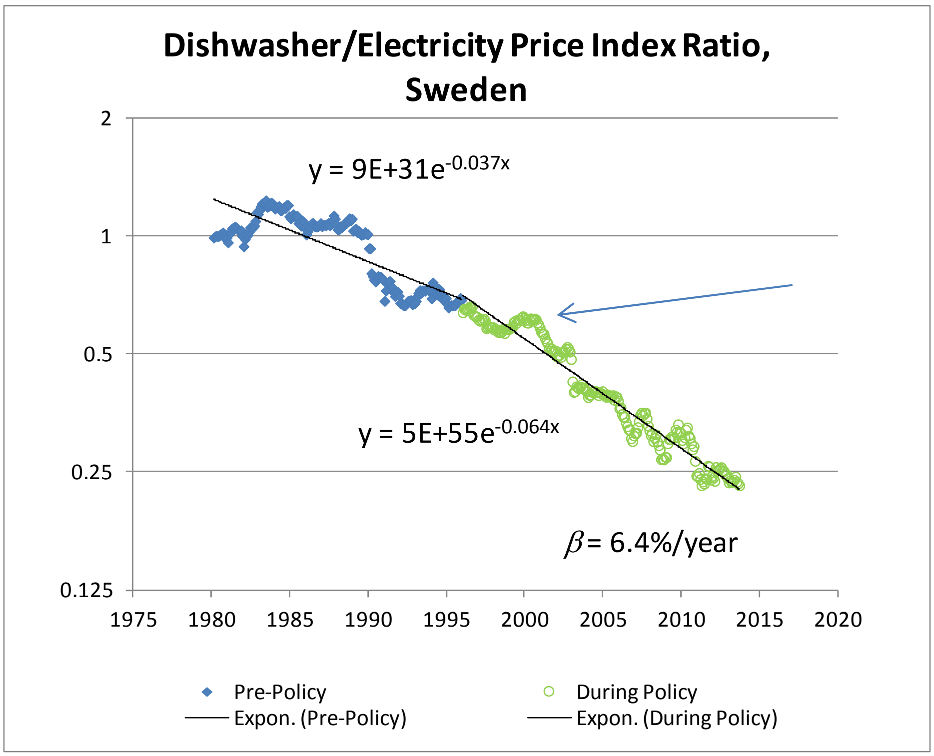


Figure 11: Dishwasher price index trend relative to the price of electricity. We note two trend periods: An earlier period before 1995 when EcoDesign policies were established when the trend in refrigerator price relative to electricity was -3.7 %/year, and a more recent period since the EcoDesign policies were established where the trend is a similar -6.4 %/year.

Figure 12 illustrates the currently observed price premium for the highest energy efficiency levels of dishwashers observed in the current (October 2013) Swedish market. High prices may be a barrier to accelerating energy efficiency trends.

[10] Swiss appliance sales data, 2004 - 2011: Analysis and conclusions for EU Market monitoring 24. July 2013, Anette Michel, Eric Bush, Topten International Services (TIS)

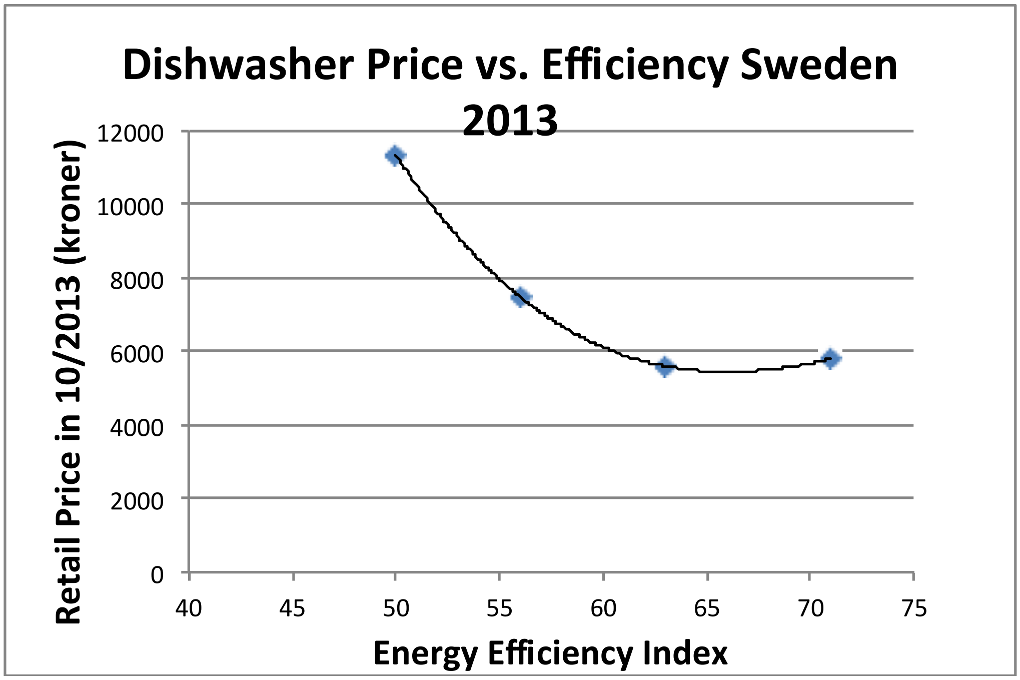


Figure 12: Market price as a function of Energy Efficiency Index (EEI) for dishwashers in Sweden in October 2013. There does appear to be a substantial price premium for energy efficiency in the market at this time. It is possible that with greater market volumes, this price premium could decrease substantially over time.

Television Market Results

As a rapidly innovating electronics product, recent rates of price decline and efficiency improvement are much higher than major kitchen appliances.

Figures 13 and 14 illustrate the rate of price decline for small and large televisions. In each of these graphs, we illustrate three key periods. In the first period (before 2004) the television market was dominated by cathode ray tube (CRT) technology. Since 2004, new television screen technologies have developed at a rapid pace, and there is a very rapid acceleration of quality-adjusted price decline to a negative 22%/year trend for small screen televisions and a -29%/year for large screen televisions. In the period since the implementation of efficiency policies in the EU (since 2010), the strong negative trend in price decline appears to have moderated somewhat.

Figure 15 illustrates the trends in active energy use seen in television markets since implementation of the Ecodesign regulations. What we see in this data is a consistent very steep decline in energy use that is largely consistent with (10) presented in the Technical Background section above. We find that both the energy use and the appliance price are decreasing at approximately 15% to 25% per year in the Swedish television market since 2010.

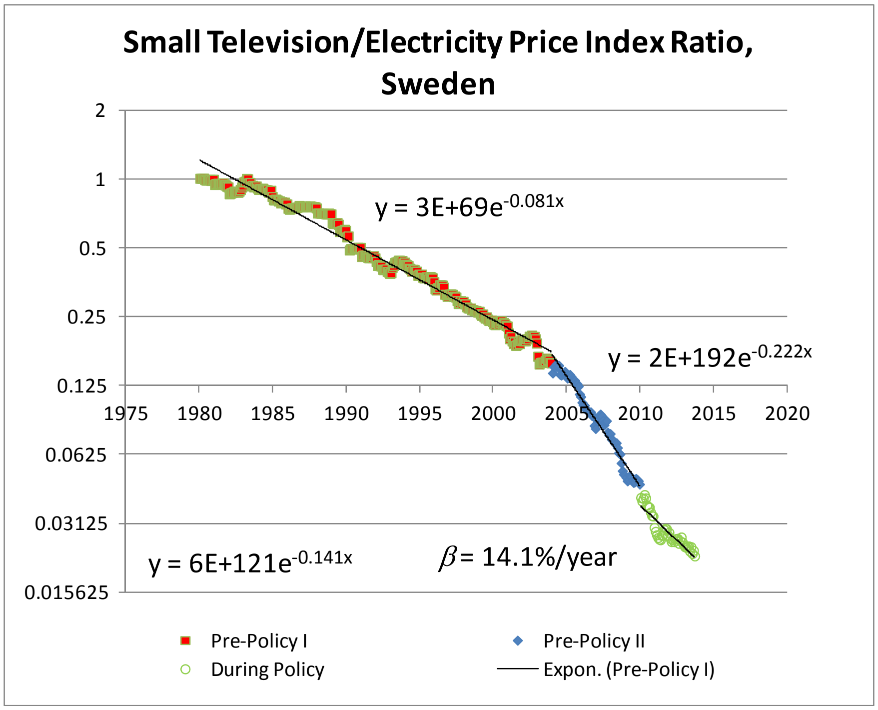


Figure 13: Small television price index trend relative to the price of electricity. We note three trend periods. An earlier period before 2004 when the trend in television price relative to electricity was -8.1 %/year, an intermediate period between 2004 and 2010 when the trend was -22.2 %/year, and a more recent period since the most recent EU regulations where the trend is -14.1 %/year.

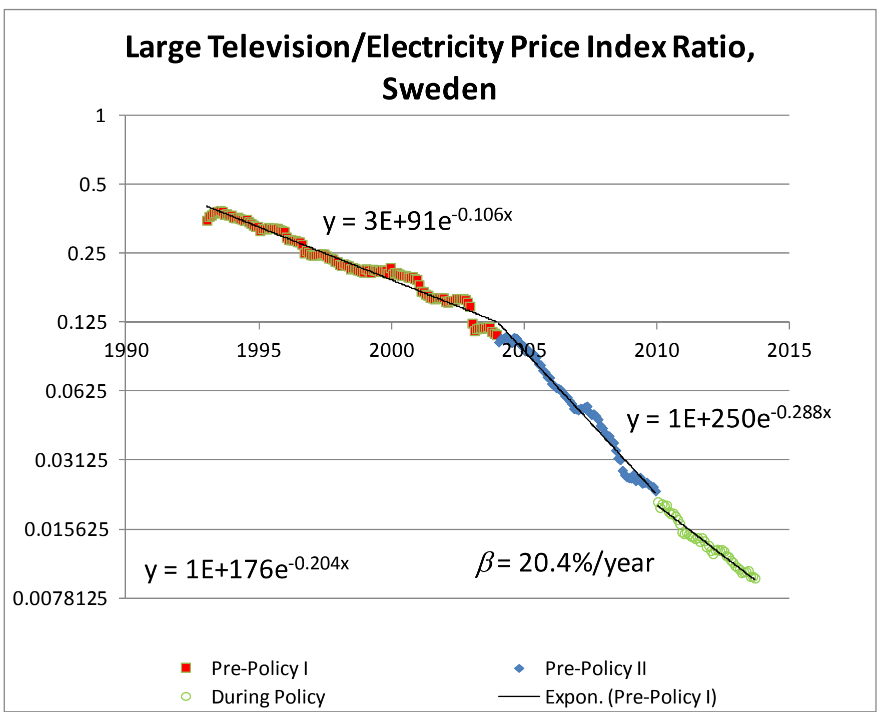


Figure 14: Large television price index trend relative to the price of electricity. We note three trend periods. An earlier period before 2004 when the trend in television price relative to electricity was -10.6

%/year, an intermediate period between 2004 and 2010 when the trend was -28.8 %/year, and a more recent period since the most recent EU regulations where the trend is -20.4 %/year.

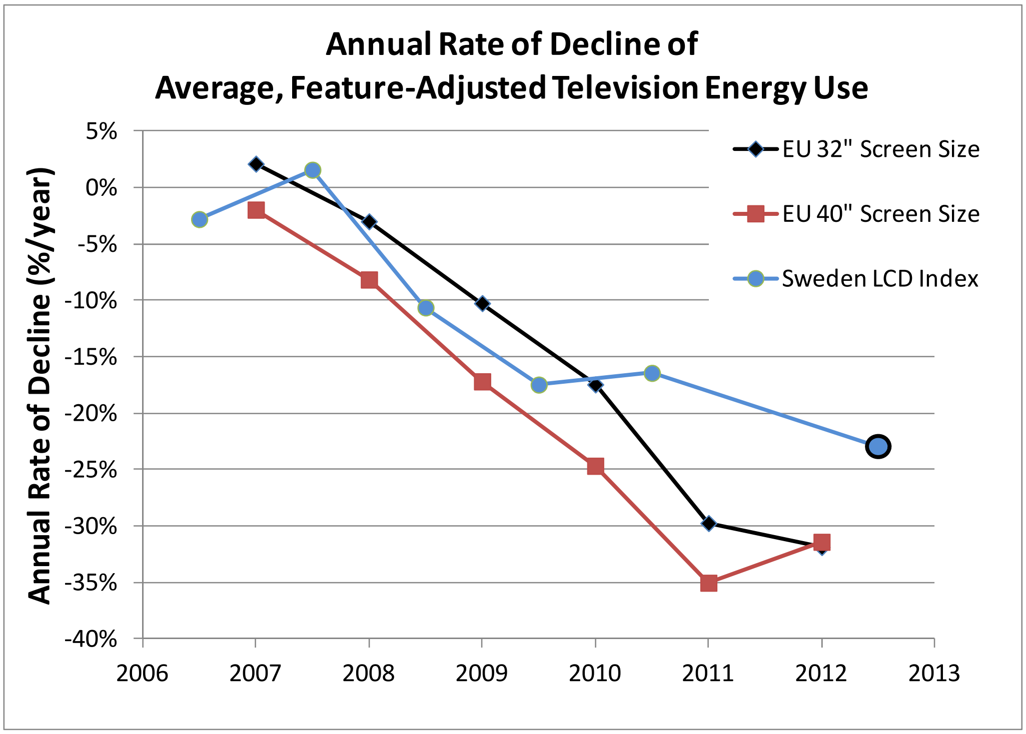


Figure 15: Trends in active mode energy use for televisions. With the implementation of the EcoDesign policies, the trend in active mode energy use has dropped to the range of -15% to -35% per year from 2010 to the present. The corresponds roughly to the -14% to -29% annual price decline seen in quality-adjusted television prices relative to electricity costs in Sweden from 2004 to the present. The EU trends are derived from data presented in the Topten report: "European TV market 2007 – 2012: Energy efficiency before and during the implementation of the Ecodesign and Energy Labelling regulations."

Conclusion

Appliance efficiency and appliance markets are highly dynamic phenomenon. In this report we provide an initial analysis of recent energy efficiency improvements for refrigerators, clothes washers, dishwashers, and televisions in the Swedish market. We have utilized new equations describing the dynamics of appliance energy efficiency economics and current market data collected by computer programs over the Internet. These new capabilities provide a methodology for real time benchmarking of the Swedish market in respect to its optimum rate of energy efficiency improvement.

We find for refrigerators, the market appears to be progressing rather smoothly with a long term energy use decline of slightly more than 5%/year that appears to be sustainable over the long term. For clothes washers, we find that energy efficiency improvement appears to be hampered recently by the lack of high efficiency level definitions. For dishwashers, the highest efficiency level products appear to have a high price premium. And for televisions, they appear to be decreasing their active energy use at the amazingly rapid pace of 15% to 25% per year.

Possibilities for Further Research and Development

One of the key accomplishments of this study is to demonstrate the basic idea of utilising web-crawling data which provides a new data source that has the advantage of being available at higher volumes, and higher resolution in markets and time.

Theoretically, greater volumes of data allows for the statistical determination of underlying relationships and dynamics with higher precision and resolution.

The next question to be answered is whether these greater volumes of data can be analyzed to create better information that is useful to policy-making and policy-makers and how much more useful information can be derived from these larger data volumes? The reason that the answer to this question is not obvious is because simply the fact that an analysis is theoretically possible does not necessarily mean that the analysis can be feasibly implemented in practice.

Yet, in this case it is quite likely that energy efficient product market analysis at higher resolution and precision will become practical in the next few years for two key reasons: (1) data volumes should continue increasing at a very fast rate, and (2) the very rapid increase in data volumes produces many new ways in which the corresponding market analysis may be improved.

The rate of expansion of internet-based market data is likely to be as fast if not faster than expansion of the internet. Because internet market transactions are getting more and more convenient using the internet and cell phones, more and more of these transactions are migrating to the internet and cell phone networks. For many of the markets of interest, the pace of market transactions globally is of the order of several tens of millions of transactions per year, or millions of transactions per month. Currently the web crawling pulls off the internet a volume of data that is of the order of thousands of data points per month per market. Given the actual transaction volume (millions of transactions per month) and the migration of transactions to the internet, the availability of more and more internet-based market transaction data over time is a virtual certainty.

Now, given that rapidly growing volumes of internet-based market data is almost a certainty, the remaining question is will it be possible to do anything new and useful with this data. If there are theoretically many new possibilities for improving the analysis, then there is a good chance that at least a few of the many possibilities will yield good results.

As demonstrated in this report, one vision for analytical improvement is to use the high resolution data to estimate price-efficiency curves and life-cycle cost curves and see how these different curves and costs are trending over time. An interesting follow-up analysis that can be performed for this investigation is to test if it is possible measure these trends with good precision using more than two-months of data but less than a year's worth of data.

This initial study found that while it may not currently be possible to measure these trends with only a couple month's worth of data, it is possible to demonstrate snap-shots of market conditions. Given the short timeframe, rate of motion of key market statistics using just web-crawling data is not yet demonstrated. But it may be to do this within the next year using a combination of increased data volume and improved statistical models. The hope is that through a combination of both more data, and improving statistical techniques it will be possible to measure some important curves along with the dynamics trends in these curves with less than six months of data. This is a key goal for future research that is likely to be worth pursuing.

After statistical measurements are improved, the next task of interest to policy-makers is creating an ability to relate the market measurements to policy implementation and design with the aim of then using those relationships to help design new and better policies.

Even though this is a very big task, an initial first step was partially demonstrated in this study is the creation of an ability to measure long term sustainable rates of efficiency improvement in terms of trends and rates in the relative prices of appliances, the incremental cost of efficiency (i.e. the price-efficiency curve), and the cost of energy.

The hope is that such research on long term efficiency improvement rates will then be able to inform international policy discussions on setting long term efficiency improvement targets for efficiency improvement for different appliances and end-uses.

Appendix A: Measuring Energy Efficiency Trends with Market Share Data

We measure energy efficiency trends from market share data by fitting market share data to a cumulative logistic distribution to estimate an interpolated distribution median. We then calculate the time rate of change of the interpolated median energy efficiency as the efficiency trend.

Much of this material is extracted from a paper presented at the ECEEE 2013 summer study:

http://proceedings.eceee.org/visabstrakt.php?event=3&doc=6-289-13

Expressing Market Distributions as Cumulative Distribution Functions

A key reason for modeling price dynamics by modeling the cumulative price distribution functions is because cumulative distributions are computationally robust given noisy empirical data.

Figure A1 illustrates the evolution of the distribution of refrigeration appliance efficiency in the European market from 1991 to 2009. By showing the distributions in terms of a cumulative distribution (i.e. the fraction of products with efficiencies equal to or less than the efficiency on the horizontal axis), the motion of the market can be seen very clearly. Pre-1997, the cumulative distribution of efficiencies was moving rather slowly, and then post-1997 the cumulative distribution function has accelerated substantially.

Note that the horizontal axis in the figure A1 is plotted on a logarithmic scale, meaning that rates of motion indicated in the plot are exponential.

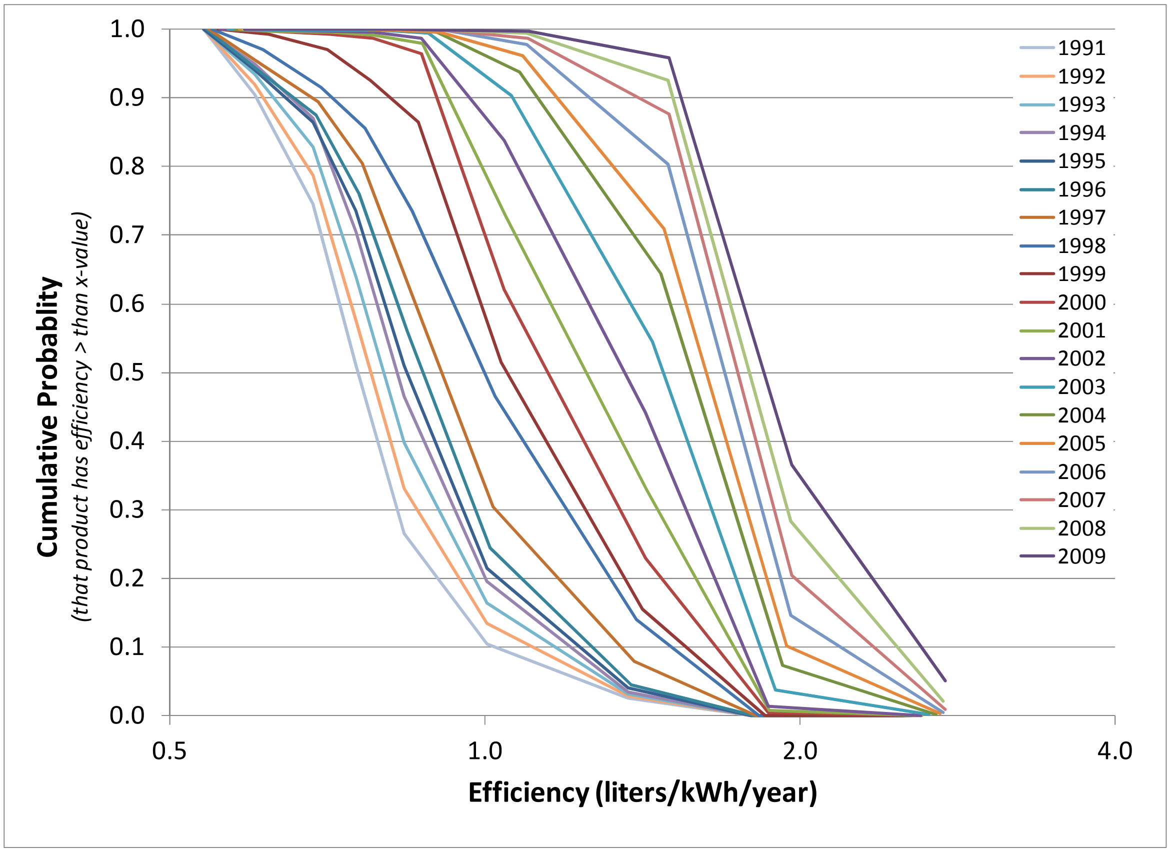


Figure A1: Evolution of the cumulative efficiency distribution of refrigeration products in the European market from 1995 to 2009. The average efficiency of the distribution increases as time progresses.

Using Logistic Distribution Functions

Because in most cases the data will not distinguish clearly between normally and logistically distributed data, we choose to use logistic distribution functions for analytic simplicity.

Figure A2 illustrates that very close similarity between logistic and normal probability distribution functions. The main difference between the two distributions is the tails of the distributions. A logistic distribution has an exponential tail, while a normal distribution has a tail that falls off as the exponential of the square of the distance from the mean.

The equations that describe the functional form of a cumulative logistic probability distribution are particularly simple.

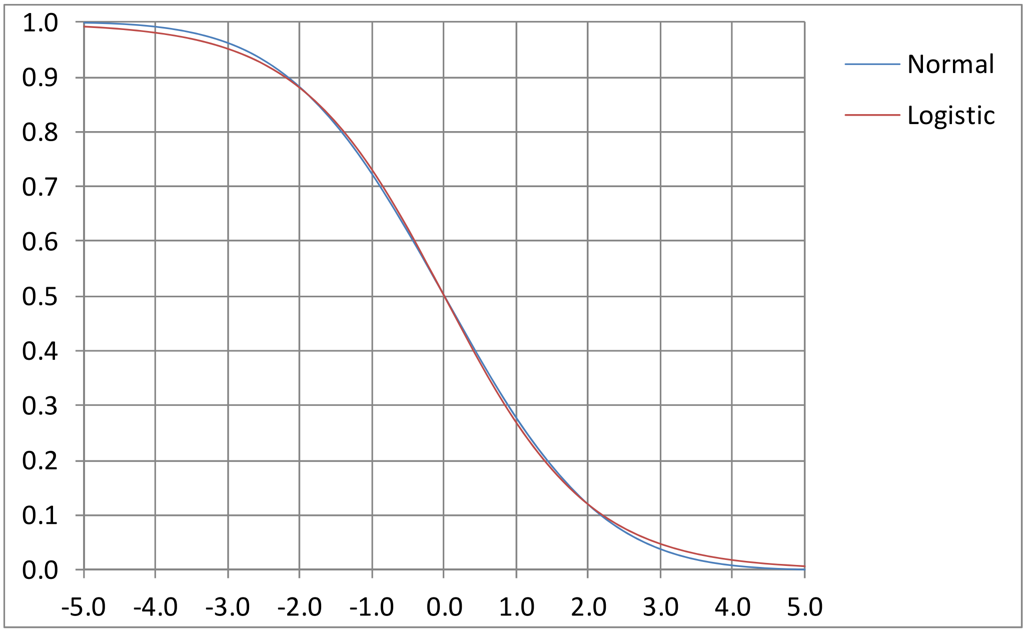


Figure A2: Comparison of logistic and normal cumulative probability distributions, demonstrating that the two functions provide similar curves (with <0.01 RMS difference).

The basic formula for a cumulative logistic distribution is:

$$F(x) = \frac{1}{1 + e^{q(x - x_0)}} \quad \text{(A1)}$$

where x_0 is the median of the distribution, and α determines the variance of the data about the mean.

Note that if we define the transformed variable ψ, where ψ=ln*((1-F)/F)*, then the equation for the cumulative distribution simplifies to a simple linear equation:

$$\psi = q(x - x_0) \quad \text{(A2)}$$

where we have the inverse variable transformation: $F=1/(1+e^{\psi})$.

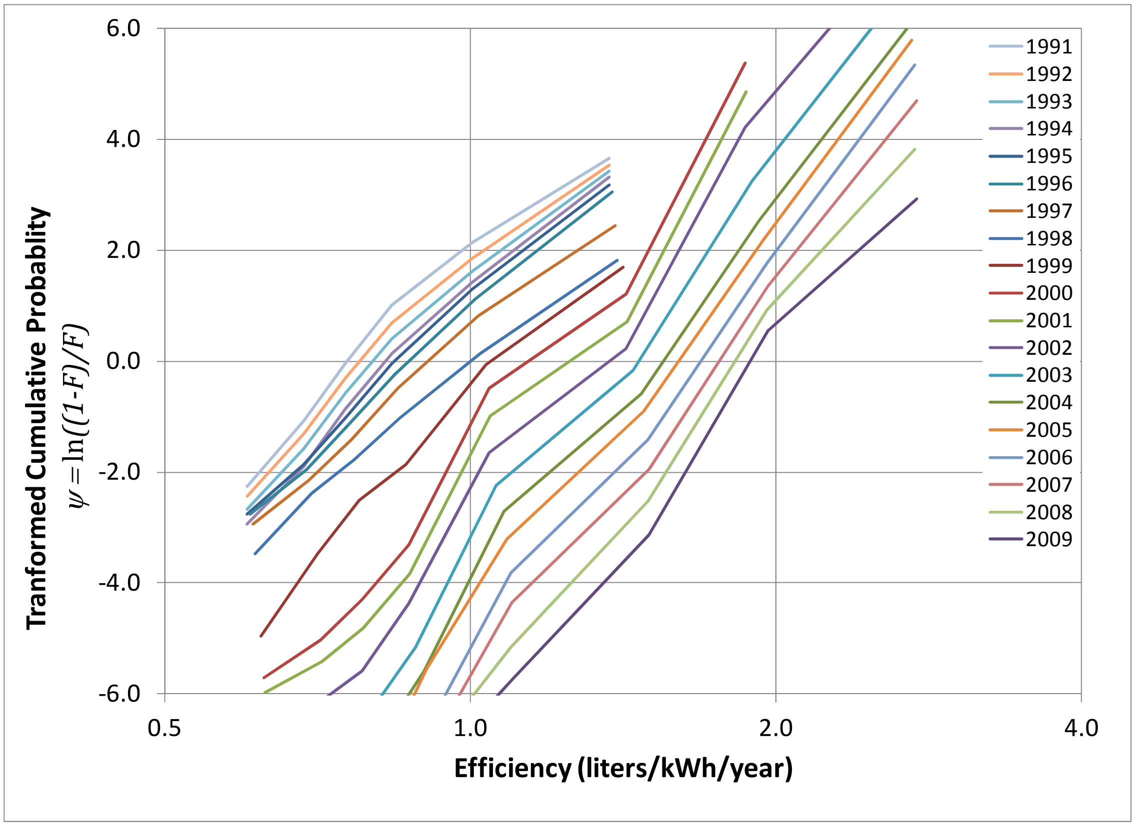


Figure A3: Cumulative distribution curves illustrated in figure 1 plotted in the transformed variable $\psi = \ln((1\text{-}F)/F)$. Note that the coordinate transformation converts the "S-curves" of the cumulative distribution functions into curves that approximate straight lines.

Figure A3 illustrates the cumulative distribution curves shown in figure A1 in the transformed variable ψ. In the transformed variable, the S-curve shape of the cumulative distribution functions straightens to a set of curves that approximate a series of straight lines.

We now use the general form of the results from the European refrigerator market to develop a model for the steady, continuous improvement of product efficiency in a market.

Note that if we have an efficiency trends that has an exponential dependence on time, then this implies there is a relationship between efficiency and t_0 of the form:

$$\text{Eff}(F=0.5) = \text{Eff}_0\, e^{\alpha*(t-t0)} \qquad \text{(A3)}$$

Where α is the rate at which efficiency is increasing over time, Eff_0 is the median efficiency of the market at $t=t_0$, and Eff is the median market efficiency at time t.

One possible solution to a dynamic with exponentially increasing efficiency consistent with a series of logistic adoption curves described by equations (A1) and (A2) is given when $\psi = q*\ln(Eff/\,Eff_0)\text{-}\ \alpha*(t\text{-}t_0)$.

This particular solution implies an equation that provides product efficiencies as a function of market share position and time assuming that all efficiency market shares follow a logistic adoption curve with a constant q:

$$\ln\left(\frac{Eff(F,t)}{Eff_0}\right) = \alpha(t-t_0) + \frac{\alpha}{q}\ln\left(\frac{1-F}{F}\right) \quad \text{(A4)}$$

or

$$Eff(F,t) = Eff_0 \cdot e^{\alpha(t-t_0)}\left(\frac{1-F}{F}\right)^{\frac{\alpha}{q}} \quad \text{(A5)}$$

If these equations describe an efficient product market, then at any point in time, the log of the efficiency will be a linear function of ln(*(1-F)/F*). With a change in sign, equation A4 can be written in terms of annual energy consumption:

$$-\ln\left(\frac{AEC(F,t)}{AEC_0}\right) = \alpha(t-t_0) + \frac{\alpha}{q}\ln\left(\frac{1-F}{F}\right) \quad \text{(A6)}$$

This relationship is illustrated in Fig. A4 where we define we use annual energy use (i.e. the inverse of efficiency for refrigerators) as the relevant product performance variable. The approximately linear relationship between ln(*AEC*) and ln(*(1-F)/F*) can be seen clearly in the Swedish market data. A significant acceleration in efficiency improvement can be seen between 2009 to 2013.

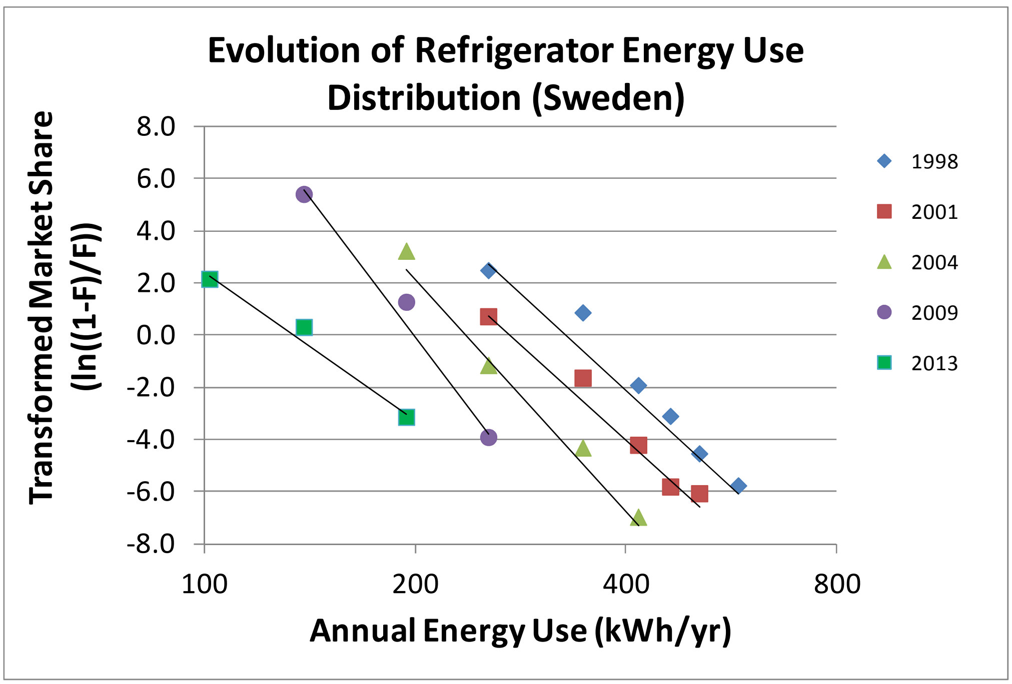


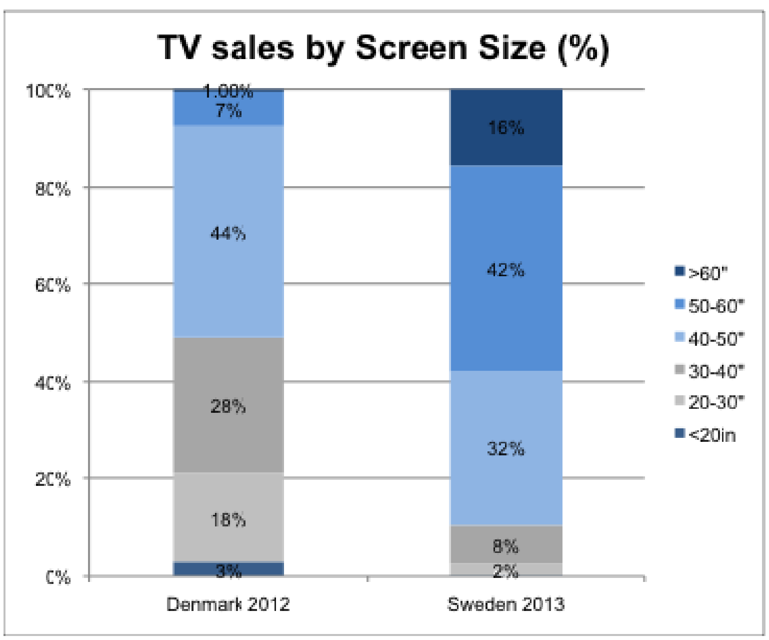
Figure A4: Demonstration of how Eq. A6 can be used to estimate annual energy use distributions for European refrigerator efficiency data. At each time, we calculate the transformed market variable ln((1-F)/F) versus energy use (e.g. inverse efficiency) where the energy use or efficiency axis is on a log scale. What we observe is that transformed market share vs. log energy use is approximately linear for each period in time, consistent with Eq. A6. The zero crossing for the line (i.e. where transformed market share equals zero) is the annual energy use that represents the median of the distribution. This way we use Eq. A6 to provide a relatively robust method for calculating median market efficiency at different times using only the market share data for the various efficiency levels.

Appendix B: Comparing the Swedish TV market with the Danish TV market

Using sales rank data from Swedish online retailers and the methodology described in Appendix A, we are able to calculate an estimated market share for TVs. To assess how the Swedish market compares to other European markets, we have done a side-by-side analysis of TVs in Sweden for November 2013 and Denmark for 2012.

Denmark and Sweden TV Market Share by Screen Size

Comparing Sweden's TV sales in November 2013 to those of Denmark in 2012 in Figure B1, we see a significant trend towards the purchasing of larger TVs. While in Denmark about 52% of TVs sold were 40" and larger, in Sweden we see that the overwhelming majority of TVs sold, about 90%, are 40" and larger. The sales-weighted average screen size was 48.1" for November 2013 in Sweden while in Denmark in 2012 it was 36.8".

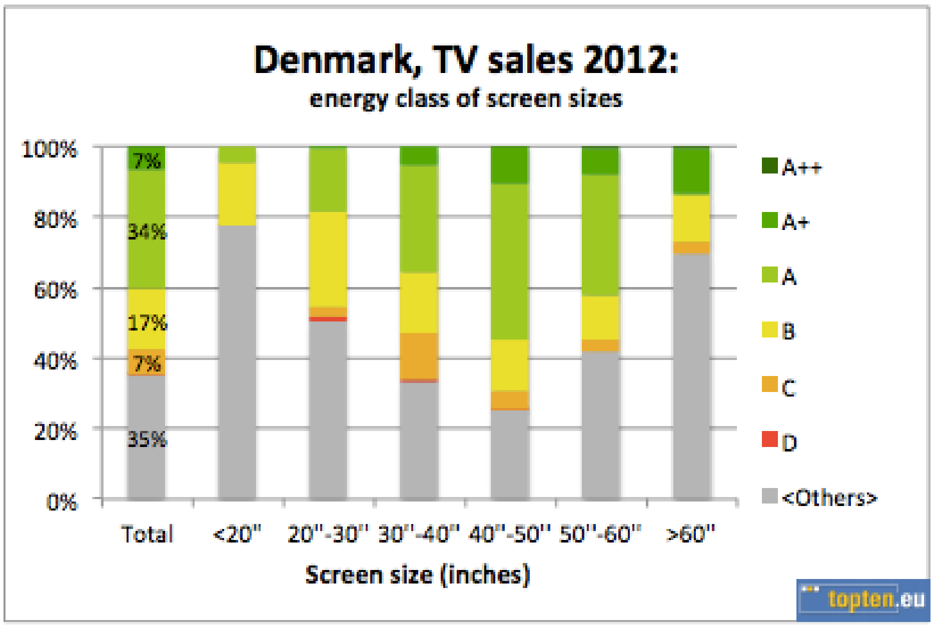


Data source: Denmark TV sales: TopTen/GfK, Swedish TV sales: Enervee

Figure B1: Danish 2012 TV sales and Swedish 2013 TV sales by screen size.

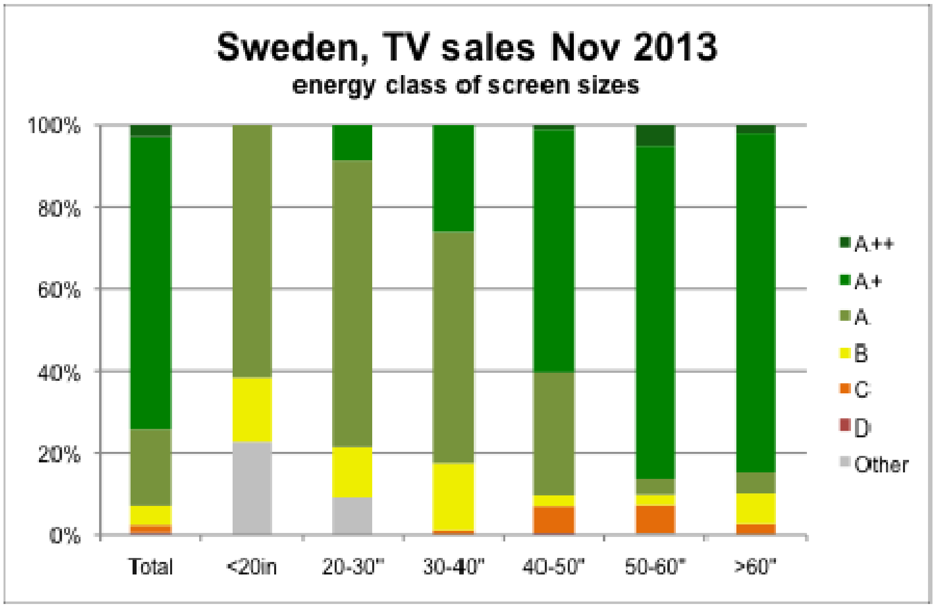
Denmark and Sweden TV Market Share by Energy Class

Comparing the market share by energy efficiency class between Denmark and Sweden, we see in Figure B2 that in Denmark in 2012 the market share of TVs class A and higher was 41%. In Sweden in November 2013 in Figure B3, we see that the market share of TVs class A and higher is approximately 93%. The class A+ has the majority share of the total market with the 50-60" and >60" screen size classes being almost exclusively at this efficiency level.



Data source: GfK

Figure B2: Sales of Danish TVs in 2012 by energy class and screen size.



Data source: Enervee

Figure B3: Sales of Swedish TVs in November 2013 by energy class and screen size.